40 CFR Part 191
Subparts B and C
Compliance Recertification Application 2026
for the
Waste Isolation Pilot Plant

Appendix TRU WASTE-2026
Transuranic Waste Inventory

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Field Office
Carlsbad, New Mexico

Compliance Recertification Application 2026
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ACRONYMS AND ABBREVIATIONS

AK	acceptable knowledge
ATWIR	Annual Transuranic Waste Inventory Report
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CH-TRU	contact-handled transuranic (waste)
Ci	curie
CPR	Cellulosic, Plastic, and Rubber
CRA	Compliance Recertification Application
DBR	direct brine release
DOE	U.S. Department of Energy
EDTA	ethylenediaminetetraacetic acid
EPA	U.S. Environmental Protection Agency
FEPs	features, events, and processes
FR	Federal Register
FRPAIR	Full Repository Performance Assessment Inventory Report
GWB	Generic Weep Brine
ISPAIR	Interim State Performance Assessment Inventory Report
LWA	Land Withdrawal Act
MgO	magnesium oxide
PA	performance assessment
PAIR	Performance Assessment Inventory Report
PAPDB	Performance Assessment Parameter Database
RH-TRU	remote-handled transuranic (waste)
RPPCR	Replacement Panels Planned Change Request
SNL	Sandia National Laboratories
TRU	transuranic
WAC	Waste Acceptance Criteria
WAP	Waste Analysis Plan
WCA	Waste Characterization Analysis
WCL	Waste Component Limits
WDS	Waste Data System
WIPP	Waste Isolation Pilot Plant
WUF	waste unit factor

TRU WASTE-1.0 INTRODUCTION

The transuranic (TRU) waste inventory for the Waste Isolation Pilot Plant (WIPP) is updated for each recertification application. The updated inventory is evaluated to determine the effects of waste components and waste characteristics on the long-term performance of the repository. The characteristics and components of the waste are based on the current TRU waste descriptions and inventory information presented in the 2024 Annual Transuranic Waste Inventory Report (ATWIR-2024) (U.S. DOE 2024) and the subsequent performance assessment inventory reports (PAIRs). Some of the content of Appendix TRU WASTE-2004 (and the appendices and attachments that it referenced) is no longer applicable, as the current understanding of waste inventory, components, and characteristics has been updated in other documents since 2004. Based on comments to the Environmental Protection Agency (EPA) on the 2019 Compliance Recertification Application (CRA-2019) and Replacement Panels Planned Change Request (RPPCR) analyses (U.S. EPA 2022 and 2024), the Department of Energy (DOE) has updated Appendix TRU WASTE to centralize the most up-to-date results of waste component and characteristics analyses.

TRU WASTE-1.1 Background: WIPP Certification and Repository Configuration

TRU WASTE-1.1.1 Initial Certification and Panel Changes

The WIPP was initially certified as a repository consisting of 10 panel equivalents, which were excavated for the long-term storage and placement of transuranic waste (U.S. EPA 1998). Owing to lost disposal capacity in Panels 1, 7, 9, and 10, there is insufficient space to dispose of the entire permitted Land Withdrawal Act (LWA) volume. The DOE determined that two new panels would be needed to replace the lost capacity. In March 2024, the DOE submitted the RPPCR to the EPA for approval of waste emplacement in two new panels, Panels 11 and 12. These panels, referred to as replacement panels, are located to the west of the existing operations area. The EPA approved the RPPCR in July 2025 (U.S. EPA 2025).

TRU WASTE-1.1.2 Interim and Final Repository States

The two replacement panels will not provide adequate space for the disposal of the waste volume permitted by the LWA. Therefore, a 12-panel configuration is regarded as an interim state of the repository. The DOE recognizes that additional panels will be needed to dispose of the permitted LWA volume (Bollinger 2024). This hypothetical 19-panel configuration is considered the anticipated final state of the repository.

TRU WASTE-1.2 Purpose: Compliance with 40 CFR § 194.24

The purpose of this appendix is to support DOE's demonstration of compliance with 40 Code of Federal Regulations (CFR) 194.24. This appendix is crucial for demonstrating that the DOE understands the characteristics and quantities of TRU waste proposed for disposal at WIPP,

along with the packaging materials and waste chemical components. It supports the conclusions as to which waste characteristics and components affect the containment of waste in the disposal system over the regulatory performance period of 10,000 years.

TRU WASTE-1.3 Scope: Overview of Appendix Content

This appendix describes the assessment of the waste characteristics associated with the chemical, radiological, and physical composition of existing and projected TRU waste destined for disposal at the WIPP. It also identifies those waste components that significantly influence waste characteristics and supports reasonable upper and lower limits for the disposal of waste components. Based on the component limits and their associated uncertainties, a set of characterization techniques is identified and referenced. Waste components are controlled, tracked, and inventoried upon emplacement in the repository. This appendix includes updates to the Waste Analysis Plan (WAP), the Waste Characterization Analysis (WCA), and the Waste Component Limits (WCL).

TRU WASTE-1.3.1 Analysis of Waste Components and Characteristics (Appendix TRU WASTE-2.0)

Appendix TRU WASTE-2.0 addresses the requirements specified in 40 CFR 194.24(b) to identify waste components and their characteristics that can influence waste containment and are used to derive inputs for PA calculations. This section identifies and assesses these waste components and their characteristics based on the DOE's current understanding of the disposal system behavior. This section also discusses the rationale for excluding specific waste characteristics or components that are not expected to influence releases from the disposal system.

TRU WASTE-1.3.2 Waste Component Limits (Appendix TRU WASTE-3.0)

Appendix TRU WASTE-3.0 shows the total limits for each identified significant component. This section addresses the requirement of 40 CFR 194.24(c)(1) to establish limiting values for each component identified in Appendix TRU WASTE-2.0 as important to the performance of the repository system. The rationale for these limits is also discussed.

TRU WASTE-1.3.3 Waste Characterization Methods (Appendix TRU WASTE-4.0)

Appendix TRU WASTE-4.0 identifies and references the methods used to quantify the limits for the waste components identified as potentially significant to the long-term performance of the disposal system. This section addresses the requirements of 40 CFR 194.24(c)(2) and (3).

TRU WASTE-1.3.4 Waste Data System (Appendix TRU WASTE-5.0)

Appendix TRU WASTE-5.0 describes a system of controls in the Waste Data System (WDS) that addresses the requirements of 40 CFR 194.24(c)(4) and (5).

TRU WASTE-1.4 Compliance Process Overview: Five Key Steps

Updating of the TRU waste inventory comprises five steps, the proper implementation of which ensures compliance with 40 CFR 194.24. The steps, which are summarized in Figure TRU WASTE-1, are described in the following sections.

TRU WASTE-1.4.1 Collect Waste Inventory Data

The update cycle begins with the compilation of waste inventory data (Figure TRU WASTE-1). This includes the waste that has been emplaced in the repository and the waste that is anticipated for emplacement over the operational life of the WIPP. The anticipated waste inventory data consist of waste that has been stored at TRU waste sites and projected estimates of waste to be generated. These data are summarized in an ATWIR. For performance assessment (PA), the volume of projected waste is scaled to a specified volume apart from the volume of the stored and emplaced waste. The combined data (emplaced, stored, and scaled projected) account for the total WIPP waste inventory used in the PA. The results of conducting Step 1 of this process for the CRA-2026 are reported in the Interim State Performance Assessment Inventory Report (ISPAIR) – 2024 (Van Soest 2025a) and in the Full Repository Performance Assessment Inventory Report – 2024 (FRPAIR-2024, Van Soest 2025b). The inventory considered for PA purposes comprises waste and packaging materials, including radionuclides and other waste components such as steel, plastic, and organic ligands.

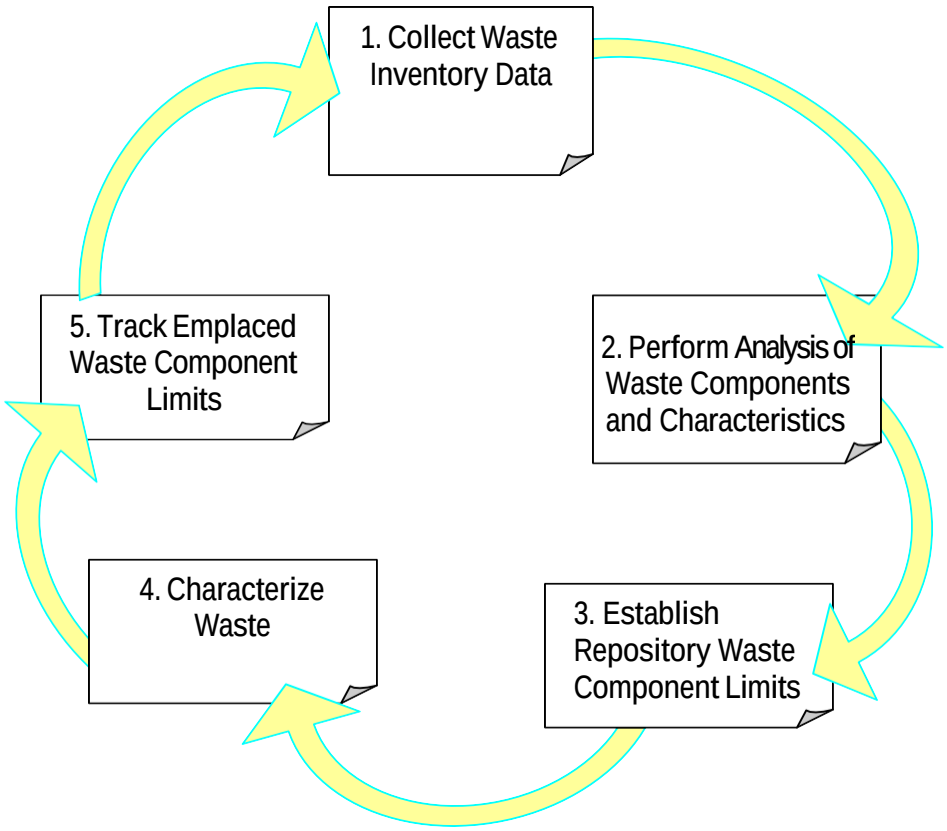


Figure TRU WASTE-1. Waste Characterization Cycle

TRU WASTE-1.4.2 Perform Analysis of Waste Components and Characteristics

The inventory is analyzed for new waste components and/or changes to existing waste components that might affect the repository system (Figure TRU WASTE-1). This is a screening step that may include using sensitivity, features, events, and processes (FEPs), and other screening analyses. If a component is determined to impact repository performance (e.g., radionuclide solubility), it is placed on the list of "significant" waste components. Some waste components indirectly influence repository performance (e.g., porosity of solid waste) and are placed on the list of "negligible" waste components. All other components are screened out and are not included in PA calculations.

TRU WASTE-1.4.3 Establish Repository Waste Component Limits

Waste components identified as "significant" are examined to determine if changes in the previously established limits are needed. If the inventory update shows changes to the "significant" waste components, the change may necessitate a new or different limit. A new or different waste component limit can be established based upon the impact to the repository.

TRU WASTE-1.4.4 Characterize Waste

Waste characterization methods are developed or refined to quantify the significant waste components. Waste characterization programs implement other regulatory requirements, but for purposes of CRA-2026, this appendix will only address those elements relevant to long-term compliance.

TRU WASTE-1.4.5 Track Emplaced Waste Component Limits

Waste component data are tracked and reported. The WDS is used to capture the waste component data for waste emplaced in the repository. The WDS is a tool used by personnel at TRU waste sites and at WIPP to control and track the waste emplaced in the repository. A query of the WDS to obtain current inventory information can be made at any time. The emplaced waste data are compiled every recertification cycle (or as necessary) to update the waste inventory.

TRU WASTE-2.0 ANALYSIS OF WASTE COMPONENTS AND CHARACTERISTICS

Appendix TRU WASTE-2.0 summarizes information on the WIPP TRU waste inventories. This includes inventories of waste already emplaced and those anticipated in the future as detailed in U.S. DOE (2024a), Van Soest (2025a), and Van Soest (2025b). This section also identifies the impact of this information on PA. Finally, it determines whether the waste characteristics and components previously deemed significant to performance continue to hold that significance.

Waste components include radionuclides, paper and other cellulosic materials, steel drums that contain the waste, solidified organic and inorganic sludges, etc. These components have the potential to impact disposal system performance. For example, paper is a component of the waste and may be a substrate for microbes in the repository. The ability of the paper to act as a substrate for microbial gas production is a characteristic of the paper. Microbes metabolizing paper can produce carbon dioxide and other gaseous metabolic products, which can increase the pressure in a waste panel and potentially impact the performance of the repository.

TRU WASTE-2.1 Updated Estimate of TRU Waste Inventory

In the certification of the WIPP, the EPA concluded that the estimates provided in Appendix BIR of the Compliance Certification Application (CCA) represented the best information available at that time (Federal Register [FR] 63 27354, May 18, 1998). The EPA recognized that the WIPP waste inventory may change as the DOE characterizes the contents of containers of TRU waste prior to shipment to WIPP and as new wastes are generated in the future. The EPA also concluded that the WIPP waste inventory estimates provided in Appendix BIR of the CCA were sufficient for purposes of PA.

TRU WASTE-2.1.1 Inventory Data Sources

Since submittal of the CCA, the DOE has updated its estimates of the TRU waste inventory destined for disposal in the WIPP. A complete description of that process and its results are presented in the ATWIR, which decays the inventory data through the end of 2033 (U.S. DOE 2024). To support PA calculations, a PAIR is prepared, which extracts inventory data from the ATWIR, decays the inventory data to a specified year, and scales the inventory data to an assumed repository capacity. The tables in the following sections summarize information from both ISPAIR-2024 (Van Soest 2025a) and FRPAIR-2024 (Van Soest 2025b) that pertain to waste characterization analysis.

TRU WASTE-2.1.2 Summary of Waste Material Masses

Tables TRU WASTE-1 and TRU WASTE-2 summarize the final form anticipated mass for the waste materials in the disposal inventory.

Table TRU WASTE-1. Summary of Mass of Waste Materials

Waste Material	Interim State of Repository CH Mass (kg)	Interim State of Repository RH Waste (kg)	Final State of Repository CH Mass (kg)	Final State of Repository RH Waste (kg)
Iron-based Metal/Alloys	1.97E+07	1.58E+05	2.12E+07	9.43E+05
Aluminum-based Metal/Alloys	3.77E+05	9.66E+03	4.31E+05	6.56E+04
Other Metal/Alloys	1.40E+06	2.35E+04	1.60E+06	1.43E+05
Other Inorganic Materials	6.14E+06	1.09E+05	6.92E+06	4.58E+05
Cellulose	4.30E+06	3.55E+04	4.48E+06	1.77E+05
Rubber	1.02E+06	1.14E+04	1.13E+06	4.71E+04
Plastic	5.26E+06	1.36E+05	5.61E+06	3.05E+05
Cement[1]	1.18E+06	3.24E+03	1.20E+06	1.60E+04
Solidified Inorganic Material	1.23E+07	1.44E+04	1.24E+07	3.68E+04
Solidified Organic Material	3.74E+06	1.86E+03	3.75E+06	9.55E+03
Soil	4.13E+06	6.27E+03	4.75E+06	1.07E+04
Vitrified	--	--	--	--

Source: Data for the interim state of the repository are provided by ISPAIR-2024 (Van Soest 2025a, Table 5-5). Data for the final state of the repository are provided by FRPAIR-2024 (Van Soest 2025b, Table 5-5). Data reported in

both ISPAIR-2024 and FRPAIR-2024 include scaled information known by the TRU waste sites as of December 31, 2023.

[1] The cement category in Table TRU WASTE-1 includes only those reported by the TRU waste sites. The emplaced cements are included in the Other Inorganic Materials, Solidified Inorganic Material, and Solidified Organic Material categories in Table TRU WASTE-1. An estimate of the total cements (i.e., emplaced cements and those reported by TRU waste sites) is provided in Table TRU WASTE-2.

Table TRU WASTE-2. Summary of Mass of Cements

Cements	Interim State of Repository CH Mass (kg)	Interim State of Repository RH Waste (kg)	Final State of Repository CH Mass (kg)	Final State of Repository RH Waste (kg)
Reacted Only	1.99E+06	4.57E+03	2.04E+06	1.73E+04
Combination Reacted / Unreacted	6.55E+06	8.63E+01	6.55E+06	1.47E+02
Total	8.54E+06	4.66E+03	8.59E+06	1.74E+04

Source: Data for the interim state of the repository are provided by ISPAIR-2024 (Van Soest 2025a, Table 5-6). Data for the final state of the repository are provided by FRPAIR-2024 (Van Soest 2025b, Table 5-6). Data reported in both ISPAIR-2024 and FRPAIR-2024 include scaled information known by the TRU waste sites as of December 31, 2023.

TRU WASTE-2.1.3 Summary of Waste Packing Material Masses

Table TRU WASTE-3 summarizes the final form anticipated mass for the waste packaging materials in the disposal inventory.

Table TRU WASTE-3. Summary of Mass of Waste Packaging Materials

Packaging Material	Interim State of Repository CH Mass (kg)	Interim State of Repository RH Waste (kg)	Final State of Repository CH Mass (kg)	Final State of Repository RH Waste (kg)
Cellulose	5.09E+06	--	6.01E+06	--
Plastic	4.17E+06	1.52E+05	4.61E+06	1.09E+06
Rubber	1.03E+05	1.20E+03	1.13E+05	4.96E+03
Steel	4.78E+07	3.44E+06	5.27E+07	1.39E+07
Lead	--	2.43E+06	--	9.05E+06

Source: Data for the interim state of the repository are provided by ISPAIR-2024 (Van Soest 2025a, Table 5-5). Data for the final state of the repository are provided by FRPAIR-2024 (Van Soest 2025b, Table 5-5). Data reported in both ISPAIR-2024 and FRPAIR-2024 include scaled information known by the TRU waste sites as of December 31, 2023.

TRU WASTE-2.1.4 Summary of Emplacement and Operational Material Masses

Table TRU WASTE-4 summarizes the anticipated mass for the waste emplacement and operational materials in the disposal inventory.

Table TRU WASTE-4. Summary of Mass of Waste Emplacement and Operational Materials

Emplacement and Operational Material	Interim State of Repository Mass (kg)[1]	Final State of Repository Mass (kg)[1]
Cellulose	2.84E+05	3.02E+05
Plastic	2.14E+06	2.46E+06
Rubber	4.85E+03	4.85E+03

Source: Data for the interim state of the repository are provided by ISPAIR-2024 (Van Soest 2025a, Table 5-7). Data for the final state of the repository are provided by FRPAIR-2024 (Van Soest 2025b, Table 5-7). Data reported in both ISPAIR-2024 and FRPAIR-2024 include scaled information known by the TRU waste sites as of December 31, 2023.

[1] The reported emplacement and operational materials are for CH waste and RH containers that are emplaced on the floor. Materials for RH waste emplaced into the walls in horizontal boreholes are not included.

TRU WASTE-2.1.5 Summary of Radionuclide Activities

Table TRU WASTE-5 summarizes the current activities for the radionuclides in the disposal inventory decayed through 2083, which is the assumed repository closure date for the CRA-2026 PA.

Table TRU WASTE-5. Summary of Activities for Radionuclides in the Disposal Inventory (Decayed through 12/31/2083).

Radionuclide	Interim State of Repository CH-TRU Waste (Ci)	Interim State of Repository RH-TRU Waste (Ci)	Final State of Repository CH-TRU Waste (Ci)	Final State of Repository RH-TRU Waste (Ci)
^{225}Ac	6.22E+00	9.21E-02	6.42E+00	6.77E-01
^{227}Ac	6.90E+01	3.37E-02	8.32E+01	1.92E-01
^{228}Ac	1.07E-01	2.96E-03	1.08E-01	2.07E-02
^{108}Ag	4.81E-04	4.03E-04	5.75E-04	2.21E-03
^{108m}Ag	5.53E-03	4.63E-03	6.61E-03	2.54E-02
^{109m}Ag	8.53E-20	2.55E-16	8.56E-20	1.40E-15
^{110}Ag	1.37E-29	5.18E-30	1.43E-29	5.01E-29
^{110m}Ag	1.01E-27	3.81E-28	1.05E-27	3.68E-27
^{241}Am	1.55E+06	4.74E+03	1.79E+06	1.77E+04

Radionuclide	Interim State of Repository CH-TRU Waste (Ci)	Interim State of Repository RH-TRU Waste (Ci)	Final State of Repository CH-TRU Waste (Ci)	Final State of Repository RH-TRU Waste (Ci)
^{242}Am	2.37E-02	6.47E-01	2.41E-02	2.09E+00
^{242m}Am	2.38E-02	6.50E-01	2.42E-02	2.09E+00
^{243}Am	3.04E+01	6.89E+01	3.32E+01	5.74E+02
^{245}Am	1.31E-24	3.33E-33	1.43E-24	1.39E-32
^{246}Am	2.62E-08	0.00E+00	3.13E-08	0.00E+00
^{39}Ar	0.00E+00	4.31E-03	0.00E+00	2.59E-02
^{42}Ar	0.00E+00	3.19E-03	0.00E+00	1.75E-02
^{217}At	6.22E+00	9.21E-02	6.42E+00	6.77E-01
^{133}Ba	8.39E-05	1.57E-02	8.42E-05	8.62E-02
^{137m}Ba	9.69E+01	2.99E+04	9.93E+01	7.79E+04
^{210}Bi	1.83E+00	2.12E+00	1.89E+00	7.13E+00
^{211}Bi	6.91E+01	3.38E-02	8.33E+01	1.92E-01
^{212}Bi	1.01E+04	9.01E-01	1.23E+04	3.68E+00
^{213}Bi	6.22E+00	9.21E-02	6.42E+00	6.76E-01
^{214}Bi	2.14E+00	2.25E+00	2.21E+00	7.57E+00
^{249}Bk	9.05E-20	2.29E-28	9.84E-20	9.59E-28
^{250}Bk	1.47E-08	0.00E+00	1.75E-08	0.00E+00
^{14}C	1.52E-01	1.15E-01	1.52E-01	1.25E+00
^{109}Cd	8.53E-20	2.55E-16	8.56E-20	1.40E-15
^{113}Cd	1.47E-22	2.97E-18	1.56E-22	9.32E-18
^{113m}Cd	3.80E-06	4.61E-02	4.03E-06	1.59E-01
^{144}Ce	1.17E-23	6.75E-23	1.41E-23	6.49E-22
^{249}Cf	7.94E+00	9.06E+00	8.50E+00	8.40E+01
^{250}Cf	4.50E-01	2.80E+00	5.38E-01	2.65E+01
^{251}Cf	2.92E-01	4.98E+00	3.39E-01	2.76E+01
^{252}Cf	1.44E-05	8.15E-06	1.73E-05	7.95E-05
^{36}Cl	1.98E-07	1.16E-02	2.08E-07	1.17E-01
^{242}Cm	1.96E-02	5.35E-01	1.99E-02	1.72E+00
^{243}Cm	3.31E+00	5.39E+00	3.55E+00	3.18E+01
^{244}Cm	1.67E+03	1.64E+03	1.85E+03	1.02E+04
^{245}Cm	4.10E+00	2.72E+00	4.46E+00	1.96E+01
^{246}Cm	9.40E+01	1.31E+02	1.00E+02	7.29E+02
^{247}Cm	7.72E-01	9.26E-05	9.23E-01	8.64E-04

Radionuclide	Interim State of Repository CH-TRU Waste (Ci)	Interim State of Repository RH-TRU Waste (Ci)	Final State of Repository CH-TRU Waste (Ci)	Final State of Repository RH-TRU Waste (Ci)
^{248}Cm	1.36E+00	3.85E-01	1.63E+00	3.62E+00
^{250}Cm	1.05E-07	0.00E+00	1.25E-07	0.00E+00
^{60}Co	5.14E-04	1.01E-01	5.25E-04	7.80E-01
^{134}Cs	8.79E-10	4.76E-07	1.03E-09	3.47E-06
^{135}Cs	1.50E-03	5.94E-03	1.50E-03	5.78E-02
^{137}Cs	1.03E+02	3.17E+04	1.05E+02	8.25E+04
^{152}Eu	5.36E-01	4.69E+00	5.42E-01	4.61E+01
^{154}Eu	4.02E-02	1.11E+01	4.47E-02	6.20E+01
^{155}Eu	4.02E-04	1.44E-02	4.57E-04	7.41E-02
^{55}Fe	1.02E-06	2.78E-06	1.02E-06	1.83E-05
^{221}Fr	6.22E+00	9.21E-02	6.42E+00	6.77E-01
^{223}Fr	9.52E-01	4.66E-04	1.15E+00	2.65E-03
^{152}Gd	4.12E-13	3.57E-12	4.16E-13	3.46E-11
^{153}Gd	7.13E-34	3.97E-31	7.13E-34	2.17E-30
^{3}H	3.67E+03	1.87E+01	4.46E+03	1.18E+02
^{166m}Ho	3.03E-03	0.00E+00	3.63E-03	0.00E+00
^{129}I	1.45E-03	8.62E-02	1.45E-03	8.82E-01
^{115}In	0.00E+00	1.36E-17	0.00E+00	7.47E-17
^{194}Ir	0.00E+00	3.62E-06	0.00E+00	1.98E-05
^{40}K	4.05E-02	0.00E+00	4.84E-02	0.00E+00
^{42}K	0.00E+00	3.19E-03	0.00E+00	1.75E-02
^{85}Kr	1.59E-03	7.60E+00	1.61E-03	1.84E+01
^{54}Mn	4.20E-24	5.78E-22	5.06E-24	5.53E-21
^{93}Mo	0.00E+00	4.33E-02	0.00E+00	4.49E-01
^{22}Na	6.20E-07	5.62E-10	6.34E-07	3.08E-09
^{91}Nb	0.00E+00	6.95E-03	0.00E+00	3.81E-02
^{93m}Nb	1.24E-02	7.29E-02	1.24E-02	6.31E-01
^{94}Nb	1.60E-03	3.82E-01	1.61E-03	3.59E+00
^{144}Nd	1.36E-12	1.74E-13	1.36E-12	1.57E-12
^{59}Ni	1.54E-07	4.29E-01	1.69E-07	3.94E+00
^{63}Ni	4.94E+02	4.24E+01	5.92E+02	4.09E+02
^{235}Np	0.00E+00	6.62E-19	0.00E+00	3.62E-18
^{237}Np	6.95E+01	2.71E+00	7.85E+01	1.31E+01

Radionuclide	Interim State of Repository CH-TRU Waste (Ci)	Interim State of Repository RH-TRU Waste (Ci)	Final State of Repository CH-TRU Waste (Ci)	Final State of Repository RH-TRU Waste (Ci)
^{238}Np	1.07E-04	2.92E-03	1.09E-04	9.43E-03
^{239}Np	3.04E+01	6.89E+01	3.32E+01	5.74E+02
^{240}Np	7.00E-05	4.45E-09	8.34E-05	1.47E-08
^{240m}Np	5.83E-02	3.71E-06	6.95E-02	1.23E-05
^{194}Os	0.00E+00	3.62E-06	0.00E+00	1.98E-05
^{231}Pa	2.14E+01	1.87E-03	2.61E+01	3.25E-03
^{233}Pa	6.95E+01	2.71E+00	7.85E+01	1.31E+01
^{234}Pa	1.25E-01	2.30E-03	1.40E-01	4.56E-03
^{234m}Pa	9.59E+01	1.77E+00	1.08E+02	3.50E+00
^{209}Pb	6.22E+00	9.21E-02	6.42E+00	6.76E-01
^{210}Pb	1.82E+00	2.11E+00	1.89E+00	7.12E+00
^{211}Pb	6.91E+01	3.38E-02	8.33E+01	1.92E-01
^{212}Pb	1.01E+04	9.01E-01	1.23E+04	3.68E+00
^{214}Pb	2.14E+00	2.25E+00	2.21E+00	7.57E+00
^{107}Pd	1.49E-05	1.07E-03	1.50E-05	1.04E-02
^{145}Pm	0.00E+00	2.43E-02	0.00E+00	1.33E-01
^{146}Pm	1.20E-09	1.15E-04	1.20E-09	6.33E-04
^{147}Pm	5.59E-05	5.39E-06	6.69E-05	4.52E-05
^{210}Po	1.83E+00	2.12E+00	1.89E+00	7.13E+00
^{211}Po	1.90E-01	9.30E-05	2.29E-01	5.29E-04
^{212}Po	6.49E+03	5.77E-01	7.91E+03	2.36E+00
^{213}Po	6.09E+00	9.02E-02	6.28E+00	6.62E-01
^{214}Po	2.14E+00	2.25E+00	2.21E+00	7.57E+00
^{215}Po	6.91E+01	3.38E-02	8.33E+01	1.92E-01
^{216}Po	1.01E+04	9.01E-01	1.23E+04	3.68E+00
^{218}Po	2.14E+00	2.25E+00	2.21E+00	7.57E+00
^{144}Pr	1.17E-23	6.75E-23	1.41E-23	6.49E-22
^{144m}Pr	1.64E-25	9.45E-25	1.97E-25	9.09E-24
^{236}Pu	2.68E-15	5.39E-08	2.90E-15	2.96E-07
^{238}Pu	1.37E+06	4.96E+03	1.57E+06	2.58E+04
^{239}Pu	3.51E+06	1.86E+03	4.17E+06	4.53E+03
^{240}Pu	9.28E+05	1.31E+03	1.10E+06	4.55E+03
^{241}Pu	4.87E+05	1.74E+03	5.81E+05	8.60E+03

Radionuclide	Interim State of Repository CH-TRU Waste (Ci)	Interim State of Repository RH-TRU Waste (Ci)	Final State of Repository CH-TRU Waste (Ci)	Final State of Repository RH-TRU Waste (Ci)
^{242}Pu	2.45E+02	4.05E+00	2.86E+02	2.39E+01
^{243}Pu	7.72E-01	9.26E-05	9.23E-01	8.64E-04
^{244}Pu	5.84E-02	3.71E-06	6.96E-02	1.23E-05
^{246}Pu	2.62E-08	0.00E+00	3.13E-08	0.00E+00
^{223}Ra	6.91E+01	3.38E-02	8.33E+01	1.92E-01
^{224}Ra	1.01E+04	9.01E-01	1.23E+04	3.68E+00
^{225}Ra	6.22E+00	9.21E-02	6.42E+00	6.77E-01
^{226}Ra	2.14E+00	2.25E+00	2.21E+00	7.57E+00
^{228}Ra	1.07E-01	2.96E-03	1.08E-01	2.07E-02
^{87}Rb	1.76E-10	1.55E-07	1.87E-10	1.57E-06
^{102}Rh	0.00E+00	1.32E-35	0.00E+00	7.23E-35
^{106}Rh	9.73E-18	1.09E-16	1.17E-17	1.08E-15
^{219}Rn	6.91E+01	3.38E-02	8.33E+01	1.92E-01
^{220}Rn	1.01E+04	9.01E-01	1.23E+04	3.68E+00
^{222}Rn	2.14E+00	2.25E+00	2.21E+00	7.57E+00
^{106}Ru	9.73E-18	1.09E-16	1.17E-17	1.08E-15
^{125}Sb	7.38E-08	6.17E-06	8.78E-08	3.74E-05
^{126}Sb	1.20E-06	5.09E-03	1.21E-06	1.19E-02
^{126m}Sb	1.28E-05	4.11E-02	1.31E-05	1.34E-01
^{79}Se	1.00E-04	7.97E-02	1.22E-04	1.41E-01
^{145}Sm	0.00E+00	1.59E-22	0.00E+00	8.68E-22
^{146}Sm	1.81E-13	7.28E-09	1.81E-13	4.00E-08
^{147}Sm	1.52E-08	4.00E-08	1.73E-08	3.86E-07
^{148}Sm	1.63E-15	5.17E-20	1.63E-15	2.83E-19
^{151}Sm	1.14E+01	1.89E+01	1.14E+01	6.65E+01
^{119m}Sn	0.00E+00	2.30E-25	0.00E+00	1.26E-24
^{121}Sn	4.55E-05	2.78E-01	4.55E-05	8.15E-01
^{121m}Sn	5.86E-05	3.59E-01	5.87E-05	1.05E+00
^{126}Sn	1.28E-05	4.11E-02	1.31E-05	1.34E-01
^{90}Sr	2.17E+02	1.93E+04	2.30E+02	6.06E+04
^{157}Tb	0.00E+00	1.51E-02	0.00E+00	8.26E-02
^{97}Tc	0.00E+00	6.65E-09	0.00E+00	3.64E-08
^{99}Tc	2.18E+01	5.85E+01	2.18E+01	5.65E+02

Radionuclide	Interim State of Repository CH-TRU Waste (Ci)	Interim State of Repository RH-TRU Waste (Ci)	Final State of Repository CH-TRU Waste (Ci)	Final State of Repository RH-TRU Waste (Ci)
^{123}Te	6.98E-22	3.50E-15	6.98E-22	1.92E-14
^{125m}Te	1.80E-08	1.51E-06	2.14E-08	9.14E-06
^{227}Th	6.81E+01	3.34E-02	8.22E+01	1.90E-01
^{228}Th	1.01E+04	9.01E-01	1.23E+04	3.68E+00
^{229}Th	6.22E+00	9.21E-02	6.42E+00	6.77E-01
^{230}Th	4.35E-01	4.53E-03	4.74E-01	1.49E-02
^{231}Th	1.62E+00	1.17E+00	1.74E+00	2.04E+00
^{232}Th	1.08E-01	1.87E-03	1.08E-01	9.77E-03
^{234}Th	9.59E+01	1.77E+00	1.08E+02	3.50E+00
^{204}Tl	1.37E-12	0.00E+00	1.37E-12	0.00E+00
^{206}Tl	2.41E-06	2.79E-06	2.49E-06	9.41E-06
^{207}Tl	6.89E+01	3.37E-02	8.31E+01	1.92E-01
^{208}Tl	3.64E+03	3.24E-01	4.44E+03	1.32E+00
^{209}Tl	1.31E-01	1.93E-03	1.35E-01	1.42E-02
^{171}Tm	0.00E+00	1.57E-11	0.00E+00	8.61E-11
^{232}U	9.85E+03	8.73E-01	1.20E+04	3.56E+00
^{233}U	3.13E+02	1.63E+01	3.56E+02	1.24E+02
^{234}U	6.48E+02	7.15E+00	7.36E+02	1.97E+01
^{235}U	1.62E+00	1.17E+00	1.74E+00	2.04E+00
^{236}U	2.99E+00	1.11E-01	3.58E+00	2.49E-01
^{237}U	1.17E+01	4.16E-02	1.39E+01	2.06E-01
^{238}U	9.59E+01	1.77E+00	1.08E+02	3.50E+00
^{240}U	5.83E-02	3.71E-06	6.95E-02	1.23E-05
^{49}V	0.00E+00	1.47E-21	0.00E+00	8.07E-21
^{90}Y	2.17E+02	1.93E+04	2.30E+02	6.06E+04
^{65}Zn	1.35E-29	1.71E-28	1.57E-29	1.73E-27
^{93}Zr	1.24E-02	2.40E-02	1.24E-02	1.99E-01
Total	7.93E+06	1.17E+05	9.32E+06	3.57E+05

Source: Data for the interim state of the repository are provided by ISPAIR-2024 (Van Soest 2025a, Tables 5-3 and 5-4). Data for the final state of the repository are provided by FRPAIR-2024 (Van Soest 2025b, Tables 5-3 and 5-4). Data reported in both ISPAIR-2024 and FRPAIR-2024 include scaled information known by the TRU waste sites as of December 31, 2023.

TRU WASTE-2.1.6 Summary of Other Important Component Masses

Table TRU WASTE-6 summarizes the current mass of other important components in the disposal inventory.

Table TRU WASTE-6. Summary of Masses for Other Important Components

Component	Interim State of Repository Mass Contained in the Disposal Inventory (kg)	Final State of Repository Mass Contained in the Disposal Inventory (kg)
Acetate	1.58E+04	1.66E+04
Acetic Acid	1.56E+04	1.58E+04
Citrate	2.62E+03	2.77E+03
Citric Acid	8.16E+03	8.92E+03
EDTA	3.92E+02	4.45E+02
Oxalate	7.15E+02	8.06E+02
Oxalic Acid	1.68E+04	1.69E+04
Nitrate	1.61E+06	1.64E+06
Phosphate	2.54E+05	2.57E+05
Sulfate	4.68E+05	4.75E+05

Source: Data for the interim state of the repository are provided by ISPAIR-2024 (Van Soest 2025a, Tables 5-8 and 5-9). Data for the final state of the repository are provided by FRPAIR-2024 (Van Soest 2025b, Tables 5-8 and 5-9). Data reported in both ISPAIR-2024 and FRPAIR-2024 include scaled information known by the TRU waste sites as of December 31, 2023.

TRU WASTE-2.2 Summary of Waste Components and Characteristics

Tables TRU WASTE-7, TRU WASTE-8, and TRU WASTE-9 summarize the waste characteristics and waste components considered in this section. These tables provide:

- The waste characteristics and components expected to have significant effect on disposal system performance (i.e., those included in PA) (Table TRU WASTE-7),
- The waste characteristics and components expected to have negligible effect on disposal system performance (Table TRU WASTE-8), and
- The waste characteristics and components that were considered but excluded (Table TRU WASTE-9).

TRU WASTE-2.2.1 Characteristics with Significant Effect on Performance

Table TRU WASTE-7 lists the waste characteristics and components that are included in PA because they are expected to have a significant impact on repository performance. The waste characteristics and components listed in Table TRU WASTE-7 are updated based on Table WCA-2 of the CCA. None of the inventory changes described in ISPAIR-2024 (Van Soest 2025a) for the interim state of the repository and in FRPAIR-2024 (Van Soest 2025b) for the final state of the repository led to an alternate conclusion regarding the relative importance of individual waste characteristics and components for PA since the CRA-2019. Note, however, that the relative importance for some waste characteristics and components did change between the previous version of this appendix (for the CRA-2004) and the CRA-2019 (see footnotes b and c in Table TRU WASTE-7).

Table TRU WASTE-7. Waste Characteristics and Components Used in Performance Assessment: Characteristics Expected to Have a Significant Effect on Disposal System Performance.

Characteristic	Component	Effect on Performance	Reference
Radioactivity of Each Isotope	Radionuclides	Used in Calculating Normalized Releases	Kicker (2025a and 2025b); Appendix SCR-6.1.2.1 (W2 and W3)
TRU Radioactivity at Closure	α-Emitting TRU Radionuclides, half-life > 20 Years	Determines WUF	Kicker (2025a and 2025b); Appendix SCR-6.1.2.1 (W2 and W3)
Solubility	Radionuclides	Actinide Mobilization[a]	Appendix SCR-6.5.2.1 (W56); Domski (2025a and 2025b); Kaplan et al. (2025)
Colloid Formation	Radionuclides, Soils, Cellulosic, Plastic, and Rubber (CPR) Materials	Actinide Mobilization[a]	Kaplan et al. (2025); Appendix SOTERM-3.5
Redox State	Radionuclides	Actinide Mobilization[a]	Appendix SCR-6.5.5.1 (W64 and W66)

Characteristic	Component	Effect on Performance	Reference
Redox Potential	Ferrous Metals	Actinide Oxidation State; Actinide Mobilization[a]	Appendix SCR-6.5.5.1 (W64 and W66)
Gas Generation	Ferrous Metals	Increase in Gas Pressure	Appendix SCR-6.5.1.4 (W49 and W51)
Microbial Substrate	Cellulosic, Plastic, Rubber Materials	Increase in Gas Pressure	Appendix SCR-6.5.1.1 (W44)
Particle Diameter	Solid Waste Components	Spalling Release	Appendix PA-4.7.2
Microbial Nutrients	Sulfates	Increase in Gas Pressure	Nemer and Zelinksi (2005); Appendix PA-4.2.5
Microbial Nutrients	Nitrates	Increase in Gas Pressure	Wang and Brush (1996a); Nemer and Zelinski (2005); Appendix PA-4.2.5
Compactability/Compressibility and Shear Strength	Solid Waste Components	Effect on Creep Closure, Cuttings, Caving, Spallings	Appendix PA-1.1.6; Appendix SCR-6.6.2.1 (W84, W85, W86)
Brine Radiolysis[b]	Radionuclides	Increase Gas Pressure	Appendix SCR-6.5.1.6 (W52); Appendix PA-1.1.3; Day (2019)
Brine Radiolysis	Radionuclides	Actinide Oxidation State	Appendix SOTERM-3.4
Complexation with Actinides[c]	Soil and Humic Material	Actinide Mobilization[a]	Appendix SCR-6.5.6.2 (W70)
Complexation with Actinides[d]	Organic Ligands[e]	Can Increase Radionuclide Solubility	Appendix SOTERM-3.3; Appendix SCR-6.5.6.1 (W68 and W69), Domski (2025d and 2025e)

(a) Referred to as “actinide mobility” in Appendix TRU WASTE-2004.
(b) Brine Radiolysis was moved from “Not Used in Performance Assessment” to “Expected to have a Significant Effect on Disposal System Performance” based on its inclusion in Performance Assessment discussed in Day (2019).

(c) Complexation with Actinides by Soil and Humic Material was moved from "Expected to Have a Negligible Effect on Disposal System Performance" to "Expected to have a Significant Effect on Disposal System Performance" based on impact to PA. See Appendix PA-4.4.1 for latest discussion.
(d) Complexation with Actinides by Organic Ligands "Expected to Have a Negligible Effect on Disposal System Performance" to "Expected to have a Significant Effect on Disposal System Performance" based on inclusion in PA. See Appendix SOTERM for latest discussion.
(e) "Chelating agents" is specifically mentioned in 40 CFR 194.24(b)(2) as a waste component to be analyzed. In this document, "organic ligands" is used interchangeably for "chelating agents."

TRU WASTE-2.2.2 Characteristics with Negligible Effect on Performance

Table TRU WASTE-8 lists the waste characteristics and components that are included in PA but would be expected to have a negligible impact on performance. For example, the impact of microbially generated CO_2 on performance is insignificant because the CO_2 will react with the magnesium oxide (MgO), forming Mg carbonate minerals that greatly reduce the impact of CO_2 on pH. The waste characteristics and components listed in Table TRU WASTE-8 are updated based on Table WCA-3 of the CCA. None of the inventory changes described in ISPAIR-2024 (Van Soest 2025a) for the interim state of the repository and in FRPAIR-2024 (Van Soest 2025b) for the final state of the repository led to an alternate conclusion regarding the relative importance of individual waste characteristics and components for PA since the CRA-2019. The relationships between components, characteristics, and PA codes are illustrated in Figure TRU WASTE-2.[1]

[1] The codes are: BRAGFLO (brine and gas flow in and around the Salado Formation, as well as direct brine release [(DBR]) volume calculation), SECOTP2D (radionuclide transport in the Culebra Formation), DRSPALL (spallings releases), NUTS (radionuclide transport in and around the Salado Formation), PANEL (radionuclide concentrations), CUTTINGS_S (cuttings and cavings volumes), EPAUNI (time-varying waste activity), and CCDFGF (stochastic future calculation and CCDF assembly).

Table TRU WASTE-8. Waste Characteristics and Components Used in Performance Assessment: Characteristics Expected to Have a Negligible Effect on Disposal System Performance.

Characteristic	Component	Effect on Performance	Reference
Permeability (waste)	Solid Waste Components	Negligible Effect on Brine Movement, Gas Storage	Vaughn et al. (1995); Butcher (1997); Appendix SCR-6.3.5.1 (W32)
Porosity (waste)	Solid Waste Components	Negligible Effect on Brine/Gas Storage	Appendix SCR-6.3.5.1 (W32); Brunell et al. (2025)
Microbial Nutrients, CO_2 Generation	Sulfates, Nitrates	Negligible: MgO Reacts with CO_2	Appendix SCR-6.5.1.1 (W44)
Microbial Substrate: CO_2 Generation	Cellulosic, Plastic, Rubber Materials	Negligible: MgO Reacts with CO_2	Appendix SCR-6.5.1.1 (W44)
Gas Generation	Water in the Waste	Enhances Initial Gas Generation	Appendix TRU WASTE-2.5.1
Explosivity	Other Organic Compounds (explosive)	None	Appendix SCR-6.3.3.1 (W27)
Binding to Organic Ligands[a]	Ferrous Metals	Can Reduce Actinide Mobilization[b]	Domski (2025a and 2025b); Appendix SCR-6.5.6.1 (W69)

(a) Binding to Organic Ligands by Ferrous Metals was moved from "Not Used in Performance Assessment (Table TRU WASTE-9)" to "Expected to Have a Negligible Effect on Disposal System Performance (Table TRU WASTE-8)" based on calculations completed for CRA-2026 (Domski 2025a and 2025b) that include iron citrate complexes.

(b) Referred to as "actinide mobility" in Appendix TRU WASTE-2004.

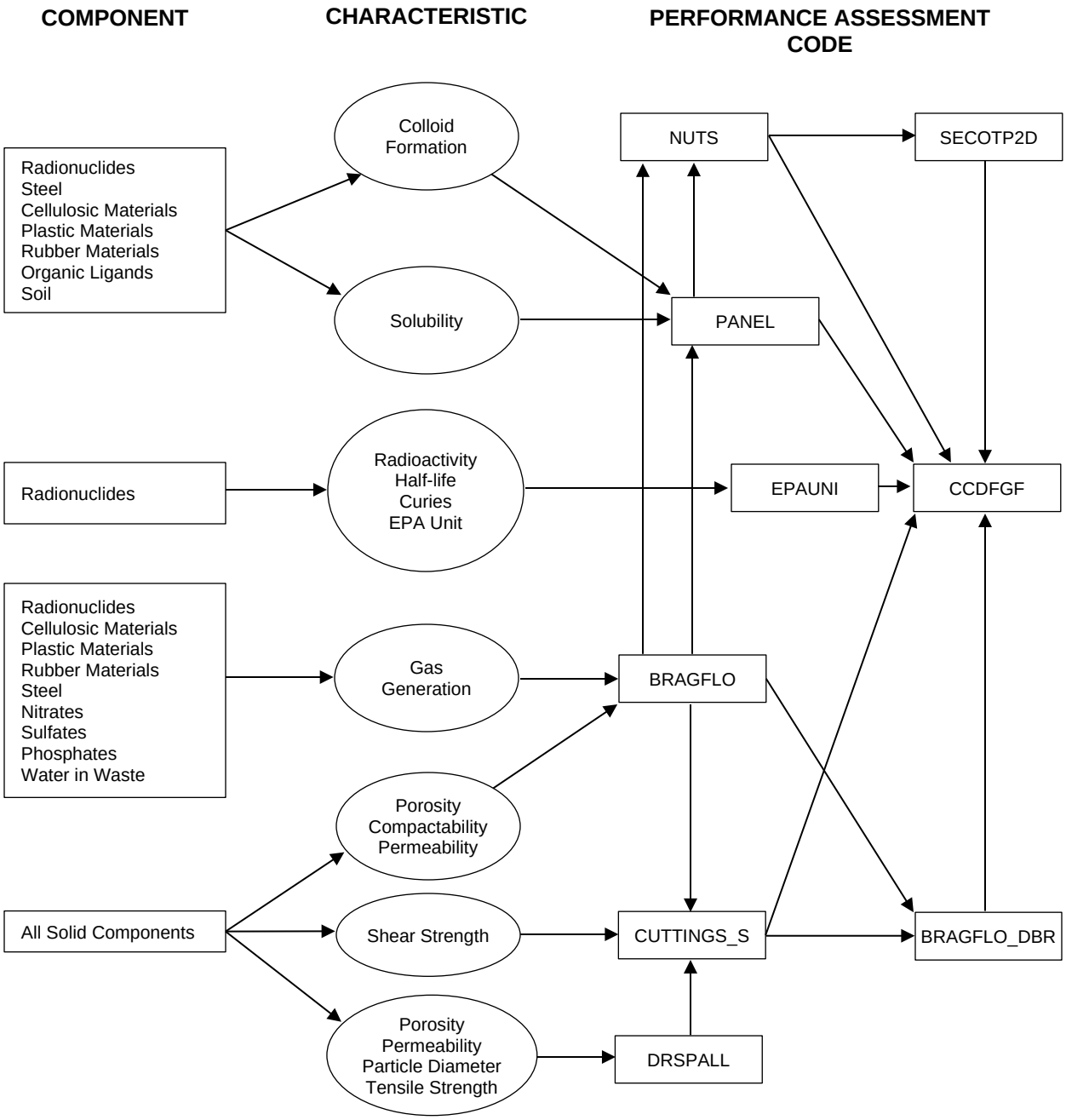


Figure TRU WASTE-2. Waste Components, the Associated Waste Characteristics, and a Performance Assessment Code Related to Each Characteristic.

TRU WASTE-2.2.3 Characteristics Not Used in Performance Assessment

Table TRU WASTE-9 lists the waste characteristics and components that are not used in PA. Some of these excluded characteristics, however, can indirectly influence performance but are not included because it is conservative (with respect to releases) to do so. For example, the

ability of nonferrous metals to bind organic ligands prevents those ligands from increasing actinide solubility, which is considered in PA analyses. The waste characteristics and components listed in Table TRU WASTE-9 are updated based on Appendix WCA, Table WCA-4, in the CCA. None of the inventory changes described in ISPAIR-2024 (Van Soest 2025a) for the interim state of the repository and in FRPAIR-2024 (Van Soest 2025b) for the final state of the repository led to an alternate conclusion regarding the relative importance of individual waste characteristics and components for PA since the CRA-2019.

Each waste characteristic shown in Tables TRU WASTE-7 and TRU WASTE-8 is reflected in one or more parameters that are used in PA. The PA parameters are compiled in the Performance Assessment Parameter Database (PAPDB) and cataloged by Feng and Kicker (2025) for CRA-2026.

Table TRU WASTE-9. Waste Characteristics and Components Not Used in Performance Assessment.

Characteristic	Component	Effect on Performance	Reference
Cellulosic Materials Radiolysis	Radionuclides	Negligible Effect on Total Gas Generation	Knerr (2020); Appendix SCR-6.5.1.7 (W53)
Galvanic Action	Nonferrous Metals	Negligible	Appendix SCR-6.5.1.5 (W50)
Buffering Action[a]	Cement[a]	Negligible: Reacts With CO_2 And $MgCl_2$	Appendix SCR-6.5.2.1.3.2 (W56)
Heat Of Solution	Cement	Negligible	Appendix SCR-6.3.4.1 (W73)
Ca^{2+} Binding to Organic Ligands	Cement	Negligible Compared to Other Metals	Appendix SCR-6.1.4.2 (W8); Appendix SCR-6.5.4.1 (W61)
Buffering Action[a]	Ferrous Metals[a]	Actinide Mobilization[b]	Appendix TRU WASTE-2.4.1.2
Galvanic Action	Ferrous Metals	Negligible	Appendix SCR-6.5.1.5 (W50)
Redox Reactions	Nonferrous Metals	Negligible Compared to Iron	Appendix SCR-6.5.5.1 (W64 and W66)
Gas Generation	Al And Other Nonferrous Metals	Negligible Relative to Iron	Appendix SCR-6.5.1.4 (W49 and W51)
Microbial Nutrients, CO_2 Generation	Phosphates	Negligible Because MgO Reacts with CO_2	Appendix SCR-6.1.5.1 (W9)

Characteristic	Component	Effect on Performance	Reference
Microbial Nutrients: CH_4 Generation	Phosphates[a]	Negligible	Cotsworth (2005), and Nemer and Stein (2005)
Heat Generation	RH-TRU	Negligible	Appendix SCR-6.2.1.2 (W13)
Electrochemical Processes	Sulfate, Nitrate, Phosphate	Negligible	Appendix SCR-6.7.4.1 (W94), Appendix SCR-6.7.4.2 (W95), and Appendix SCR-6.7.4.3 (W96)
Binding to Organic Ligands[a]	Nonferrous Metals[a]	Can Reduce Actinide Mobilization[b]	Appendix SCR-6.5.6.1 (W69)

(a) Waste characteristics and components that influence performance indirectly – by influencing components and characteristics listed in Table TRU WASTE-7.
(b) Referred to as "actinide mobility" in Appendix TRU WASTE-2004.

TRU WASTE-2.2.4 Relationship Between Inventory Data and Performance Assessment

The ISPAIR-2024 (Van Soest 2025a) provides WIPP-level data and waste stream-level data on the radionuclide inventory for the interim state of the WIPP repository. The FRPAIR-2024 (Van Soest 2025b) provides WIPP-level data and waste stream-level data on the radionuclide inventory for the final state of the WIPP repository. Performance assessment models generally use the WIPP-level data, normalized to a base year (2083) and scaled up to the WIPP capacity[2]. The one exception to this approach is the cuttings/caving model, which uses scaled waste stream-level data to capture potential variations in contact-handled TRU (CH-TRU) and remote-handled TRU (RH-TRU) waste (Appendix MASS-14.1.4).

The relationship between the 2024 ATWIR, PAIR data, and PA is shown in Figure TRU WASTE-3, which indicates that the waste stream level data are used only in modeling direct release by cuttings and cavings (see Appendix PA for additional information). This direct release scenario includes the probability of penetrating any of the 485 CH-TRU waste streams or 105 RH-TRU waste streams, as discussed in Appendix PA-2.1.2.1.

This approach for cuttings and cavings releases represents the potential variations in the CH--TRU and RH-TRU waste and is necessary because the size scale for cuttings and cavings is on the order of the drill bit diameter, which is less than the diameter of a 55-gallon drum (8 to 12 in versus 24 in). A cuttings and cavings intrusion into CH-TRU waste would, therefore, extract

[2] The final state of the repository has a capacity of 6.2 million cubic feet (175,564 cubic meters) of TRU waste at the time of closure, as authorized by the WIPP LWA (U.S. Congress 1996). However, it is recognized that the LWA volume cannot be placed in the physical space provided by the approved panels in the WIPP repository. Therefore, for PA modeling of the interim state of the repository, the DOE recommends a LWA total inventory capacity of 157,832 cubic meters (Ward 2025).

waste from three specific waste containers (assuming that waste containers are stacked three high in the disposal rooms), rather than sampling from a larger volume of waste. For RH-TRU waste intrusions, a single waste container is assumed to be encountered.

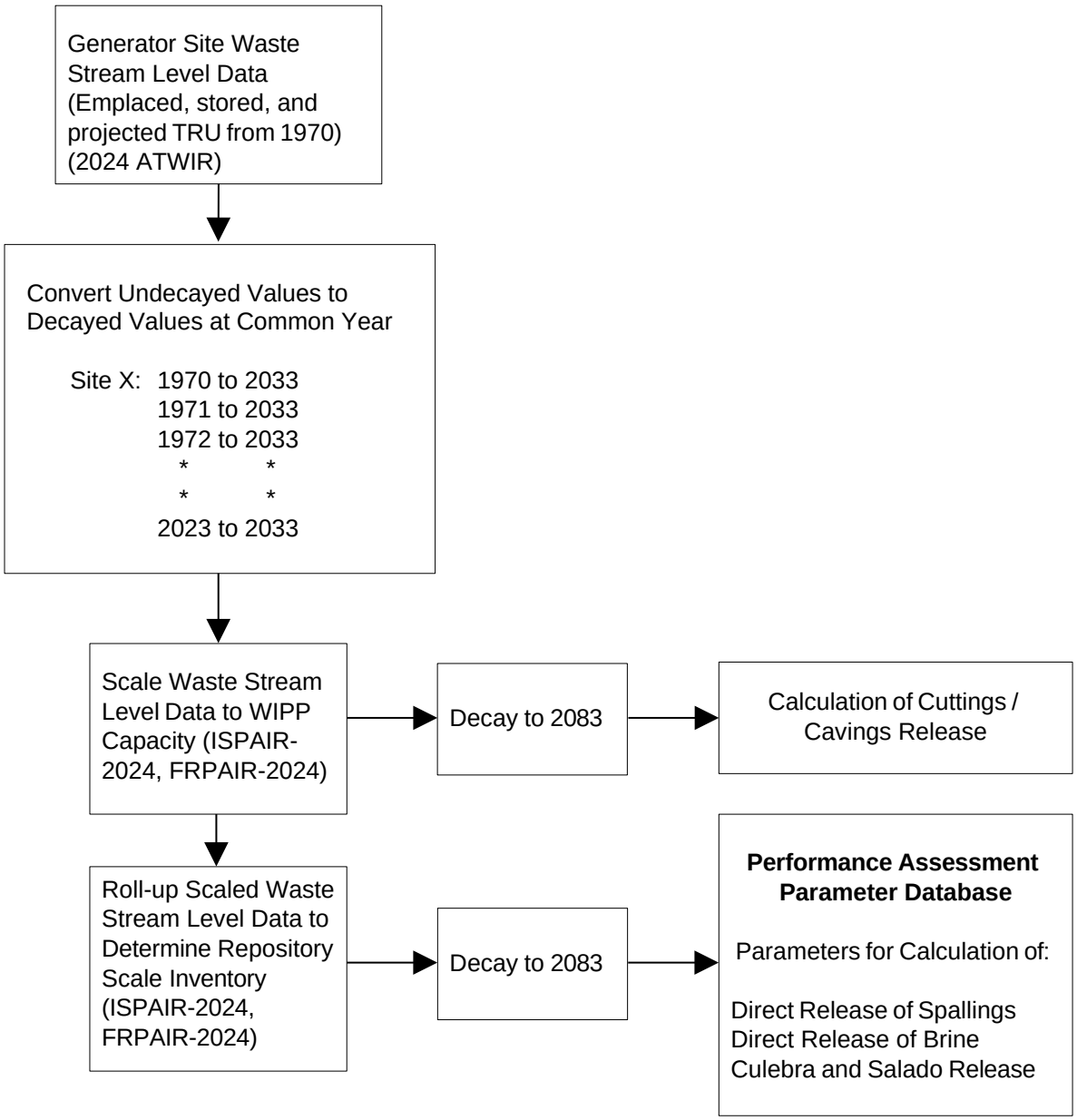


Figure TRU WASTE-3. Flow Chart for Inventory Input into Performance Assessment

In contrast, scenarios in which radionuclides would be released in brine, either directly to the surface or through the Culebra Formation, assume that the mobility of radionuclides in brine results in an essentially homogeneous mixture of radionuclides. Brine flow would contact a much larger portion of the waste than the direct release of cuttings and cavings. For brine-related release pathways, the total radionuclide inventory is more applicable than the inventory of a particular waste stream. Performance assessment, therefore, uses the average (WIPP-level)

inventory from all TRU waste sites, as shown in Figure TRU WASTE-3 for DBRs and releases to/from the Culebra. In a similar fashion, spallings releases use WIPP-level CH-TRU activity because this mechanism is assumed to release waste from a volume larger than several drums, averaging out variations in waste streams (Appendix PA-2.1.2.2).

Decay of radionuclides in the TRU waste will produce some radioactive daughter products that must be accounted for in the waste inventory. Therefore, to provide a current inventory estimate for the CRA-2026, all radionuclide values reported in both ISPAIR-2024 (Van Soest 2025a) and FRPAIR-2024 (Van Soest 2025b) are decayed to the end of 2083. The PA calculations begin at the time of closure of the WIPP facility, which is assumed to be the end of year 2083.

TRU WASTE-2.3 Components That Affect Performance: Curie Content

The radioactivity of a particular radionuclide, often called the activity, is significant to two different aspects of compliance: (1) inclusion in the waste unit factor (WUF), which is the normalization factor for the release limits given in Table TRU WASTE-10, and (2) inclusion in the source term for the compliance demonstration. The WUF is based only on TRU wastes that are alpha (α)-emitters with a half-life greater than 20 years at repository closure, while the complementary cumulative distribution function (CCDF) associated with releases (Appendix PA) is based on a radionuclide screening of the full inventory of all radionuclides in the repository. This section, therefore, includes two subsections: Appendix TRU WASTE-2.3.1, components relevant to inclusion in the WUF; and Appendix TRU WASTE-2.3.2, components relevant to inclusion in CCDFs for each applicable scenario.

TRU WASTE-2.3.1 Radioactivity Included in the Waste Unit Factor

TRU WASTE-2.3.1.1 Definition and Calculation of WUF

The WUF is the number of millions of curies (Ci) of α-emitting TRU radionuclides with half-lives longer than 20 years at repository closure (40 CFR Part 191, Appendix A), based on the TRU waste inventory to be disposed. For the interim state of the WIPP repository, 7.37×10^6 Ci (see Table TRU WASTE-11) of TRU waste are estimated to be in the repository at closure, resulting in a WUF of 7.37. For the final state of the WIPP repository, 8.68×10^6 Ci (see Table TRU WASTE-10) of TRU waste are estimated to be in the repository at closure, resulting in a WUF of 8.68. The current WUF values reflect the updated TRU waste inventory as described in Appendix TRU WASTE-2.1.2 (greater detail is available in ISPAIR-2024 (Van Soest 2025a), FRPAIR-2024 (Van Soest 2025b), and Kicker (2025a and 2025b)).

TRU WASTE-2.3.1.2 EPA Release Limits, Normalized Limits, and Radionuclides Contributing to WUF

The number of EPA units of a radionuclide is the activity (in Ci) of the radionuclide divided by the release limit for that radionuclide. EPA units are important because the containment requirement for the repository is expressed in EPA units. Kicker (2025a and 2025b) discusses current EPA units for the interim and final states of the repository in more detail.

As an example, using EPA units, the ^{239}Pu inventory for the final state of the repository at closure would be 4.17×10^6 Ci (Table TRU WASTE-11), and the release limit for ^{239}Pu would be 868 Ci (Table TRU WASTE-10); therefore, the number of EPA units is calculated as:

$$\frac{4.17 \times 10^6 \text{Ci}}{868 \text{ Ci}} = 4.80 \times 10^3 \text{ EPA units} \quad (1)$$

Table TRU WASTE-10. EPA Release Limits and Normalized Release Limits for Radionuclides

Radionuclide	Release Limit per Unit of Waste[a] (Ci)	Release Limit for the Interim State of the WIPP Repository Normalized by Total from Table TRU WASTE-11 (Ci)	Release Limit for the Final State of the WIPP Repository Normalized by Total from Table TRU WASTE-11 (Ci)
Americium: ^{241}Am or ^{243}Am	100	737	868
Carbon: ^{14}C	100	737	868
Cesium: ^{135}Cs, or ^{137}Cm	1,000	7370	8680
Iodine: ^{129}I	100	737	868
Neptunium: ^{237}Np	100	737	868
Plutonium: ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu	100	737	868
Radium: ^{226}Ra	100	737	868
Strontium: ^{90}Sr	1,000	7370	8680
Technetium: ^{99}Tc	10,000	73700	86800
Thorium: ^{230}Th or ^{232}Th	10	73.7	86.8
Tin: ^{126}Sn	1,000	7370	8680
Uranium: ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U	100	737	868
Any other α-emitting radionuclide with a half-life greater than 20 years	100	737	868
Any other radionuclide with a half-life greater than 20 years that does not emit α particles	1,000	7370	8680

(a) The unit of waste is also called a WUF. In Appendix A Table 1 of 40 CFR Part 191, the WUF for TRU waste is defined in Note 1(e) to the table as an amount of TRU wastes containing one million curies of alpha-emitting TRU radionuclides with half-lives greater than 20 years.

Table TRU WASTE-11. Radionuclides That Contribute to the Waste Unit Factor

Nuclide	Half-Life (years)	Interim State of Repository Inventory at Closure (Ci)	Interim State of Repository Percent of Waste Unit Factor	Final State of Repository Inventory at Closure (Ci)	Final State of Repository Percent of Waste Unit Factor
^{241}Am	4.32×10^{2}	1.55E+06	21.106%	1.81E+06	20.793%
^{242m}Am	1.41×10^{2}	6.74E-01	0.000%	2.12E+00	0.000%
^{243}Am	7.37×10^{3}	9.93E+01	0.001%	6.08E+02	0.007%
^{249}Cf	3.51×10^{2}	1.70E+01	0.000%	9.25E+01	0.001%
^{251}Cf	9.00×10^{2}	5.27E+00	0.000%	2.79E+01	0.000%
^{243}Cm	2.91×10^{1}	8.70E+00	0.000%	3.54E+01	0.000%
^{245}Cm	8.50×10^{3}	6.82E+00	0.000%	2.40E+01	0.000%
^{246}Cm	4.76×10^{3}	2.25E+02	0.003%	8.29E+02	0.010%
^{247}Cm	1.56×10^{7}	7.72E-01	0.000%	9.24E-01	0.000%
^{248}Cm	3.48×10^{5}	1.74E+00	0.000%	5.25E+00	0.000%
^{250}Cm	8.30×10^{3}	1.05E-07	0.000%	1.25E-07	0.000%
^{237}Np	2.14×10^{6}	7.22E+01	0.001%	9.15E+01	0.001%
^{238}Pu	8.77×10^{1}	1.37E+06	18.661%	1.60E+06	18.394%
^{239}Pu	2.41×10^{4}	3.51E+06	47.605%	4.17E+06	48.044%
^{240}Pu	6.56×10^{3}	9.30E+05	12.619%	1.11E+06	12.746%
^{242}Pu	3.75×10^{5}	2.49E+02	0.003%	3.10E+02	0.004%
^{244}Pu	8.00×10^{7}	5.84E-02	0.000%	6.96E-02	0.000%
TOTAL	—	7.37E+06	100.000%	8.68E+06	100.000%

Source: Data for the interim state of the repository provided by Kicker (2025a, Table 4). Data for the final state of the repository provided by Kicker (2025b, Table 4).

The release limit for ^{239}Pu is given by the WUF (7.37 for the interim state of the repository and 8.68 for the final state of the repository) multiplied by the release limit per million Ci of TRU. The release limit per million Ci is given in Table TRU WASTE-10, which is a copy of Table 1 in Appendix A, 40 CFR Part 191. The value for ^{239}Pu is 100 Ci/unit of waste, giving a release limit of 737 Ci for the interim state of the repository and 868 Ci for the final state of the repository. The calculation of WUF, EPA units, and release limits uses the method established for the CCA (described above).

With a mix of radionuclides, each radionuclide is normalized with respect to its release limit, and the sum of all releases must have:

- less than one chance in 10 of exceeding the release limit, and
- less than one chance in 1,000 of exceeding ten times the release limit.

The sum of releases in EPA units is expressed by

$$R_j = \frac{1}{f_w}\left[\frac{Q_{1j}}{L_1} + \frac{Q_{2j}}{L_2} + \cdots + \frac{Q_{nRj}}{L_{nR}}\right] = \sum_{i\text{-}1}^{nR} \frac{Q_{ij}}{f_w L_i} \leq \begin{cases} 1 \text{ with a probability of } 0.1 \\ 10 \text{ with a probability of } 0.001 \end{cases} \quad (2)$$

where

R_j is the total release in EPA units under scenario j,
f_w is the WUF,
Q_{ij} is the cumulative release for radionuclide i under scenario j,
L_i is the EPA release limit for radionuclide i, and
nR is the number of radionuclides contributing to the release.

The regulatory time period over which these releases are summed is 10,000 years. A brief explanation of these release limits is given in Sanchez (1996), and a comprehensive discussion of the background for these limits is provided in EPA (1985).

Figure TRU WASTE-4 is a flow diagram outlining the rationale for the selection of those radionuclides in the inventory that contribute to the WUF. As noted above, not all radionuclides are included in this factor. For example, ^{90}Sr is excluded because it is not a TRU radionuclide or an α-emitter. Even uranium is excluded because it is not a TRU radionuclide, defined as elements with atomic numbers greater than 92.

Note that the inventory in Table TRU WASTE-11 is dominated by americium and plutonium, the same elements that dominated the inventory for the CCA. More specifically, the radionuclides ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am capture 99.9 percent of the WUF. Therefore, the combined activity of these radionuclides is orders of magnitude greater than the combined activity of the remaining radionuclides.

TRU WASTE-2.3.2 Radioactivity Included in the Source Term for Performance Assessment

Unlike the WUF, all reported radionuclides are included in a demonstration of compliance (40 CFR 194.24) and must therefore be considered for inclusion in the source term for PA. A comprehensive list of radionuclides in the waste is in ISPAIR-2024 (Van Soest 2025a) and FRPAIR-2024 (Van Soest 2025b), which provides the inventory basis for the CRA-2026 PA and supplemental calculation, respectively. Many of these radionuclides are present in such small quantities (i.e., their total combined inventory is much less than one percent) that their impact on long-term performance is negligible.

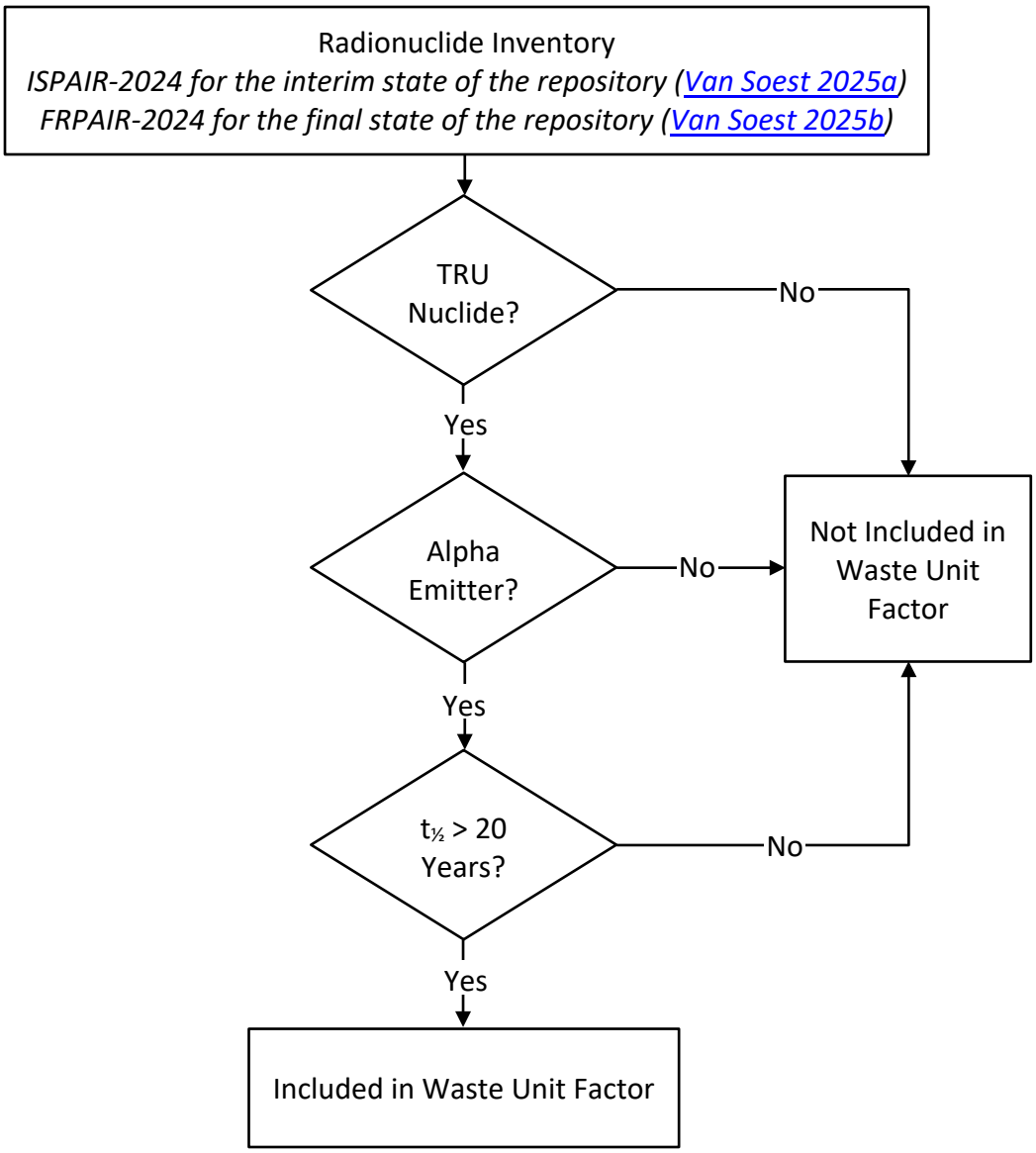
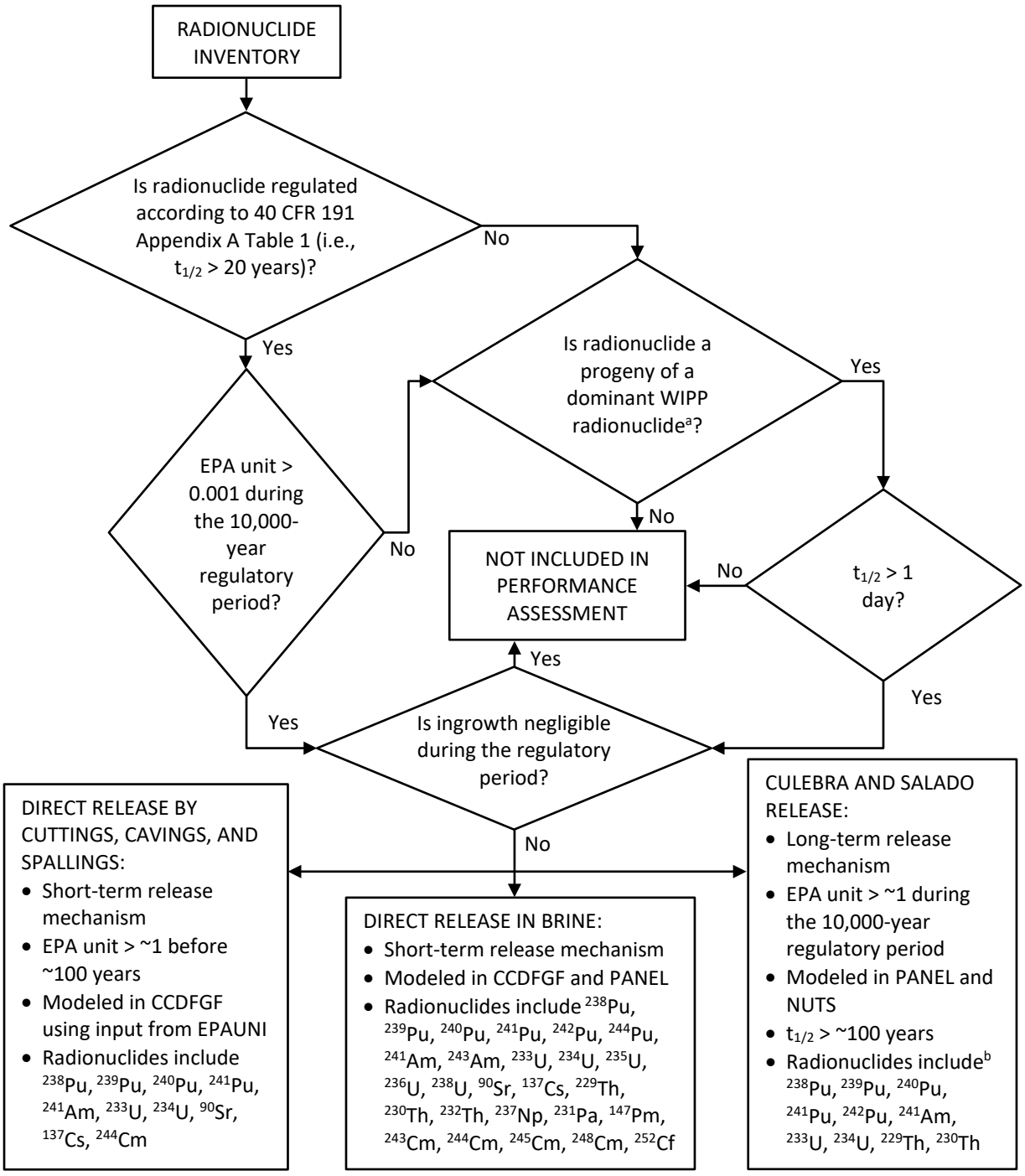


Figure TRU WASTE-4. Flow Diagram for Including Radionuclides in the Waste Unit Factor

TRU WASTE-2.3.2.1 Radionuclide Selection for Release Pathways

Two different release pathways are used in PA: (1) direct releases comprised of (a) material brought to the surface by cuttings, cavings, spallings, and (b) brine under pressure that flows to the surface during a drilling intrusion through the repository; and (2) releases to the accessible environment in brine that moves through the subsurface, primarily the Culebra aquifer. Note that the time scales for these two release pathways are quite different. The direct release during drilling events (Item 1) occurs within a few days. The flow and transport of radionuclides through the Culebra (Item 2) will require hundreds to thousands of years.

Different radionuclides are used for these pathways because of the time-scale differences and different release media (solid particles containing radionuclides or brine containing radionuclides) as well as the computational efficiency of each computer code used in the PA calculations. Figure TRU WASTE-5 is a flow diagram outlining the rationale for selecting radionuclides for different release mechanisms according to the criteria of Table TRU WASTE-10. The result of applying these criteria to the radionuclides in ISPAIR-2024 (Van Soest 2025a) and FRPAIR-2024 (Van Soest 2025b) is shown in Table TRU WASTE-12. The inventory analyses that follow Figure TRU WASTE-5 are documented in Kicker (2025a and 2025b). Table TRU WASTE-12 also lists the radionuclides used for specific release mechanisms. The activity in EPA units at 10,000 years is also shown in Table TRU WASTE-12, because some nuclides experience considerable ingrowth, but not enough to affect the domination by the most prevalent radionuclides ^{239}Pu and ^{240}Pu. The ^{241}Am component is also important for the first approximately 3,000 years after closure.



[a] Dominant WIPP radionuclides include ^{238}Pu, ^{241}Am, ^{239}Pu, ^{240}Pu, ^{137}Cs, ^{147}Pm, and ^{90}Sr (Kicker 2025a, Section 3).
[b] For the Culebra and Salado (long-term) release case, ^{241}Pu is accounted for even though its half-life is less than 20 years because its inventory activity is significant (dominant) and it directly decays to ^{241}Am.

Figure TRU WASTE-5. Flow Diagram for Selecting Radionuclides for the Release Pathways Conceptualized by Performance Assessment (This diagram describes the criteria for selecting radionuclides in Table TRU WASTE-12).

TRU WASTE-2.3.2.2 Radionuclides Included in Direct Releases by Cuttings, Cavings, and Spallings

The 10 isotopes listed in the column headed "Cuttings/Cavings/Spall Release" in Table TRU WASTE-12 are used to model direct release by cuttings, cavings, or spallings (i.e., solids releases). Release is assumed to occur when containers of CH-TRU or RH-TRU waste are breached during a borehole intrusion. The amount of radionuclides in the source term for solids releases is calculated from the inventory of individual waste streams (cuttings and cavings) and volume-averaged CH-TRU waste stream (spallings) penetrated, including decay and ingrowth. Details of the activity distribution in the waste streams for the interim state inventory are provided in Kim and Kicker (2025). The direct release scenario is discussed in greater detail in Appendix PA-2.1.2.

Eight of the listed isotopes comprise more than 99.9 percent of the activity in EPA units for the entire regulatory period for both the interim state of the repository (Kicker 2025a, Table 11) and the final state of the repository (Kicker 2025b, Table 11). The other two radionuclides (^{241}Pu and ^{244}Cm), which are not regulated under the EPA-specified release limits, are included because they are parent nuclides of significant daughters (^{241}Am and ^{240}Pu, respectively) that have the second and fourth largest activities in EPA units at closure (Table TRU WASTE-12). Inclusion of 99 percent or more of the total number of EPA units provides an accurate representation of the source term, while maintaining efficiency in computation by limiting the total number of isotopes to 10. The addition of the many radionuclides that make up the final 0.1 percent does not provide additional benefit in understanding the long-term behavior of the repository (Kicker 2025a and 2025b).

TRU WASTE-2.3.2.3 Radionuclides Included in Direct Releases of Brine to the Surface

Direct release of brine to the surface can carry radionuclides that are mobilized (i.e., dissolved in the brine or sorbed on colloidal particles).

Table TRU WASTE-12. Radionuclides Included in the Performance Assessment Source Term

Radio-nuclide (1)	Interim State Inventory at Closure (EPA Units)	Interim State Inventory at 10,000 Years (EPA Units)	Final State Inventory at Closure (EPA Units)	Final State Inventory at 10,000 Years (EPA Units)	CCDFGF and EPAUNI: Cuttings, Cavings, & Spall Release (2)	CCDFGF and PANEL: Direct Brine Release (2)	PANEL and NUTS: Salado Release (2)	PANEL, NUTS, and SECOTP2D: Culebra Release (2, 5)
^{239}Pu	4.76E+03	3.57E+03	4.80E+03	3.60E+03	×	×	×	×
^{241}Am	2.11E+03	4.78E-03	2.08E+03	1.45E-02	×	×	×	×
^{238}Pu	1.87E+03	8.98E-25	1.84E+03	2.40E-24	×	×	×	×
^{240}Pu	1.26E+03	4.39E+02	1.27E+03	4.43E+02	×	×	c	c

Radio-nuclide (1)	Interim State Inventory at Closure (EPA Units)	Interim State Inventory at 10,000 Years (EPA Units)	Final State Inventory at Closure (EPA Units)	Final State Inventory at 10,000 Years (EPA Units)	CCDFGF and EPAUNI: Cuttings, Cavings, & Spall Release (2)	CCDFGF and PANEL: Direct Brine Release (2)	PANEL and NUTS: Salado Release (2)	PANEL, NUTS, and SECOTP2D: Culebra Release (2, 5)
^{137}Cs	4.31E+00	0.00E+00	9.51E+00	0.00E+00	×	×	—	—
^{90}Sr	2.64E+00	0.00E+00	7.01E+00	0.00E+00	×	×	—	—
^{234}U	8.90E-01	1.52E+00	8.70E-01	1.49E+00	×	×	×	×
^{243}Am	1.35E-01	5.32E-02	7.00E-01	2.74E-01	—	×	—	—
^{233}U	4.46E-01	4.49E-01	5.54E-01	5.52E-01	×	×	c	c
^{242}Pu	3.38E-01	3.35E-01	3.57E-01	3.59E-01	—	×	c	c
^{238}U	1.33E-01	1.33E-01	1.28E-01	1.28E-01	—	×	—	—
^{237}Np	9.79E-02	5.27E-01	1.05E-01	5.29E-01	—	×	—	—
^{243}Cm	1.18E-02	0.00E+00	4.07E-02	0.00E+00	—	×	—	—
^{231}Pa	2.91E-02	2.85E-02	3.00E-02	2.94E-02	—	×	—	—
^{245}Cm	9.25E-03	4.53E-03	2.77E-02	1.43E-02	—	×	—	—
^{226}Ra	5.96E-03	1.05E-01	1.13E-02	1.03E-01	—	—	—	—
^{210}Pb	5.35E-03	1.05E-01	1.04E-02	1.03E-01	—	—	—	—
^{229}Th	8.57E-03	2.65E-01	8.17E-03	3.26E-01	—	×	c	c
^{248}Cm	2.36E-03	2.32E-03	6.04E-03	5.92E-03	—	×	—	—
^{230}Th	5.97E-03	1.35E+00	5.63E-03	1.32E+00	—	×	×	×
^{236}U	4.21E-03	2.35E-01	4.41E-03	2.37E-01	—	×	—	—
^{235}U	3.78E-03	4.45E-02	4.36E-03	4.55E-02	—	×	—	—
^{232}Th	1.48E-03	1.49E-03	1.36E-03	1.36E-03	—	×	—	—
^{244}Pu	7.92E-05	7.94E-05	8.02E-05	8.07E-05	—	×	—	—
^{147}Sm	7.49E-11	7.49E-11	4.65E-10	4.65E-10	—	—	—	—
^{252}Cf	(3)	(3)	(3)	(3)	—	×	—	—
^{147}Pm	(3)	(3)	(3)	(3)	—	×	—	—
^{244}Cm	(3)	(3)	(3)	(3)	×	×	—	—
^{241}Pu	(3)	(3)	(3)	(3)	×	×	c	c
^{228}Ra	(3)	(3)	(3)	(3)	—	—	—	—
				Closure (4):	99.83%	99.85%	99.67%	99.67%
				10,000 Years (4):	99.91%	99.99%	99.96%	99.96%

Source: Data for the interim state of the repository provided by Kicker 2025a, Tables 6 and 7. Data for the final state of the repository provided by Kicker (2025b, Tables 6 and 7).

(1) The 30 radionuclides listed in this table are included in PANEL decay calculations. ^{210}Pb, ^{226}Ra, ^{228}Ra, and ^{147}Sm are only included in the PANEL decay calculations. All other radionuclides are included in both PANEL decay and actinide mobilization calculations.
(2) See Appendix PA-2.0, for a discussion of scenarios analyzed by PA and the release pathways.
(3) ^{252}Cf, ^{147}Pm, ^{244}Cm, ^{241}Pu, and ^{228}Ra are not regulated by 40 CFR Part 191 but are included because their daughters are significant to performance.
(4) Percent of EPA units represented by nuclides in the source term in the final state of the repository.
(5) ^{238}Pu is excluded from the SECOTP2D calculations because of its low half-life.

× indicates an isotope included in calculation.
c indicates isotopes that are included in calculation and combined for transport with isotopes having similar characteristics.

The radionuclides released in direct release of brine to the surface include several isotopes that comprise negligible fractions of the total activity in EPA units, but they are included in the source term because of their influence on the total quantity of dissolved radionuclides. This influence occurs because the isotopes of a radionuclide will dissolve based on mass ratio, rather than the activity ratio, in which they are present in the waste. That is, if 90 percent of the mass of uranium in the waste is ^{238}U (for example), 90 percent of the dissolved uranium in moles/liter will be ^{238}U, even though 90 percent of the radioactivity will not be from ^{238}U.

TRU WASTE-2.3.2.4 Radionuclides Included in Releases to the Culebra Aquifer

Release of brine from the repository to the Culebra also potentially carries mobilized radionuclides. The 10 radionuclides in the source term for Culebra release include those that dominate the activity in EPA units for all but the earliest part of the regulatory period. Other less prevalent radionuclides are excluded because they would comprise a negligible fraction of the total activity in EPA units or because transport through the Culebra is sufficiently slow that shorter-lived radionuclides would decay to negligible amounts before reaching the accessible environment. The selection of the 10 radionuclides is discussed in Kicker (2025a and 2025b).

Of the 10 radionuclides, only ^{239}Pu, ^{241}Am, ^{234}U, and ^{230}Th are transported separately in PA. Isotopes of the same element will be transported together, unless their half-lives differ greatly. The movement of most of the radionuclides can be calculated indirectly. This concept was presented in detail in Garner (1996):

- The ^{233}U component is combined with ^{234}U for transport because the half-lives of each are similar.
- Similarly, ^{229}Th is combined with ^{230}Th because they will be in a fixed ratio to each other. The ^{232}Th component can be dropped because it is a constant small fraction of the total activity in EPA units throughout the regulatory period.
- The ^{240}Pu and ^{242}Pu components are combined with ^{239}Pu; their long half-lives also indicate a fixed ratio between them.

- The ^{238}Pu component will have decayed to about 0.5 percent of its initial inventory after 700 years, and its contribution to the total activity in EPA units will be minimal because travel time in the Culebra is much greater than 700 years.

- Additionally, 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.

The ^{239}Pu and ^{240}Pu components dominate the EPA limit during the regulatory period, and ^{241}Am is also a factor for the first 3,000 years. Toward the end of the regulatory period, ^{230}Th has grown by about 2.5 orders of magnitude, ^{229}Th by about 1.5 orders of magnitude, and ^{234}U by a factor of three, but all are still small fractions of the total activity in EPA units. The ^{226}Ra component grows during the regulatory period, but even at 10,000 years it would comprise a very small fraction of the EPA limit.

Calculation of radionuclide inventories for this transport mechanism is presented in Kicker (2025a and 2025b).

TRU WASTE-2.3.2.5 Radionuclides Included in Releases Through the Salado

Release of brine from the repository through the Salado (either to the Culebra or to the accessible boundary) can also potentially carry mobilized radionuclides. The 10 radionuclides in the source term for Salado release include those that dominate the total activity in EPA units for all but the earliest part of the regulatory period. Other less prevalent radionuclides are excluded, because they would comprise a negligible fraction of the total activity in EPA units or because transport through the Salado is sufficiently slow that shorter-lived radionuclides would decay to negligible amounts before reaching the accessible environment. The selection of the 10 radionuclides is discussed in Kicker (2025a and 2025b).

TRU WASTE-2.3.2.6 Radionuclides Excluded From Source Terms

A large number of radionuclides were not included in any source term because they did not survive the screening process outlined in Figure TRU WASTE-5. Table TRU WASTE-13 lists those excluded radionuclides and indicates (marked with an "×" in Table TRU WASTE-13) the reason for their exclusion.

Table TRU WASTE-13. Radionuclides Excluded From All Source Terms

Radionuclide	Reason for Exclusion: Short Half-life and Progeny with Short Half-life[1]	Reason for Exclusion: Low Activity in EPA Units[2]	Reason for Exclusion: Negligible Ingrowth
^{225}Ac	×	NA	NA
^{227}Ac	NA	NA	×

Radionuclide	Reason for Exclusion: Short Half-life and Progeny with Short Half-life[1]	Reason for Exclusion: Low Activity in EPA Units[2]	Reason for Exclusion: Negligible Ingrowth
^{228}Ac	×	NA	NA
^{108}Ag	×	NA	NA
^{108m}Ag	NA	×	NA
^{109m}Ag	×	NA	NA
^{110}Ag	×	NA	NA
^{110m}Ag	×	NA	NA
^{242}Am	×	NA	NA
^{242m}Am	NA	NA	×
^{245}Am	×	NA	NA
^{246}Am	×	NA	NA
^{39}Ar	NA	×	NA
^{42}Ar	NA	×	NA
^{217}At	×	NA	NA
^{133}Ba	×	NA	NA
^{137m}Ba	×	NA	NA
^{210}Bi	×	NA	NA
^{211}Bi	×	NA	NA
^{212}Bi	×	NA	NA
^{213}Bi	×	NA	NA
^{214}Bi	×	NA	NA
^{249}Bk	×	NA	NA
^{250}Bk	×	NA	NA
^{14}C	NA	NA	×
^{109}Cd	×	NA	NA
^{113}Cd	NA	×	NA
^{113m}Cd	×	NA	NA
^{144}Ce	×	NA	NA
^{249}Cf	NA	NA	×
^{250}Cf	×	NA	NA
^{251}Cf	NA	NA	×

Radionuclide	Reason for Exclusion: Short Half-life and Progeny with Short Half-life[1]	Reason for Exclusion: Low Activity in EPA Units[2]	Reason for Exclusion: Negligible Ingrowth
^{36}Cl	NA	×	NA
^{242}Cm	×	NA	NA
^{246}Cm	NA	NA	×
^{247}Cm	NA	NA	×
^{250}Cm	NA	×	NA
^{60}Co	×	NA	NA
^{134}Cs	×	NA	NA
^{135}Cs	NA	×	NA
^{152}Eu	×	NA	NA
^{154}Eu	×	NA	NA
^{155}Eu	×	NA	NA
^{55}Fe	×	NA	NA
^{221}Fr	×	NA	NA
^{223}Fr	×	NA	NA
^{152}Gd	NA	×	NA
^{153}Gd	×	NA	NA
^{3}H	×	NA	NA
^{166m}Ho	NA	×	NA
^{129}I	NA	NA	×
^{115}In	NA	×	NA
^{194}Ir	×	NA	NA
^{40}K	NA	×	NA
^{42}K	×	NA	NA
^{85}Kr	×	NA	NA
^{54}Mn	×	NA	NA
^{93}Mo	NA	×	NA
^{22}Na	×	NA	NA
^{91}Nb	NA	×	NA
^{93m}Nb	×	NA	NA
^{94}Nb	NA	×	NA

Radionuclide	Reason for Exclusion: Short Half-life and Progeny with Short Half-life[1]	Reason for Exclusion: Low Activity in EPA Units[2]	Reason for Exclusion: Negligible Ingrowth
^{144}Nd	NA	×	NA
^{59}Ni	NA	×	NA
^{63}Ni	NA	NA	×
^{235}Np	×	NA	NA
^{238}Np	×	NA	NA
^{239}Np	×	NA	NA
^{240}Np	×	NA	NA
^{240m}Np	×	NA	NA
^{194}Os	×	NA	NA
^{233}Pa	×	NA	NA
^{234}Pa	×	NA	NA
^{234m}Pa	×	NA	NA
^{209}Pb	×	NA	NA
^{211}Pb	×	NA	NA
^{212}Pb	×	NA	NA
^{214}Pb	×	NA	NA
^{107}Pd	NA	×	NA
^{145}Pm	×	NA	NA
^{146}Pm	×	NA	NA
^{210}Po	×	NA	NA
^{211}Po	×	NA	NA
^{212}Po	×	NA	NA
^{213}Po	×	NA	NA
^{214}Po	×	NA	NA
^{215}Po	×	NA	NA
^{216}Po	×	NA	NA
^{218}Po	×	NA	NA
^{144}Pr	×	NA	NA
^{144m}Pr	×	NA	NA
^{236}Pu	×	NA	NA

Radionuclide	Reason for Exclusion: Short Half-life and Progeny with Short Half-life[1]	Reason for Exclusion: Low Activity in EPA Units[2]	Reason for Exclusion: Negligible Ingrowth
^{243}Pu	×	NA	NA
^{246}Pu	×	NA	NA
^{223}Ra	×	NA	NA
^{224}Ra	×	NA	NA
^{225}Ra	×	NA	NA
^{87}Rb	NA	×	NA
^{102}Rh	×	NA	NA
^{106}Rh	×	NA	NA
^{219}Rn	×	NA	NA
^{220}Rn	×	NA	NA
^{222}Rn	×	NA	NA
^{106}Ru	×	NA	NA
^{125}Sb	×	NA	NA
^{126}Sb	×	NA	NA
^{126m}Sb	×	NA	NA
^{79}Se	NA	×	NA
^{145}Sm	×	NA	NA
^{146}Sm	NA	×	NA
^{148}Sm	NA	×	NA
^{151}Sm	NA	NA	×
^{119m}Sn	×	NA	NA
^{121}Sn	×	NA	NA
^{121m}Sn	NA	×	NA
^{126}Sn	NA	×	NA
^{157}Tb	NA	×	NA
^{97}Tc	NA	×	NA
^{99}Tc	NA	NA	×
^{123}Te	NA	×	NA
^{125m}Te	×	NA	NA
^{227}Th	×	NA	NA

Radionuclide	Reason for Exclusion: Short Half-life and Progeny with Short Half-life[1]	Reason for Exclusion: Low Activity in EPA Units[2]	Reason for Exclusion: Negligible Ingrowth
^{228}Th	×	NA	NA
^{231}Th	×	NA	NA
^{234}Th	×	NA	NA
^{204}Tl	×	NA	NA
^{206}Tl	×	NA	NA
^{207}Tl	×	NA	NA
^{208}Tl	×	NA	NA
^{209}Tl	×	NA	NA
^{171}Tm	×	NA	NA
^{232}U	NA	NA	×
^{237}U	×	NA	NA
^{240}U	×	NA	NA
^{49}V	×	NA	NA
^{90}Y	×	NA	NA
^{65}Zn	×	NA	NA
^{93}Zr	NA	×	NA

[1] "Short" half-life means $t_{½}$ < 20 years. Radionuclides with $t_{½}$ < 20 years are not regulated by 40 CFR Part 191 Subparts (b) and (c). NA indicates that the column heading does not apply to the particular isotope.
[2] Low activity means activity < 0.001 EPA unit during the 10,000-year regulatory period.

TRU WASTE-2.4 Radionuclide Characteristics: Solubility, Colloid Formation, and Radiolysis

The major characteristics of the radionuclides that are expected to affect disposal system performance are: (1) solubility and (2) the tendency to form or sorb to colloidal particles. Except for direct release from drilling (cuttings, cavings, and spallings), in which particles containing radionuclides will be released with circulation of drilling mud and/or high-pressure conditions, radionuclides are mobilized for transport from the repository either in brine or as colloidal particles transported by brine (Appendix SCR-6.6.1 [FEPs W77, and W78]). Gas-phase transport is not expected to occur (Appendix SCR-6.6.4 [FEP W89]).

All isotopes of a particular radioactive element in the same oxidation state are assumed to exhibit identical characteristics of solubility, colloid formation, and sorption. The experimental determination and modeling of solubility and colloid formation, and the manner in which they

are taken into account by PA, are discussed in Appendix GEOCHEM. Cesium and strontium are assumed to be extremely soluble and their concentrations will be limited by their inventories (see Appendix SOTERM-5.1). Thus, these two elements are not considered in this section. Radium is excluded from the source term because of its short half-life.

Actinide mobilization depends on the chemical environment (brine pH, fugacity of CO_2, , organic ligand concentration, etc.) and actinide oxidation state. Magnesium oxide is added to stabilize the pH of brine in the repository. The mechanism of the control is discussed in Appendix MgO-4.2.

Actinide mobilization also depends on the formation of colloids. Actinides can either form intrinsic colloids by condensation of hydrolyzed ions or can be sorbed on to nonradioactive colloidal particles (see Appendix SOTERM-3.5).

TRU WASTE-2.4.1 Components and Characteristics Influencing Solubility

Actinide baseline solubilities for the +III, +IV, and +V oxidation states are calculated based on inputs both pertaining to and not pertaining to waste components and characteristics (Domski 2025a and Domski 2025b). Non-waste inputs include components of the brine (e.g., ionic strength, activity of water, CO_2 fugacity, pH, pcH, total inorganic carbon) (Appendix GEOCHEM-3.1.1). Inputs associated with the waste include the oxidation state of the radionuclide (which is controlled by redox conditions influenced by iron content in the waste) and the concentration of organic complexing agents (influenced by the organic ligand waste inventory). Additionally, MgO acts as a buffer, impacting pH; while it is not a waste component, the amount of MgO emplaced in the WIPP is directly related to the amount of CPR waste emplaced (Appendix MgO-2.1). Due to the lack of a baseline solubility model for an actinide in the +VI oxidation state in PA calculations, the baseline solubility of the actinide in this oxidation state is derived solely from experimental data determined by Kaplan et al. (2025) and is, therefore, not impacted by waste components or characteristics.

Actinide solubilities used in WIPP PA are based on a combination of baseline solubilities and solubility uncertainties (Domski 2025c), which are derived from comparisons of experimental solubility data and the model-predicted solubilities under the corresponding experimental conditions. Therefore, they do not incorporate additional waste components or characteristics.

Actinide solubility also depends on temperature. However, the temperature in the repository will remain almost constant (about 300 K). Exothermic reactions and cement hydration in the repository only cause small temperature increases which would be transitory on the repository time scale (Appendix SCR, FEP W29, CRA-2004 Appendix TRU WASTE-2.5.3.1). Repository pressure does not influence solubility until it is at least an order of magnitude higher than lithostatic pressure and this is not expected to occur (Butcher et al. 1991).

The following subsections discuss waste characteristics and components that influence solubility.

TRU WASTE-2.4.1.1 Brine Source and Composition

The range of actinide baseline solubility is dependent upon the ionic strength (i.e., type of brine). Consequently, the solubility is estimated for both Salado (7.44 M) and Castile brines (5.32 M) in PA (Appendix GEOCHEM-3.0). In the solubility calculations, a synthetic Castile brine composition is based on an early exploratory borehole ERDA-6 (Appendix GEOCHEM-3.0). The synthetic intergranular Salado brine composition is based on Generic Weep Brine (GWB) has substantially more magnesium, potassium, chloride, and boron than Castile brine.

TRU WASTE-2.4.1.2 Components Influencing Redox Environment

The radionuclides contributing to the brine release source terms are all actinides. Because of their electronic structure, these elements can form a wide variety of inorganic compounds that dissolve in aqueous solutions like brine in several different valence or oxidation states. In the WIPP environment, the solubilities of these compounds can vary from about 10^{-9} to about 10^{-5} molar (see Domski 2025a and Domski 2025b). The redox environment, which is impacted by the presence of ferrous materials, determines which oxidation states are likely to be stable in solution under WIPP conditions—an important determinant of solubility because of the differences among oxidation states. A detailed discussion of the experimental determination of oxidation state distribution is found in Appendix SOTERM-6.4 and Kaplan et al. 2025.

TRU WASTE-2.4.1.3 Components Influencing pH

The pH (i.e., negative common logarithm of the activity of hydronium ion [H^+]) of the solution greatly influences the actinide solubility (Appendix GEOCHEM-3.1.1). For WIPP, enough MgO (with an excess factor of 1.2) is placed in the repository such that any CO_2 generated by microbial degradation of organic material in the waste forms hydromagnesite (Appendix MgO-5.0). With MgO emplaced, the pH of the brine stays within the range of 8.8 to 9.0 in the disposal area (Domski 2025a; Domski 2025b, Appendix MgO-1.0). Narrowing the pH range narrows the actinide solubility range.

Hence, the reacted mass of hydromagnesite, and the mass of the hydrated MgO precursor, brucite ($Mg(OH)_2$), are compounds in the chemical equilibrium. In turn, the mass of CPR in containers is necessary to determine the MgO mass placed in the disposal area. The MgO mass is calculated assuming a one-to-one correspondence between CO_2 produced and 1.2 times the carbon inventory in CPR materials. In this calculation, plastic mass is first converted to an equivalent cellulose mass using a factor of 1.7 to account for its higher carbon content, and the total equivalent CPR mass is then treated as cellulose ($C_6H_{10}O_5$), which contains six carbon atoms per monomer unit (1.2 is a safety factor) (Wang and Brush 1996a; Wang and Brush 1996b, Reyes 2008; Kim and Domski 2025).

Additionally, the presence of cement in the waste inventory can also potentially impact repository pH. To determine if the MgO engineered barrier system at WIPP is sufficient to buffer any pH effects of cement in the waste inventory, the ratio of total moles of carbonate to total moles of portlandite is estimated (Kim and Domski 2025). If the ratio is less than one, then

the capacity of the MgO buffer could be exceeded by cement, thereby affecting the pH and actinide solubility. If the ratio exceeds one, then the MgO buffer effectively neutralizes the potential pH increase due to the increase in hydroxide concentration from portlandite dissolution and, as a result, there would be no effect of cement inventory on the system pH. For the ISPAIR-2024 inventory, the ratio of carbonate to portlandite is 5.4 (Kim and Domski 2025).

TRU WASTE-2.4.1.4 Organic Ligand Concentration and Brine Mixing Volume

A number of organic ligands are capable of forming strong complexes with actinide ions, thereby mobilizing the actinide in the solution. Of the approximately 60 organic compounds in the waste (Drez and James-Lipponer 1989; Brush 1990; Drez 1996), four of these (acetate, citrate, oxalate, and ethylenediaminetetraacetic acid [EDTA]) have been identified to have an effect on actinide mobilization, because they are water-soluble and present in significant quantities (Appendix GEOCHEM-1.1.1; Appendix SCR, FEPs W68 and W69). In the CCA, the DOE proposed that metal species in the TRU waste would bind organic ligands and thereby reduce the free ligand concentration. Simple competition calculations showed that under expected WIPP conditions, 99.8% of the EDTA was complexed by nickel, effectively rendering it unavailable for complexation with the actinides (CCA, Appendix SOTERM). Since the CRA-2004, however, the DOE has included organic ligand complexation of actinides in the solubility model, based on experimentally derived complexation constants (Appendix GEOCHEM-4.1.6). By not accounting for complexation of EDTA by metals, actinide solubilities are overestimated. The masses of acetate, citrate, oxalate, and EDTA are estimated in the ISPAIR-2024 and FRPAIR-2024 (Van Soest 2025a; Van Soest 2025b).

The minimum solution volume used to determine the organic ligand concentrations is set at the minimum brine volume for which a DBR to the surface is possible after a drilling intrusion (Appendix GEOCHEM-1.1.1; Domski 2025a; Domski 2025b). The minimum brine volume has been revised to be consistent with geomechanical modeling that predicts repository porosity and is dependent on the repository footprint (Appendix PA-1.3). The organic ligand concentrations are also evaluated at factors of 2, 3, 4, and 5 times the minimum brine volume to correlate actinide solubilities (based on organic ligand concentrations) with repository brine volumes.

TRU WASTE-2.4.2 Components and Characteristics Influencing Colloidal Actinide Mobilization

The waste components that directly contribute to actinide colloid formation include mineral fragments and humic substances (soil). Furthermore, actinides can sorb onto microbial colloids. Finally, actinides can form intrinsic colloids. A complete discussion of colloid formation and stability in the WIPP can be found in Appendix SOTERM-3.5, Appendix SCR (FEP W79), and Papenguth (1996a , 1996b, 1996c, 1996d, 1996e). The colloidal conceptual model is discussed in Appendix GEOCHEM-5.1.

TRU WASTE-2.4.3 Radiolysis

Gas generation due to radiolysis of brine from radionuclides in solution and in wetted-solid form has been assessed by Day (2019). Brine radiolysis potentially influences repository pressure and brine saturation conditions, contributing to total gas generation. Increases in alpha-emitting radionuclides in the inventory contribute to increased gas generation due to brine radiolysis (Appendix SCR, FEP W52).

TRU WASTE-2.5 Nonradioactive Waste Components and Characteristics

TRU WASTE-2.5.1 Gas Generation

The waste components that contribute to gas generation are: (a) ferrous metal (Appendix SCR, FEP W49), (b) CPR materials (Appendix SCR, FEP W44), (c) radionuclides (specifically, the ionizing radiation interacting with brine) (Appendix SCR, FEP W52) and (d) nitrate and sulfate in the waste and sulfate in the repository brine, which support microbial growth and thus factor into the degradation of CPR materials. Conceptually, the water content of the waste may contribute to the generation of gas, but most water of reaction required for corrosion or biodegradation of CPR materials is Salado brine in the host rock or Castile brine in the hypothetical brine pocket that flows into the repository following an intrusion into the Castile Formation. The mechanisms and reactions for gas generation are discussed in Appendix PA.

Metal can contribute to gas generation through corrosion. The anoxic corrosion reaction of iron consumes water and produces hydrogen gas but is not assumed to affect repository chemistry (Appendix GEOCHEM-2.4.1). Nonferrous metals such as aluminum alloys can also corrode, producing hydrogen, but their contribution to total gas pressure is negligible, because they are present in much smaller quantities than iron (Van Soest 2025a; Van Soest 2025b).

The CPR materials, nitrate, and sulfate control microbial gas generation. The CPR materials can be used as substrates by anaerobic microbes in the WIPP repository. Nitrate (from the waste) and sulfate (both from the waste and from the anhydrite beds in the Salado) can be used as electron acceptors by microbes to oxidize the organic materials (CRA-2019 Appendix GEOCHEM-2.1.5 and Appendix GEOCHEM-2.4.2). Because the CO_2 produced by these reactions will be removed by reaction with MgO, nitrogen and hydrogen sulfide are the primary microbially generated gases that contribute to the total gas in the repository.

The initial water content of the waste also contributes to the generation of gas because it defines how much brine is immediately available for the corrosion reaction. Materials such as dried Portland cement, vermiculite, and other sorbents have intentionally been added to the waste to absorb any excess water that may be present. Sorbed water is much less readily available than any brine available from the surrounding rock. Therefore, the effect of initial water content of the waste on gas generation is negligible.

TRU WASTE-2.5.2 Components and Characteristics Influencing Physical Properties

As noted in Tables TRU WASTE-7 and TRU WASTE-8, the following physical properties of the solid waste components are used in PA:

Compactability/Compressibility[3]: This property is a measure of deformational stress-strain response of the waste material. The response of the waste is modeled to represent typical waste containers (including the conventional 55-gallon drums and pipe overpack configurations), as well as supercompacted waste. Waste composition considered in the latest compaction experiments include metals, CPRs, sorbents, and sludges (Jensen et al., 2023).

Strength: Strength of the waste is only of concern in the highly degraded state. Strength properties enter directly into PA human intrusion scenarios, whereby a driller inadvertently intersects a repository room. If high pressures exist in the disposal room, a pressure gradient pulse could induce tensile failure and transport of waste particulate into the wellbore—the spalling event. In addition, the drill bit and drilling fluid circulate in the advancing wellbore and set up fluid shear stress in the degraded waste. The effects of waste strength on room closure are included in the discussion of compactability/compressibility.

Porosity: Initial porosity of the waste room is modified by salt creep. The waste inventory establishes the initial porosity as well as mechanical resistance to the impinging salt. Waste porosity is directly incorporated into the PA via a porosity surface.

Permeability: Permeability controls movement of fluids in the waste rooms and is, therefore, an important parameter for the Salado fluid flow calculations. Permeability is also a key consideration within the human intrusion conceptual model, as it enters into the calculations of material transport to well bore.

TRU WASTE-2.5.2.1 Compactability/Compressibility

An important characteristic of the WIPP repository is the closure of the disposal rooms over time due to the creep response of the surrounding salt in response to the presence of the mined openings. This ability of salt to deform with time, eliminate voids, and create an impermeable salt barrier around waste is one of the principal reasons for locating the WIPP repository in a bedded salt formation, as suggested by the National Academy of Sciences (NAS-NRC 1957). This closure process is rather complex, and the rate at which it occurs depends in large part on the balance of forces tending to close the repository (the far-field lithostatic stresses) and those resisting the closure. These resisting forces are the tendency of the waste to

[3] Waste "compactability" is specifically mentioned in 40 CFR 194.24(b)(1) as a waste characteristic to be analyzed. In previous descriptions of WIPP waste characteristics, the term "compressibility" has been used; for the purposes of this discussion, the two terms are used interchangeably.

resist deformation, measured in terms of its compactability/compressibility, and the effect of any gas pressure within the rooms.

At the time of the CCA, the compactability/compressibility of the waste was determined from laboratory experiments on 55-gallon drums (Butcher et al. 1991). Earlier waste compaction experiments have been updated with additional experiments, different waste composition assumptions, and model development (Jensen et al. 2023). Appendix PORSURF-2.0 describes the calculations that are used to evaluate the competing conditions of creep closure, waste rigidity, and gas generation to yield porosity histories that are compiled into a porosity surface (Vignes et al. 2023) for incorporation into PA calculations.

TRU WASTE-2.5.2.2 Strength

Shear and tensile strength are important parameters in the models for cavings and spallings releases, respectively. It is likely that alternative waste forms, such as the pipe overpacks and the supercompacted wastes, will be less likely to degrade and corrode to the same extent as standard waste forms, and as such their mechanical strengths may be expected to be equal to or higher than standard waste.

Degraded material property estimates were summarized for the spallings model peer review (Hansen et al. 2003). The authors asserted that degraded waste properties determined for the spallings model represent extreme bounds of the future possible states of the waste because strengthening processes are not included in the minimal shear and tensile strength properties determined for surrogate degraded waste. It was likely that new waste forms, such as the pipe overpacks, would render the waste less vulnerable to collapse and more resistant to massive corrosion.

Shear Strength. The shear strength implemented in PA is used to calculate the volume of cavings release; hence, it is a measure of erosional shear resistance. In the CCA, the waste shear strength was conservatively based on properties of marine clays (Appendix PA-2004, Attachment MASS, Table MASS-1) and some changes to the assumed distribution of strength values have been considered (e.g., Jepsen et al. (1998), Hansen et al. 1997, Hansen et al. 2003). Waste shear strength experiments have since been performed with surrogate waste in order to update the parameterization of waste shear strength (Herrick et al. 2012, Herrick and Kirchner 2013, Zeitler 2019).

Tensile Strength. Tensile strength is used in the calculation of spall volumes following a drilling intrusion. In the CCA, spall volumes were computed by a model of gas flow through fractures. Later, a new mechanistic model for spallings was developed in which gas flow in the waste may induce tensile failure of the waste material, and thus lead to spallings (see Appendix PA-4.7). In support of the new model, a separate analysis determined an appropriate distribution for tensile strength which assumes that the waste is a weakly consolidated particulate material represents an extreme case of waste degradation (Hansen et al. 2003). The characteristics of the more robust waste forms (e.g., supercompacted and pipe overpack waste) would tend to less degradation, so the tensile strength of these waste forms would certainly be greater than

the minimal values currently used in the model. Therefore, the current range of tensile strength used in the model for the CRA-2026 is conservative.

TRU WASTE-2.5.2.3 Permeability

The likely mechanical and physical form of the supercompacted and pipe overpack wastes over time indicates that the permeability of these waste forms will be at least as great as that of standard waste. In the CCA, the waste permeability was assigned a value based on the value used in the 1991 PA (SNL 1991, WIPP PA 1991), a composite value based on the relative quantities of three different types of materials (combustible, metals/glass, and sludges) each with an inherent range of permeabilities, which had previously been determined for compressed surrogate wastes (Luker et al. 1990). In their review of the data used in the CCA, the EPA recalculated a slightly higher value (U.S. EPA 1997) that continues to be used in PA calculations.

A constant value for permeability is used in PA, even though it is expected that there will be some variability in this parameter. The reason for this single value being acceptable is primarily because this permeability value is much higher than the surrounding salt and the disturbed rock zone, as discussed in the 1991 PA. In addition, the coefficient of variation for the uncertainty in measured permeabilities is too small to justify treating waste permeability as an uncertain parameter (Rechard and Tierney 2003). Finally, Vaughn et al. (1995) discuss whether permeability should be a function of porosity, since porosity is treated as a time-varying quantity in BRAGFLO while permeability is a constant. Their analysis concluded that including a dynamic model for permeability had an insignificant effect on waste room conditions (pressure and saturation), and an insignificant effect on resulting releases.

Waste Permeability and Waste Forms. The underlying assumption with respect to the new waste forms is that the pipe overpacks and supercompacted wastes are more durable than the original baseline package of the 55-gallon drum. The rigidity of the waste and its packaging, such as the pipe overpack and supercompacted waste, tends to hold the room open and preserve the structural integrity of the waste stack. The logical evolution involved with disposal of a more rigid and armored waste package would be preservation of a large portion of the waste in its original, intact form as it will deform only modestly as compared to the standard waste form. Thus, the architecture of the waste comprises bulky, compressed steel containers that envelope the waste, and the rigid structure would tend to maintain the open channels between individual drums and packages, such that much of the original porosity inherent in the three-dimensional disposal configuration would be preserved.

Permeability of this future state of the waste would tend to be high relative to the values implemented in PA. This conclusion is reinforced by the results of the legacy porosity surface calculations (Park and Hansen 2003), which showed that in the absence of gas generation, the long-term porosity of the supercompacted and pipe overpack wastes is considerably higher than for standard waste. With high gas generation rates, however, the porosities are essentially the same. The porosity surface used in PA has been updated, but the constant waste permeability assumption is maintained (Jensen et al. 2023).

Waste Permeability in Process Models. Other conclusions can be drawn about the possible effects of waste heterogeneity on brine and gas flow in the repository. Vaughn et al. (1995, DR6) discuss how heterogeneity in the waste may cause flow to follow channels or preferential paths and result in spatially varying saturations referred to as "puddling." Their analysis demonstrated that inclusion of puddling in the Salado flow model had an insignificant effect on waste room conditions (i.e., pressure and saturation), and an insignificant effect on resulting releases.

Waste Permeability in Direct Release Models. Waste permeability can affect the models for spallings and for DBRs. A pertinent study of the effects of spatially variable waste permeability was conducted as part of the spalling model investigations reported in Hansen et al. (1997). Calculations of gas flow through the porous waste regions were conducted to evaluate the influence of model assumptions on the predicted two-phase pressure response of the disposal rooms during a drilling intrusion. Results of the modeling indicated that the effect of waste heterogeneity is to reduce the pore pressure gradient close to the intruded wellbore; because this gradient is the major cause of tensile failure, any possible spall volumes are reduced.

TRU WASTE-2.5.3 Components and Characteristics Affecting Heat Generation

Heat generation is a characteristic of some components of the waste or of their interactions. The WIPP repository includes two possibly significant sources of heat: the heat generated by RH-TRU waste (U.S. DOE 1995) and the heat generated by MgO hydration and carbonation, aluminum corrosion, cement hydration, and organic biodegradation.

TRU WASTE-2.5.3.1 Exothermal Reactions

Magnesium oxide hydration and carbonation, aluminum corrosion, cement hydration, and organic biodegradation are all exothermal reactions. Evaluation of the ability of each of these reactions to produce heat while conservatively accounting for the repository's ability to dissipate the resulting heat generated has provided a total maximum temperature increase of about 4°C (Appendix SCR, FEP W72). However, the temperature extremes will not persist, if they are ever reached at all. The effect of small temperature increases arising from exothermal reactions has been screened out of the PA on the basis of low consequence to factors such as creep closure, seal performance, transport, etc. (see Appendix SCR-6.3.4).

TRU WASTE-2.5.3.2 RH-TRU Thermal Heat Load

The "worst case" heat load from RH-TRU emplaced in the WIPP repository is estimated to result in a temperature rise near the canister of about 3°C (Appendix SCR, FEP W93). The RH-TRU thermal heat load is small enough that there is no impact on repository performance.

TRU WASTE-3.0 WASTE COMPONENT LIMITS

The objective of this section is to satisfy the requirements specified in 40 CFR.194.24(c)(1) as stated in Appendix TRU WASTE-1.0.

This section presents the rationale for the upper and lower limits for waste components identified as potentially significant to disposal system performance (Table TRU WASTE-7). Appendix WCL in the CCA first discussed the waste component limits. The sensitivity analysis in Appendix PA-2004 subsequently supported the conclusions that the disposal system performance was not sensitive to most waste properties and limits remained unnecessary for the waste components identified in Tables TRU WASTE-8 and TRU WASTE-9.

TRU WASTE-3.1 Overview of Emplacement Limits

Table TRU WASTE-14 shows:

- Waste components listed as potentially significant in Table TRU WASTE-7,
- Waste characteristics influenced by these components,
- Constituents of the components for which assaying during emplacement is required, and
- Limits for emplacement of each component, if necessary.

The following discussion provides the rationale for the assaying and emplacement limits for each component listed in Table TRU WASTE-14. All the components listed in Tables TRU WASTE-8 and TRU WASTE-9 were found to be insignificant to disposal system performance. Therefore, it is not necessary to establish emplacement limits for those components other than limits based on the current TRU waste inventory or imposed on waste through limitations in the Transuranic Waste Acceptance Criteria (WAC) for the Waste Isolation Pilot Plant (U.S. DOE 2025a).

The emplacement limits identified in Table TRU WASTE-14 provide an envelope of fixed inventory values on a repository scale, without an associated uncertainty. That is, the limiting values are imposed to ensure compliance and, in fact, represent the upper “end” of an uncertain range. To ensure these waste component limits are not exceeded, inventory quantities and uncertainty in those quantities are tracked during the operational phase of the repository. This tracking is accomplished using the WDS (see TRU WASTE-5.0). When inventory estimates change over the operational life of the WIPP, new inventory estimates are used in PA and revised limits for waste components may be developed.

Table TRU WASTE-14. Emplacement Limits for Waste Components

Components	Associated Characteristics	Constituent Components Requiring Assaying	Emplacement Limits
Radionuclides	Radioactivity at closure Radioactivity after closure Solubility Colloid formation Redox state	^{241}Am ^{238}Pu ^{239}Pu ^{240}Pu ^{242}Pu ^{233}U ^{234}U ^{238}U ^{90}Sr ^{137}Cs	None[1]
Ferrous metals (iron)	Redox potential H_2 gas generation complexing with organic ligands	None	Minimum = 7.11×10^7 kg (amount from containers and waste)[2]
CPR materials	Gas generation Humic colloids (see below)	Sum	Maximum = 2.27×10^7 kg (total amount of CPR)[3]
Sulfates	Gas generation	None	None
Nitrates	Gas generation	None	None
Solid components	Particle size Effective shear resistance to erosion Tensile strength	None	None
Free water emplaced with waste	Gas generation	None	Maximum = 1,562 m^3 (limit of one percent total CH waste volume as set by the WAC)[4]
Humic substances	Radionuclide-bearing humic colloids	None	None
Nonferrous metals (metals other than iron)	Gas generation	None	None
Organic ligands	Solubility	None	None[5]

[1] In its evaluation of the CCA, the EPA concluded that while there is no limit for the radionuclide inventory, the EPA considers the radionuclide inventory used in the PA to be a de facto upper bound (U.S. EPA 2010, Section 24.5.3). Therefore, the inventory that is used in PA calculations to determine compliance with release standards resets the limits on radionuclide emplacement at the WIPP. Radionuclide inventory details are found in Kicker (2025a and 2025b).

[2] Minimum set to ensure sufficient reactants for reducing radionuclides to lower and less soluble oxidation states. The ferrous metals inventory provided by ISPAIR-2024 (Van Soest 2025a, Table 5-5).

[3] Maximum set to ensure sufficient MgO is available to react with CO_2 produced. The total CPR inventory provided by ISPAIR-2024 (Van Soest 2025a, Tables 5-5 and 5-7). Data for the final state of the repository are provided by FRPAIR-2024 (Van Soest 2025b, Tables 5-5 and 5-7).

[4] One percent of the CH-TRU waste volume assumed for the ISPAIR-2024 inventory of 156,247 m^3 (Ward 2025).

[5] No upper or lower limit is established for the quantity of organic ligands in the waste, however because organic ligands can increase solubilities, the current mass may be considered a de facto upper bound similar to the radionuclide inventory.

TRU WASTE-3.2 Radionuclide Components

The following radionuclides dominate the total repository activity at closure and are designated to be assayed in the WAC (U.S. DOE 2025a): ^{241}Am, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{233}U, ^{234}U, ^{238}U, ^{90}Sr, and ^{137}Cs. The total activity of the waste at emplacement and during the entire 10,000-year performance period is dominated by the activities of four radionuclides: ^{241}Am, ^{238}Pu, ^{239}Pu, and ^{240}Pu. The radionuclides, ^{242}Pu, ^{233}U and ^{234}U, have significantly less total activity than the other Am and Pu components, but since their activities have exceeded one EPA unit in past PAs, they continue to be included in assaying requirements. The ^{238}U component is assayed as well, because its large mass fraction and low activity dilutes the overall activity of transported uranium species. The ^{90}Sr and ^{137}Cs components can contribute to direct releases at the surface resulting from inadvertent intrusion during the first several hundred years after closure.

Because of radioactive decay and ingrowth, the major contributors to the overall activity of the repository among these radionuclides change during 10,000 years. For the first several hundred years, ^{241}Am, ^{238}Pu, ^{239}Pu, and ^{240}Pu are important contributors to the total activity of the waste. At the present and projected inventory level, ^{90}Sr and ^{137}Cs may be important for about 200 years. The ^{241}Am component continues to be important for about 3,000 years. At 10,000 years, ^{239}Pu and ^{240}Pu remain as the only significant contributors to the total activity of the waste. Because the activities of these radionuclides in existing and projected waste overwhelmingly exceed the activities of all other radionuclides combined, they are the most important for repository performance modeling.

The total activity of the waste is not important for compliance with the criteria at 40 CFR 194.24(c) because the containment requirements are normalized to the initial inventory. However, the evolution of the EPA Unit inventory in PA is sensitive to relative changes in initial inventory curie content due to radionuclide decay and ingrowth over time. The magnitude of change in the total curie content depends on the initial ratios of the total activities of the assayed radionuclides at the time of repository closure. Accordingly, the results of the PA are conditional on the initial ratios in the inventory.

In its evaluation of the CCA, the EPA concluded that while there is no limit for the radionuclide inventory, the EPA considers the radionuclide inventory used in the PA to be a de facto upper bound (U.S. EPA 2010, Section 24.5.3). Therefore, the inventory that is used in PA calculations to determine compliance with release standards resets the limits on radionuclide emplacement at the WIPP. Radionuclide inventory details are found in Kicker (2025a and 2025b).

The PA for this and future recertifications must, therefore, incorporate the adjusted inventory curie content reflecting any significant changes relative to projected values for the important radioisotopes (plus ^{238}U) that are being accumulated, as is currently done when the inventory described in the ATWIR is used to generate a PAIR for use in PA.

TRU WASTE-3.3 Ferrous and Ferrous Alloy Components

Ferrous metal and alloy components in the waste have two significant effects on the repository. Ferrous metals and alloys may corrode, thus creating gas, and they provide reducing conditions in the repository (see Appendix TRU WASTE-2.4.1.2 and Appendix TRU WASTE-2.5.1).

The waste inventory contains sufficient gas-generating components, including ferrous metal and alloy inventory, that gas could be generated sufficiently in excess of that required to reach 8.0 MPa in the repository, the pressure required for DBR. In previous PAs, the inventory of ferrous materials was never depleted in any of the realizations, so there was no need to assign an upper limit for the mass of these materials, as a maximum value higher than the inventory value would have no impact on PA. The inventory of these materials is not depleted in the far majority of the realizations for the CRA-2026 PA (Appendix PA), so that a maximum value for the mass of ferrous metals and alloys would have little impact on PA. The excess mass of ferrous metals and alloys in the initial inventory imply that it is unnecessary to place restrictions on the quantity of ferrous metals and alloys emplaced for the purpose of controlling the quantity of gas generated.

Additionally, ferrous metals and alloys (and their corrosion products) provide the reactants that reduce radionuclides to lower and less-soluble oxidation states. As discussed in Appendix SOTERM-6.2, the anticipated quantity of these materials, principally from waste containers but also including waste, to be emplaced in the WIPP is in excess of the quantity required to assure reducing conditions. Therefore, the lower limit established for the quantity of ferrous metals and alloys that may be emplaced is the current estimation of the ferrous metal and alloy inventory in the waste and waste containers. For the interim state inventory described in the ISPAIR-2024 (Van Soest 2025a), the total iron inventory is 7.11×10^7 kg.

TRU WASTE-3.4 CPR Materials, Nitrate, and Sulfate Components

The CPR materials, nitrate, and sulfate components of the waste influence the production of CO_2, N_2, and H_2S gases in the repository via CPR degradation by microbial action (Appendix GEOCHEM-2.1.5). The lower limit for these materials is zero, as there is no minimum amount that would be necessary to control gas generation from CPR in PA. Additionally, the amount of MgO emplaced is sufficient to ensure the consumption of all potential CO_2 generated if all CPR were consumed (See Appendix TRU WASTE-2.4.1.2 and Appendix MgO-5.0). Thus, while an upper limit on the amount of CPR materials allowed in the repository equal to the expected CPR inventory is assigned, it is also noted that the net impact on total gas generation would only be due to the generation of N_2 and H_2S, since CO_2 will be consumed by the emplaced MgO. For the interim state inventory described in the ISPAIR-2024 (Van Soest 2025a), the total CPR inventory is 2.27×10^7 kg.

TRU WASTE-3.5 Solid Components

Solid components in the waste affect the waste characteristics of effective shear resistance to erosion, particle size, and tensile strength. These properties affect releases from cavings and spallings during a drilling intrusion. The basic conceptualization for the assignment of these properties is that fully degraded waste will have the least favorable properties, and will eventually be similar to granular materials whose properties can be measured today. The actual properties of the waste over the 10,000-year regulatory period are unknown, since the physical nature of the degraded waste is unknown. For these reasons, the parameter values assigned are chosen to conservatively reflect measured properties of natural and constructed materials.

These properties are reasonable analogs for degraded waste. The effective shear resistance to erosion used to calculate cavings is based on experimental measurements (Herrick et al. 2012) using a conservative estimate (mandated by the EPA [EPA 2017]) of degraded TRU waste materials at the end of the regulatory period. The minimum particle size used in the range for the spallings model is based on assuming an average pore diameter consistent with an average waste permeability; this value is considered conservative because waste will not have a uniform distribution of permeability. The larger particles will define the more permeable pathways, along which most gas will flow during a spalling event, and larger particles are less likely to spall than smaller particles. Lastly, the tensile strength of the waste assigned for the spalling process is uncertain and for PA has used a range of values developed from laboratory experiments on surrogate materials, which represented highly degraded residuals from typical waste inventory (Hansen et al. 2003). These values are felt to represent extreme, low-end tensile strengths because they do not account for several strengthening mechanisms, such as MgO hydration and halite precipitation/cementation (see Hansen et al. 1997).

The properties assumed for solid components in PA bound the least favorable behavior of these components. Therefore, the PA analysis is not conditional on the quantities and kinds of solid components that will be emplaced. Upper or lower limits are not necessary for solid waste components because parameter values have been chosen conservatively.

TRU WASTE-3.6 Water Components

The amount of water emplaced with the waste can affect the rate at which gas is generated for a short period soon after closure, but the small quantity of water acceptable in the waste is not a concern for long-term performance. The quantity of water in the waste used for PA calculations is greater than the WAC (U.S. DOE 2025a) allows, due to the accumulation of brine in the repository. The limit on free water (i.e., observable liquid) content of the waste is set by the WAC, a maximum of one percent of the volume of the waste. The FEPs screening analysis (Appendix SCR) also assumes no more than one percent volume of observable liquid by container. Note that the WAC specifies a repository limit for free water of 1,684 m^3 based on the LWA maximum CH waste volume. However, for PA modeling of the interim state of the repository, the DOE recommends a LWA CH waste volume of 156,247 m^3 (Ward 2025), so an upper limit of 1,562 m^3 of free water is specified here.

TRU WASTE-3.7 Humic Substances Components

Humic substances are likely to be introduced into the repository as a component of wastes containing soils or may form in situ from reactions involving microbial metabolites produced during degradation of cellulosic materials. Humic substances will dissolve until a solubility limit is reached. Dissolved humic substances are colloidal in nature and may complex radionuclides. The radionuclide-bearing humic colloids may be transported in moving liquid and contribute to a radionuclide release.

In PA, the concentration of humic colloids assumed to exist in the repository during the performance period is based on the amount of dissolved actinides (Appendix GEOCHEM-5.2.3). This concentration is not inventory limited; in other words, it is assumed in PA that sufficient source materials exist to maintain the concentration of humic colloids at all times. Because it is assumed that there is sufficient solid material present at all times in the repository, PA results are not conditional on the quantity of total humic substances present, and there is no need to provide a maximum or minimum limit for the quantity of humic substances that may be emplaced in the repository.

TRU WASTE-3.8 Nonferrous Metal Components

In the CCA, the nonferrous metals present in the waste were assumed to impact PA dissolving and binding to organic ligands, thereby reducing the impact of organic ligands on the solubility of radionuclides (see CCA Appendix WCL). A minimum limit for these metals was set to the projection (at the time) of the non-ferrous metals in waste containers. However, the minimum emplacement limit for nonferrous metals is no longer applicable. Since the CRA-2004, the effect of organic ligands on actinide solubility has been included in the PA (see Appendix GEOCHEM-3.1.5). The minimum emplacement limit is no longer necessary to eliminate the effect of organic ligands on the actinide solubility in the PA. Additionally, lead has continued to be screened out in terms of impact on gas generation (see Appendix SCR-6.5.1.4) and impact on actinide solubility (see Appendix GEOCHEM-3.2.6). Therefore, no upper or lower limit need be established for the quantity of non-ferrous metals, and assay is not required for these metals. However, the mass of nonferrous metals will continue to be tracked as part of the waste inventory.

TRU WASTE-3.9 Organic Ligands Components

The effects of organic ligands on actinide solubility are directly considered in PA (see Appendix GEOCHEM-3.1.5). Inventories of specific organic ligands are estimated with each new PAIR (Callicoat 2025). The lower limit for this component is zero, as there is no minimum amount that would be necessary to control their impact on actinide baseline solubility in PA. Organic ligand inventories are assumed to be completely dissolved in the process of calculating baseline solubilities using multiples of the minimum brine volumes (Appendix GEOCHEM-1.1.1). No upper or lower limit is established for the quantity of organic ligands in the waste, however

because organic ligands can increase solubilities, the current mass may be considered a de facto upper bound similar to the radionuclide inventory.

TRU WASTE-4.0 WASTE CHARACTERIZATION

Title 40 CFR 194.24(c)(2) requires that the DOE identify and describe the methods used to quantify the limits presented in Appendix TRU WASTE-3.0 for the waste components identified as potentially significant to the long-term performance of the disposal system (see Table TRU WASTE-14). Title 40 CFR 194.24(c)(3) requires that the DOE demonstrate that the use of acceptable knowledge (AK) to quantify components in waste for disposal conforms with the quality assurance requirements of 40 CFR 194.22.

The methods used to quantify the waste components are summarized in the DOE documentation for CRA-2026, Section 24.3.5 with more detailed descriptions in the following documents:

- Transuranic Waste Acceptance Criteria (WAC) for the Waste Isolation Pilot Plant (U.S. DOE 2025a)
- WIPP Hazardous Waste Facility Permit, Attachment C, Waste Analysis Plan (WAP) (U.S. DOE 2025b)

This section does not repeat the provisions of the WAP and the WAC. References to the WAP and WAC will direct the reader to more detailed information on the TRU waste characterization methods, where appropriate.

The DOE documentation for CRA-2026, Section 24.3.6 describes the process for using AK to quantify waste components.

TRU WASTE-5.0 WASTE DATA SYSTEM

Title 40 CFR 194.24(c)(4) requires that the DOE provide information for the system of controls used to confirm that the total amount of each waste component that will be emplaced in the disposal system will be within the limits presented in Appendix TRU WASTE-3.0 for the waste components identified as potentially significant to the long-term performance of the disposal system (see Table TRU WASTE-14). A description of the WDS is provided in the DOE documentation for CRA-2026, Section 24.3.7 with more detailed descriptions in Appendix MON-2014-3.5. Note that organic ligands, oxyanions, cements, and emplacement materials are not tracked in the WDS therefore, analyses are performed to account for their emplaced mass.

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