SANDIA NATIONAL LABORATORIES

WASTE ISOLATION PILOT PLANT

ANALYSIS PACKAGE FOR INVENTORY EPA UNITS IN THE 2019 COMPLIANCE RECERTIFICATION APPLICATION PERFORMANCE ASSESSMENT (CRA-2019 PA)

REVISION 0

	Print	Signature	Date
Author:	Dwayne C. Kicker	D C Kicker	6-5-2019
Technical Reviewer:	R. Chris Camphouse	[signature]	6-5-2019
QA Reviewer:	Shelly Nielsen	Shelly R. Nielsen	6-5-19
Management Reviewer:	Sean Dunagan	[signature]	6/5/2019

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Executive Summary

The Land Withdrawal Act requires that the U.S. Department of Energy (DOE) apply for recertification of the Waste Isolation Pilot Plant (WIPP) every five years following the initial 1999 waste shipment. The 2019 Compliance Recertification Application (CRA-2019) is the fourth WIPP recertification application submitted for approval by the U.S. Environmental Protection Agency. A performance assessment (PA) has been executed by Sandia National Laboratories in support of the DOE submittal of the CRA-2019. Results found in the CRA-2019 PA are compared to those obtained in the 2014 Compliance Recertification Application (CRA-2014) in order to assess repository performance in terms of the current regulatory baseline. This package documents the inventory activity analysis component of the CRA-2019 PA. Changes incorporated into the CRA-2019 PA include repository planned changes, parameter updates, and refinements to PA implementation. Changes included in the CRA-2019 PA that potentially affect inventory activity analysis results as compared to the CRA-2014 include updates to WIPP waste inventory parameters.

The primary impacts to inventory from the CRA19 analysis when compared to the CRA14 analysis are as follows:

- The CRA19 inventory includes 607 CH- and RH-TRU waste streams. One waste stream, SR-KAC-PuOx, comprises almost 30% of the total EPA units at closure.
- The total EPA units for both inventories start at similar levels, and remain similar throughout the 10,000-year regulatory period.
- The total activity (Ci) as a function of time for the CRA19 and CRA14 inventories are compared. The total activity (Ci) for the CRA19 inventory is higher throughout the entire regulatory period. The higher activities can be attributed to increased inventory of ^{239}Pu, which has a relatively long half-life.
- The total activity concentration in EPA units/m^3 for both CRA14 and CRA19 inventories starts at similar levels and remain similar throughout the 10,000-year regulatory period.
- While higher activities in Ci are shown for the CRA19 inventory, the activities in EPA units (and activity concentration in EPA units/m^3) are nearly identical compared to the CRA14 inventory due to the normalization process of converting Ci to EPA units. The increased ^{239}Pu inventory does not significantly impact direct solids releases for CRA-2019 PA calculations.

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1.0 INTRODUCTION

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

PA calculations were included in the 1996 Compliance Certification Application (CCA) (U.S. DOE 1996), and in a subsequent Performance Assessment Verification Test (PAVT) (MacKinnon and Freeze 1997a, 1997b and 1997c). Based in part on the CCA and PAVT PA calculations, the EPA certified that the WIPP met the regulatory containment criteria. The facility was approved for disposal of transuranic waste in May 1998 (U.S. EPA 1998). PA calculations were an integral part of the 2004 Compliance Recertification Application (CRA-2004) (U.S. DOE 2004). During their review of the CRA-2004, the EPA requested an additional PA calculation, referred to as the CRA-2004 Performance Assessment Baseline Calculation (PABC) (Leigh et al. 2005), be conducted with modified assumptions and parameter values (Cotsworth 2005). Following review of the CRA-2004 and the CRA-2004 PABC, the EPA recertified the WIPP in March 2006 (U.S. EPA 2006).

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

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

The Land Withdrawal Act (U.S. Congress 1992) requires that the DOE apply for WIPP recertification every five years following the initial 1999 waste shipment. The 2019 Compliance Recertification Application (CRA-2019) is the fourth WIPP recertification application submitted by the DOE for EPA approval. The PA executed by SNL in support of the CRA-2019 is detailed in AP-181 (Zeitler 2019). The CRA-2019 PA includes repository planned changes, parameter updates, and refinements to PA implementation. Results found in the CRA-2019 PA are compared to those obtained in the CRA-2014 in order to assess repository performance in terms of the current regulatory baseline. This analysis package documents the inventory activity analysis component of the CRA-2019 PA analysis.

1.1 Changes Since the CRA-2014

Several changes are incorporated in the CRA-2019 PA relative to the CRA-2014 that potentially impact analysis results. The changes that potentially affect inventory activity analysis results as compared to the CRA-2014 include updates to WIPP waste inventory parameters. These changes are discussed in more detail in the sections that follow.

1.2 Overview

The PA code EPAUNI is used to generate EPA unit information based on WIPP inventory data. The number of EPA units associated with a radionuclide is the quotient of the source term activity (in curies (Ci)) for that radionuclide and the product of its associated release limit (in Ci) and the waste unit factor (Equations 1 and 2). See Kicker (2019) for more information on the Ci to EPA unit conversion. For both analyses, a repository closure date of 2033 was assumed.

The waste unit factor (WUF), also referred to as the "unit of waste," is defined in Equation 1:

$$WUF = \frac{\sum_i W_i}{10^6 \, \text{Ci}} \qquad (1)$$

where W_i is the activity in Ci at closure for α-emitting TRU repository wastes having half-lives greater than 20 years. The activity of radionuclide i at time t in EPA units, $E_i(t)$, is defined in Equation 2:

$$E_i(t) = \left(\frac{1}{WUF}\right)\left(\frac{w_i(t)}{L_i}\right) \qquad (2)$$

where $w_i(t)$ is the inventory activity for radionuclide i at time t in Ci and L_i is the EPA release limit for radionuclide i (Ci/unit of waste) as specified in 40 CFR 191 (EPA 1993).

2.0 CONCEPTUAL APPROACH FOR THE CRA-2019

Environmental radiation protection standards for management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes as defined in 40 CFR 191 require human intrusion scenarios to be included in the PA calculations for repositories. Five distinct human intrusion scenarios that impact release from the repository are defined for the WIPP PA. Four of these involve a single drilling intrusion that occurs at various times after repository closure. Two types of drilling intrusions are considered: 1) a borehole is drilled through a single waste panel and intersects a pressurized brine pocket located approximately 250 meters below the repository, and 2) a borehole is drilled into the repository, but does not intersect a brine pocket. One multiple intrusion scenario is considered.

For scenarios that involve a drilling intrusion into the repository, solid release mechanisms include cuttings, cavings and spallings. To calculate the extent of release from these mechanisms, an estimate of the radionuclide content, expressed as the EPA unit of the waste encountered via drilling is required.

Determination of the radionuclide content of the waste encountered via drilling is problematic because it is uncertain. The radionuclide content of waste streams disposed in the WIPP repository is uncertain, as is the loading of those waste streams. The EPA has offered guidance about how to handle this uncertainty, stating that in the absence of a waste loading plan for the repository, random waste emplacement should be assumed (see 40 CFR 194.24). Therefore, following EPA guidance, it is assumed that waste is emplaced randomly in the repository and the probability of encountering any given waste stream in a drilling intrusion is directly proportional to the volume of that waste stream in the repository.

EPAUNI calculates the time varying activity of waste, accounting for radioactive decay, which is used in calculating direct solid releases during a drilling intrusion (Sanchez et al. 1997). An initial waste inventory in Ci comes from the summary of an annual inventory data collection effort headed by Los Alamos National Laboratory (Van Soest 2018). The EPAUNI code then converts radionuclide activities from units of Ci to EPA units as described in Kicker (2019). Ten radionuclides are modeled for the solid release source term: ^{241}Am, ^{244}Cm, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{90}Sr, ^{233}U, and ^{234}U. Kicker (2019) indicates that these ten radionuclides account for 99.94% of the EPA units of TRU waste inventory at the time of repository closure in the CRA-2019 inventory. Calculated activities in EPA units are used to determine normalized releases corresponding to the cuttings and cavings and spallings release mechanisms (Brunell 2019).

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3.0 INVENTORY ACTIVITY ANALYSIS METHODOLOGY

For the WIPP PA, information about the radionuclides that would be encountered during drilling is quantified using the metric of EPA units. The activity in EPA units for a radionuclide is the initial source term activity (in Curies (Ci)) of that radionuclide divided by the product of the WUF and the release limit (in Ci/unit of waste) for the same radionuclide (Sanchez et al. 1997). The WUF is defined in Equation 1 and the activity of an isotope in EPA units is calculated using Equation 2.

For the TRU waste to be disposed of in the WIPP, the WUF is "An amount of transuranic wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years" (40 CFR 191, Appendix A, Table 1). Release limits in Ci are specified in Appendix A of 40 CFR 191. Release limits and the number of Ci in an EPA unit vary by radionuclide. For example, the release limit for ^{239}Pu is 100 Ci per unit of waste. Therefore, if the unit of waste is 1, one EPA unit is 100 Ci of the isotope. However, for an isotope with a release limit of 1000 Ci per unit of waste (e.g., ^{135}Cs), one EPA unit is 1000 Ci of the isotope.

For the WIPP PA, the activity in EPA units at each time interval of interest of each of the major radionuclides (i.e., those for which 40 CFR 191 specifies release limits) in each waste stream is calculated. Then, the activity of the entire waste stream (at the time interval) in EPA units is calculated using Equation 3:

$$E_{ws} = \sum E_i \tag{3}$$

where E_{ws} is the radionuclide activity of a waste stream expressed in EPA units,
E_i is the radionuclide activity expressed in EPA units for radionuclide i.

Once the activity of each waste stream in the metric of EPA units is determined at each time interval, the probability of encountering each stream during a drilling intrusion is calculated using Equation 4:

$$p_{ws} = \frac{v_{ws}}{V} \tag{4}$$

where p_{ws} is the probability of encountering a waste stream during a drilling intrusion,
v_{ws} is the volume of an individual waste stream, and
V is the total volume of waste in the repository.

Ten radionuclides (including ^{241}Am, ^{244}Cm, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{90}Sr, ^{233}U, and ^{234}U) are modeled in EPAUNI, Version 1.19, which is the computational code that generates the data described above for use in calculating potential cuttings/cavings releases from the repository. These ten radionuclides accounted for 99.94% of the EPA units at the time of repository closure in the CRA-2019 inventory (Kicker 2019).

A full description of the run control for the CRA19 analysis, including names and locations of input and output files, can be found in Long (2019). As outlined in AP-181 (Zeitler 2019), in cases where comparisons are made to the CRA-2014 PA results, the CRA14 (Rev. 2) results from the Solaris migration integration tests are used (Kirchner et al. 2014, Kirchner et al. 2015).

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4.0 RESULTS

Inventory analysis results for the CRA19 analysis (based on CRA-2019 inventory data from Van Soest 2018) are presented in this section and compared to inventory analysis results for the CRA14 analysis (based on inventory data from Van Soest 2012).

4.1 Total Waste Volume

The individual waste stream volumes of TRU waste inventory shown in Table 1 and Table 2 are provided to illustrate which waste streams are the primary contributors to total waste inventory volume in the CRA-2019 and CRA-2014 inventories, respectively. Table 1 and Table 2 show that in both the CRA-2019 and CRA-2014 inventories, 12 wastes streams (out of a total of 607 and 528 waste streams for CRA-2019 and CRA-2014, respectively) contribute over 40% of the volume.

Table 1 – WIPP CH- and RH-TRU Waste Streams by Total Volume from CRA-2019 Inventory

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	% of Total	Cumulative %
1	WP-BN510	CH	9.63E+03	5.48%	5.48%
2	RLPFP-01	CH	7.97E+03	4.54%	10.02%
3	RL200-02	CH	6.85E+03	3.90%	13.93%
4	IN-BN650	CH	6.53E+03	3.72%	17.64%
5	SR-T001-WSB-1	CH	6.30E+03	3.59%	21.23%
6	WP-BNINW216	CH	6.19E+03	3.53%	24.76%
7	SR-KAC-PuOx	CH	6.07E+03	3.46%	28.22%
8	LA-MHD01.001	CH	5.86E+03	3.34%	31.55%
9	WP-ID-SDA-SLUD	CH	5.76E+03	3.28%	34.83%
10	WP-LA-MHD01.00	CH	5.37E+03	3.06%	37.89%
11	SR-W026-MFFF-1	CH	4.35E+03	2.48%	40.37%
12	WP-RF029.01	CH	4.32E+03	2.46%	42.83%
⋮	⋮	⋮	⋮	⋮	⋮
607	WP-SR-RL-BCLDP	RH	2.10E-01	0.00%	100.00%
	Total:		175574	100.00%	

NOTE: From EPAUNI output files *epu_CRA19_ch.out* and *epu_CRA19_rh.out*.

Table 2 – WIPP CH- and RH-TRU Waste Streams by Total Volume from CRA-2014 Inventory

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	% of Total	Cumulative %
1	RLPFP-01	CH	1.31E+04	7.46%	7.46%
2	WP-BN510	CH	9.63E+03	5.48%	12.95%
3	LA-MHD01.001	CH	9.01E+03	5.13%	18.08%
4	SR-W026-MFFF-1	CH	7.89E+03	4.49%	22.57%
5	IN-ID-RF-S5300	CH	6.69E+03	3.81%	26.38%
6	IN-BNINW216	CH	6.15E+03	3.50%	29.89%
7	RL200-02	CH	5.89E+03	3.35%	33.24%
8	WP-ID-SDA-SLUD	CH	5.42E+03	3.09%	36.33%
9	WP-BNINW216	CH	5.37E+03	3.06%	39.39%
10	IN-BN510.1	CH	4.77E+03	2.72%	42.10%
11	WP-RF029.01	CH	4.32E+03	2.46%	44.56%
12	WP-LA-MHD01.00	CH	3.71E+03	2.11%	46.68%
⋮	⋮	⋮	⋮	⋮	⋮
528	AW-5410N	RH	1.13E-01	0.00%	100.00%
	Total:		175570	100.00%	

NOTE: From Kicker and Zeiter (2013b, Table 4-1, EPAUNI output files *epu_CRA14BL_ch.out* and *epu_CRA14BL_rh.out*).

In both the CRA19 and CRA14 inventory assessments, the volume of anticipated and emplaced TRU waste was less than the legislated capacity for WIPP as set by the WIPP Land Withdrawal Act (U.S. Congress 1992). Because WIPP PA modeling assumes that WIPP is filled to its legislated capacity, the inventory volume of both the CRA19 and CRA14 inventory assessments were scaled up to equal the legislated capacity (total volume ≈ 175,570 m^3 as shown in Table 1 and Table 2).

4.2 Waste Stream Activity

The waste stream inventories in EPA units in Table 3 and Table 4 are provided to illustrate which waste streams are the primary contributors to the total number of EPA units over the entire population of waste inventory at closure in the CRA-2019 and CRA-2014 inventories, respectively. The tables identify the 12 waste streams that offer the greatest contribution at closure as output by the code EPAUNI. For the CRA-2019 inventory, 12 waste streams contribute approximately 68% of the total EPA units at closure in the waste inventory (Table 3), while the top 12 CRA-2014 waste streams contribute approximately 60% (Table 4). The top CRA19 waste stream, SR-KAC-PuOx (one of the waste streams that is new since 2012), provides approximately 29% of the total EPA units at closure in the waste inventory. The distribution of EPA units by waste stream at closure for both the CRA19 and CRA14 inventories is shown in Figure 1. For example, about 60% of the activity in the CRA19 and CRA14 inventories comes from waste streams with greater than 200 EPA units each (top nine CRA19 entries in Table 3 and top 12 CRA14 entries in Table 4). Note that individual waste stream inventories may decrease in terms of EPA units (even for the same or increased activity in Ci) due to the normalization process in converting Ci to EPA units (Kicker 2019). For example, waste stream WP-LA-MHD01.00 went from 549 EPA units in the CRA14 inventory to 466 in the CRA19 inventory, while the inventory in Ci was 113,000 for CRA14 and 153,700 for CRA19. The nearly vertical portion of the CRA19 plot in Figure 1 from 0 to 29% represents the SR-KAC-PuOx waste stream.

The total number of EPA units in the CRA19 waste inventory at the closure year of 2033 is 10,140 (Table 3). This number is slightly lower than the value of 10,197 EPA units corresponding to the CRA14 waste inventory at year 2033 (Table 4). By 10,000 years post-closure, the total number of EPA units in the CRA19 inventory decreases to 2,324 (Table 5). The corresponding number in the CRA14 analysis was 2,388 EPA units (Table 6). The top CRA19 waste stream at 10,000 years is still SR-KAC-PuOx, providing 42.02% of the total EPA units (Table 5); that is, this single waste stream accounts for over 40% of the repository activity at the end of the regulatory time period.

Table 3 – WIPP CH- and RH-TRU Waste Streams by Total EPA Units; Time 0 (Calendar Year 2033) from CRA-2019 Inventory

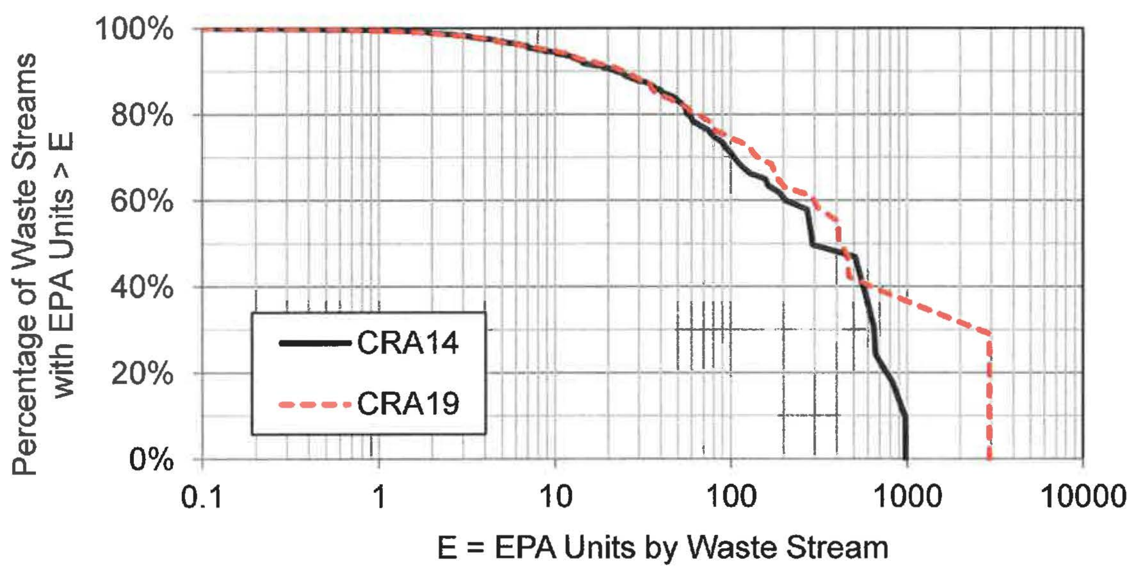
Rank Order	Waste Stream ID	Stream Type	EPA Units	% of Total	Cumulative %
1	SR-KAC-PuOx	CH	2.95E+03	29.07%	29.07%
2	LA-MHD01.001	CH	8.72E+02	8.60%	37.68%
3	SR-T001-WSB-1	CH	4.71E+02	4.65%	42.32%
4	WP-LA-MHD01.00	CH	4.66E+02	4.59%	46.92%
5	WP-RF009.01	CH	4.15E+02	4.09%	51.01%
6	WP-SR-W027-221	CH	4.13E+02	4.07%	55.08%
7	WP-RF118.01	CH	3.18E+02	3.13%	58.21%
8	WP-SR-MD-PAD1	CH	2.90E+02	2.86%	61.07%
9	LA-CIN01.001	CH	2.04E+02	2.01%	63.08%
10	WP-SR-W027-235	CH	1.87E+02	1.85%	64.93%
11	WP-INW216.001	CH	1.79E+02	1.76%	66.69%
12	SR-W026-WSB-2	CH	1.72E+02	1.69%	68.39%
⋮	⋮	⋮	⋮	⋮	⋮
607	LB-T002	CH	5.04E-07	0.00%	100.00%
	Total:		10140	100.00%	

NOTE: From EPAUNI output files *epu_CRA19_ch.dia* and *epu_CRA19_rh.dia*.

Table 4 – WIPP CH- and RH-TRU Waste Streams by Total EPA Units; Time 0 (Calendar Year 2033) from CRA-2014 Inventory

Rank Order	Waste Stream ID	Stream Type	EPA Units	% of Total	Cumulative %
1	SR-W026-WSB-2	CH	9.78E+02	9.59%	9.59%
2	LA-MHD01.001	CH	8.30E+02	8.14%	17.73%
3	WP-RF009.01	CH	6.63E+02	6.50%	24.23%
4	RLPFP-01	CH	6.49E+02	6.37%	30.60%
5	WP-SR-W027-221	CH	5.98E+02	5.87%	36.47%
6	WP-LA-MHD01.00	CH	5.49E+02	5.38%	41.85%
7	WP-RF118.01	CH	5.10E+02	5.00%	46.85%
8	WP-SR-MD-PAD1	CH	2.92E+02	2.87%	49.71%
9	WP-INW216.001	CH	2.86E+02	2.80%	52.51%
10	LA-CIN01.001	CH	2.79E+02	2.73%	55.25%
11	WP-SR-W027-235	CH	2.72E+02	2.67%	57.92%
12	RL308-01	CH	2.06E+02	2.02%	59.94%
⋮	⋮	⋮	⋮	⋮	⋮
528	SA-W138M	CH	1.91E-08	0.00%	100.00%
	Total:		10197	100.00%	

NOTE: From Kicker and Zeiter (2013b, Table 4-2, EPAUNI output files *epu_CRA14BL_ch.dia* and *epu_CRA14BL_rh.dia*).



Source: EPAUNI output files: *epu_*_ch.dia* and *epu_*_rh.dia*, where * is *CRA14* and *CRA19*.

Figure 1 – WIPP CH- and RH-TRU Waste EPA Units Versus Cumulative Percent; Time 0 (Calendar Year 2033)

Table 5 – WIPP CH- and RH-TRU Waste Streams by Total EPA Units; Time 10,000 (Calendar Year 12033) from CRA-2019 Inventory

Rank Order	Waste Stream ID	Stream Type	EPA Units	% of Total	Cumulative %
1	SR-KAC-PuOx	CH	9.77E+02	42.02%	42.02%
2	WP-RF118.01	CH	1.70E+02	7.32%	49.34%
3	WP-RF009.01	CH	1.39E+02	5.99%	55.33%
4	WP-LA-MHD01.00	CH	1.16E+02	5.00%	60.33%
5	LA-MHD01.001	CH	6.92E+01	2.98%	63.30%
6	RLPFP-01	CH	4.76E+01	2.05%	65.35%
7	RLPURX-01	CH	4.01E+01	1.72%	67.08%
8	WP-BN510	CH	3.40E+01	1.46%	68.54%
9	WP-RF003.01	CH	3.21E+01	1.38%	69.92%
10	SR-W026-MFFF-1	CH	3.04E+01	1.31%	71.23%
11	RL308-01	CH	2.79E+01	1.20%	72.43%
12	LA-CIN01.001	CH	2.61E+01	1.12%	73.55%
⋮	⋮	⋮	⋮	⋮	⋮
607	WC-LA-MSG04.00	CH	7.68E-12	0.00%	100.00%
	Total:		2324	100.00%	

NOTE: From EPAUNI output files *epu_CRA19_ch.dia* and *epu_CRA19_rh.dia*.

Table 6 – WIPP CH- and RH-TRU Waste Streams by Total EPA Units; Time 10,000 (Calendar Year 12033) from CRA-2014 Inventory

Rank Order	Waste Stream ID	Stream Type	EPA Units	% of Total	Cumulative %
1	RLPFP-01	CH	2.77E+02	11.62%	11.62%
2	WP-RF118.01	CH	2.72E+02	11.41%	23.03%
3	WP-RF009.01	CH	2.23E+02	9.33%	32.36%
4	LA-MHD01.001	CH	1.89E+02	7.93%	40.29%
5	WP-LA-MHD01.00	CH	1.27E+02	5.31%	45.60%
6	SR-W026-MFFF-1	CH	9.02E+01	3.78%	49.38%
7	WP-BN510	CH	5.45E+01	2.28%	51.66%
8	LA-CIN01.001	CH	5.40E+01	2.26%	53.92%
9	WP-RF003.01	CH	5.14E+01	2.15%	56.08%
10	RL308-01	CH	4.47E+01	1.87%	57.95%
11	RL200-02	CH	4.00E+01	1.67%	59.62%
12	WP-RLMPDT.001	CH	3.81E+01	1.59%	61.22%
⋮	⋮	⋮	⋮	⋮	⋮
528	SA-W138M	CH	2.15E-15	0.00%	100.00%
	Total:		2388	100.00%	

NOTE: From Kicker and Zeiter (2013b, Table 4-3, EPAUNI output files *epu_CRA14BL_ch.dia* and *epu_CRA14BL_rh.dia*).

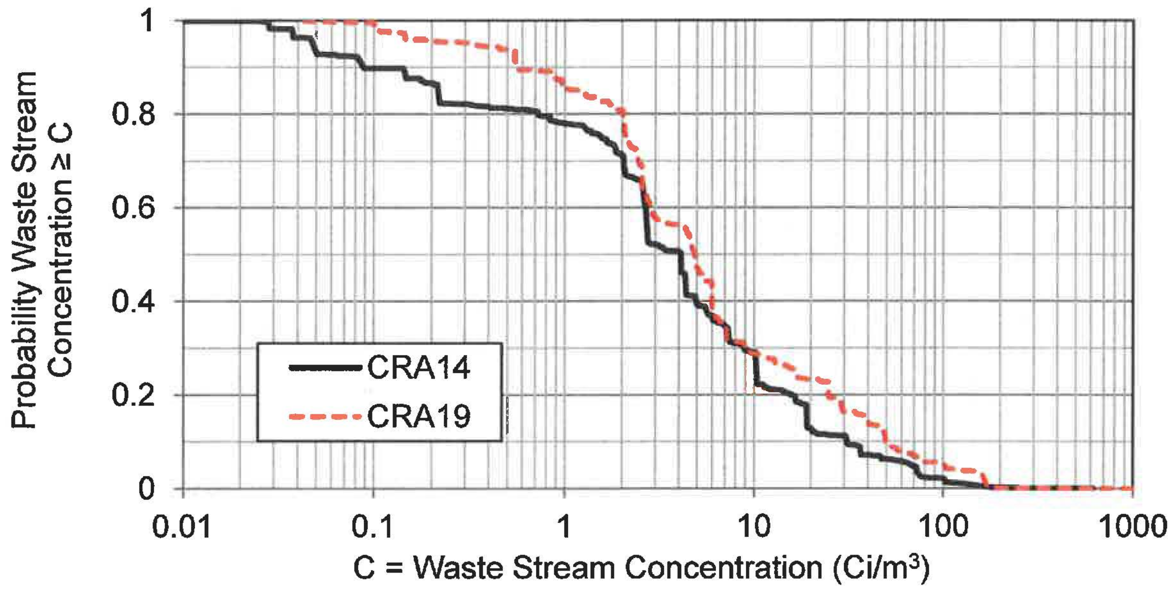
Another important result from the running of the EPAUNI code is the activity concentration for each waste stream. Waste stream concentrations are used in cuttings and cavings (Brunell 2019) release calculations. In those calculations, waste streams are selected based on waste type (contact-handled (CH) or remote-handled (RH)) and waste stream volume. Figure 2 illustrates the distribution of activity concentration at closure versus the cumulative probability of intersection for each waste stream for both the CRA-2019 and CRA-2014 inventories. While the CRA-2019 inventory shows increased activity concentration (Ci per m^3) in almost 100% of the total waste volume (Figure 2a), the concentration of EPA units per m^3 for each CRA19 waste stream (Figure 2b) shows increased activity concentration in only about 31% of the total waste volume (from those waste streams with selection probabilities between approximately 10 to 15%, 20 to 23%, and 77 to 100%). The normalization process of converting Ci to EPA units coupled with changing volumes reduces the activity concentration in EPA units per m^3 compared to the CRA-2014 inventory for some waste streams. The activity concentrations for the top 12 contributing waste streams at closure are provided in Table 7 and Table 8 in the CRA-2019 and CRA-2014 inventories, respectively.

At closure (year 0), the maximum concentration for the CRA-2019 inventory, approximately 3.9 EPA unit per m^3, is slightly higher than the maximum for the inventory used for CRA-2014, 3.0 EPA units per m^3. The overall CRA19 activity concentration (total CH and RH activity in EPA units/total CH and RH volume) is similar to the overall CRA14 activity concentration at closure (5.78E-02 EPA units/m^3 compared to 5.81E-02 EPA units/m^3), and remains nearly identical to the CRA14 activity for the rest of the 10,000-y regulatory period.

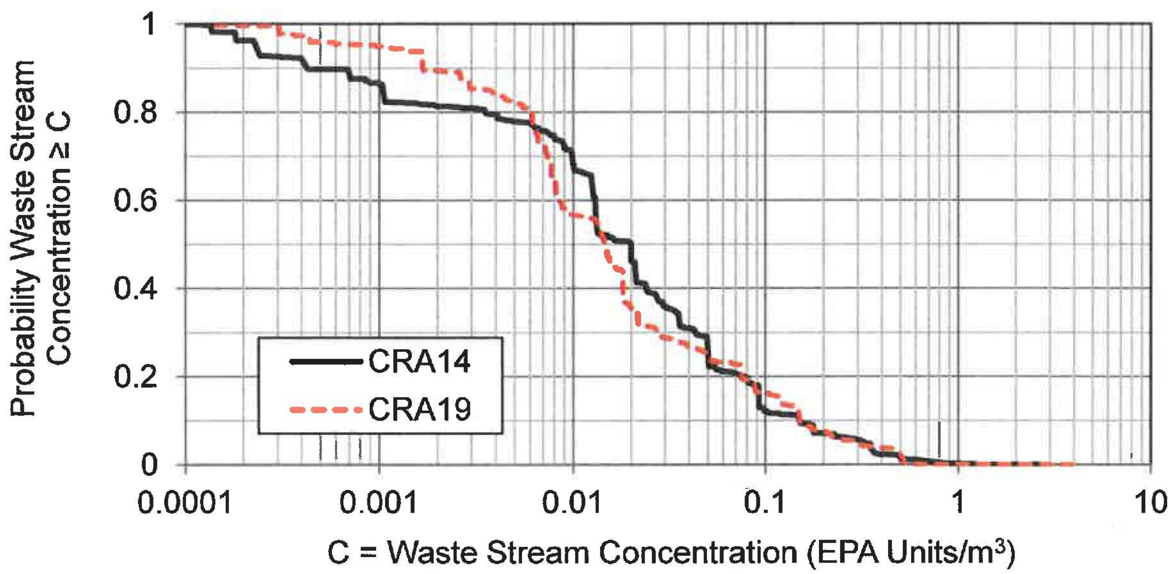
Scatter plots of activity concentrations and waste volumes are shown in Figure 3 for both the CRA19 and CRA14 inventories. Both the Ci per m^3 activity concentration and EPA units per m^3 activity concentration scatter plots show that the CRA19 and CRA14 inventories have a similar data scatter of activity concentration versus volume (Figure 3a and Figure 3b).

At 10,000 years post-closure, the concentration of EPA units has decreased due to decay, as shown in Figure 4, Table 9, and Table 10. Figure 4 illustrates that at 10,000 years, the CRA19 inventory is increased in activity concentration in about 20% of the total waste volume compared to the CRA14 volume (from those waste streams between approximately 3 to 6% and 79 to 96% of activity concentrations). The maximum waste stream concentration for the CRA19 inventory, approximately 0.16 EPA units per m^3, remains lower than the maximum for the inventory used for CRA14, 0.35 EPA units per m^3. At 10,000 years, the overall CRA19 activity concentration (total CH activity/total CH volume + total RH activity/total RH volume) is similar to the overall CRA14 activity concentration (1.32E-02 EPA units/m^3 compared to 1.36E-02 EPA units/m^3).

A comparison of the total activity as a function of time for the CRA19 and CRA14 waste inventories is shown in Figure 5. As seen in Figure 5a, the total EPA units for both inventories start at similar levels, and remain similar throughout the 10,000-year regulatory period. Figure 5b compares the total activity (Ci) as a function of time for the CRA19 and CRA14 inventories. The total activity (Ci) for the CRA19 inventory is higher throughout the entire regulatory period. The higher activities can be attributed to increased inventory of ^{239}Pu, which has a relatively long half-life.



a. Activity Concentration in Ci per m^3



b. Activity Concentration in EPA Units per m^3

Source: EPAUNI output files *epu_*_ch.dia*, *epu_*_ch_activity.dia*, *epu_*_rh.dia*, and *epu_*_rh_activity.dia*, where * is *CRA14* and *CRA19*

Figure 2 – WIPP CH- and RH-TRU Waste Complementary Cumulative Distribution Function for Activity Concentration; Time 0 (Calendar Year 2033)

Table 7 – WIPP CH- and RH-TRU Waste Streams by Activity Concentration; Time 0 (Calendar Year 2033) from CRA-2019 Inventory

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	Activity		Concentration		Probability		Cumulative Probability
				Ci	EPA Units	Ci per m^3	EPA Units per m^3	Stream Type	Overall	
1	IN-MO-530	CH	3.80E-01	4.95E+02	1.50E+00	1.30E+03	3.94E+00	2.26E-06	1.98E-06	1.98E-06
2	IN-MO-535	CH	1.14E+00	1.34E+03	4.05E+00	1.17E+03	3.55E+00	6.77E-06	5.93E-06	7.90E-06
3	SR-RH-MNDPAD1.	RH	3.15E+00	2.00E+03	6.07E+00	6.36E+02	1.93E+00	4.45E-04	5.51E-05	6.30E-05
4	WP-SR-RL-BCLDP	RH	2.10E-01	1.30E+02	3.93E-01	6.18E+02	1.87E+00	2.97E-05	3.67E-06	6.67E-05
5	SR-RH-235F.01	RH	1.26E+00	5.45E+02	1.65E+00	4.32E+02	1.31E+00	1.78E-04	2.20E-05	8.87E-05
6	IN-ID-Miscella	RH	6.30E-01	2.70E+02	8.19E-01	4.29E+02	1.30E+00	8.90E-05	1.10E-05	9.97E-05
7	LA-LA238HOR	CH	2.10E-01	8.42E+01	2.55E-01	4.01E+02	1.22E+00	1.25E-06	1.09E-06	1.01E-04
8	SR-LA-PAD1	CH	4.62E+00	1.64E+03	4.97E+00	3.55E+02	1.08E+00	2.74E-05	2.40E-05	1.25E-04
9	OR-OXIDE-CH-HE	CH	1.13E+01	3.39E+03	1.03E+01	3.00E+02	9.08E-01	6.71E-05	5.88E-05	1.84E-04
10	SR-RH-221H.01	RH	4.41E+00	1.31E+03	3.98E+00	2.98E+02	9.02E-01	6.23E-04	7.71E-05	2.61E-04
11	SR-MD-PAD1	CH	6.21E+01	1.50E+04	4.54E+01	2.41E+02	7.31E-01	3.69E-04	3.23E-04	5.84E-04
12	SR-W027-235F-H	CH	2.10E-01	4.50E+01	1.36E-01	2.14E+02	6.49E-01	1.25E-06	1.09E-06	5.85E-04
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
607	LB-T002	CH	5.42E-01	1.66E-04	5.04E-07	3.07E-04	9.30E-07	3.22E-06	2.82E-06	1.00E+00
	Total:		175574	3.35E+06	1.01E+04	1.91E+01	5.78E-02		1.00E+00	

NOTES: 1. Total CH stream type volume = 168,494 m^3; total RH stream type volume = 7,080 m^3.

2. CH area = 111,500 m^2; RH area = 15,760 m^2; CH stream type area probability = 0.876; RH stream type area probability = 0.124; stream type probability = waste stream volume/total stream type volume; overall probability = stream type probability * stream type area probability.

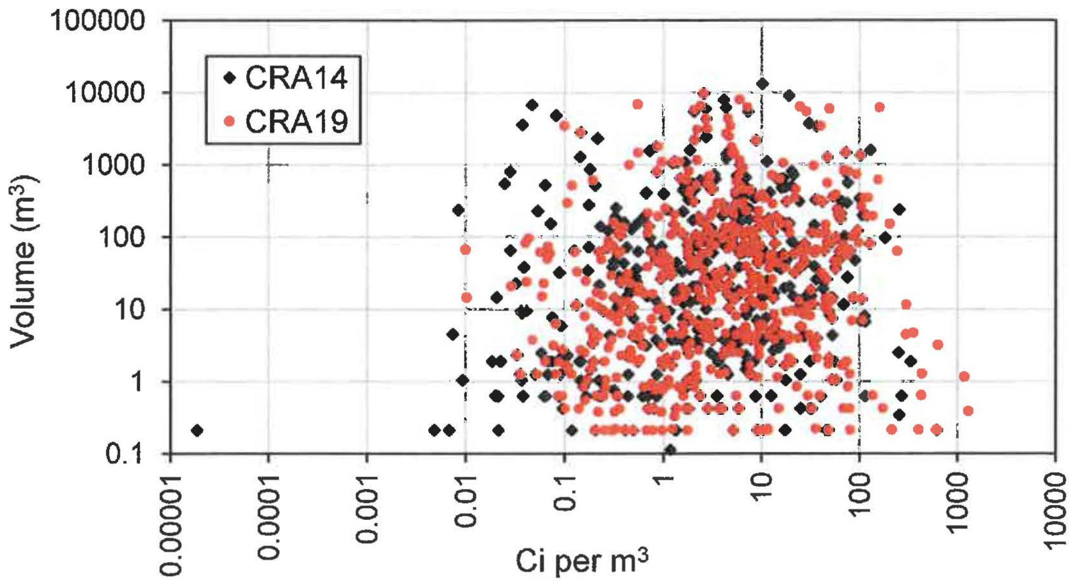
3. From EPAUNI output files *epu_CRA19_ch.dia*, *epu_CRA19_ch_activity.dia*, *epu_CRA19_rh.dia*, and *epu_CRA19_rh_activity.dia*.

Table 8 – WIPP CH- and RH-TRU Waste Streams by Activity Concentration; Time 0 (Calendar Year 2033) from CRA-2014 Inventory

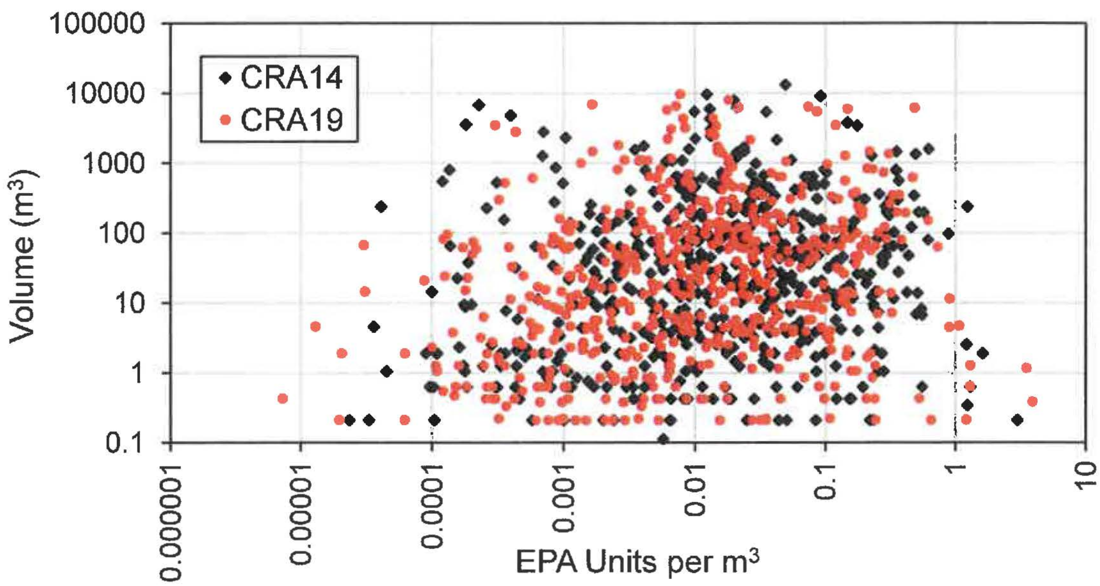
Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	Activity		Concentration		Probability		Cumulative Probability
				Ci	EPA Units	Ci per m^3	EPA Units per m^3	Stream Type	Overall	
1	WP-SR-RL-BCLDP	RH	2.10E-01	1.30E+02	6.30E-01	6.18E+02	3.00E+00	2.97E-05	3.68E-06	3.68E-06
2	SR-RH-235F.01	RH	1.87E+00	6.24E+02	3.03E+00	3.33E+02	1.62E+00	2.64E-04	3.27E-05	3.64E-05
3	SR-RH-MNDPAD1.	RH	6.24E-01	1.67E+02	8.12E-01	2.68E+02	1.30E+00	8.82E-05	1.09E-05	4.73E-05
4	SR-RH-SDD.01	RH	3.39E-01	8.62E+01	4.18E-01	2.54E+02	1.23E+00	4.79E-05	5.93E-06	5.33E-05
5	WP-SR-MD-PAD1	CH	2.37E+02	6.02E+04	2.92E+02	2.54E+02	1.23E+00	1.41E-03	1.23E-03	1.29E-03
6	IN-W358	CH	2.50E+00	6.25E+02	3.03E+00	2.50E+02	1.21E+00	1.48E-05	1.30E-05	1.30E-03
7	WP-SR-LA-PAD1	CH	9.66E+01	1.76E+04	8.56E+01	1.83E+02	8.86E-01	5.73E-04	5.02E-04	1.80E-03
8	SR-W026-WSB-2	CH	1.57E+03	2.02E+05	9.78E+02	1.28E+02	6.23E-01	9.32E-03	8.16E-03	9.96E-03
9	WP-RF005.02	CH	7.92E+01	1.01E+04	4.88E+01	1.27E+02	6.16E-01	4.70E-04	4.12E-04	1.04E-02
10	WP-RLHMOX.001	CH	1.96E+02	2.30E+04	1.12E+02	1.18E+02	5.70E-01	1.16E-03	1.02E-03	1.14E-02
11	SR-W027-235F-H	CH	6.69E+00	7.62E+02	3.70E+00	1.14E+02	5.53E-01	3.97E-05	3.48E-05	1.14E-02
12	LA-LANHD02238	CH	6.20E-01	7.06E+01	3.43E-01	1.14E+02	5.53E-01	3.68E-06	3.22E-06	1.14E-02
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•
528	SA-W138M	CH	2.10E-01	3.94E-06	1.91E-08	1.88E-05	9.11E-08	1.25E-06	1.09E-06	1.00E+00
	Total:		175570	2.10E+06	1.02E+04	1.20E+01	5.81E-02		1.00E+00	

NOTES:

1. Total CH stream type volume = 168,496 m^3; total RH stream type volume = 7,074 m^3.
2. CH area = 111,500 m^2; RH area = 15,760 m^2; CH stream type area probability = 0.876; RH stream type area probability = 0.124; stream type probability = waste stream volume/total stream type volume; overall probability = stream type probability * stream type area probability.
3. From EPAUNI output files *epu_CRA14BL_ch.dia*, *epu_CRA14BL_ch_activity.dia*, *epu_CRA14BL_rh.dia*, and *epu_CRA14BL_rh_activity.dia*.



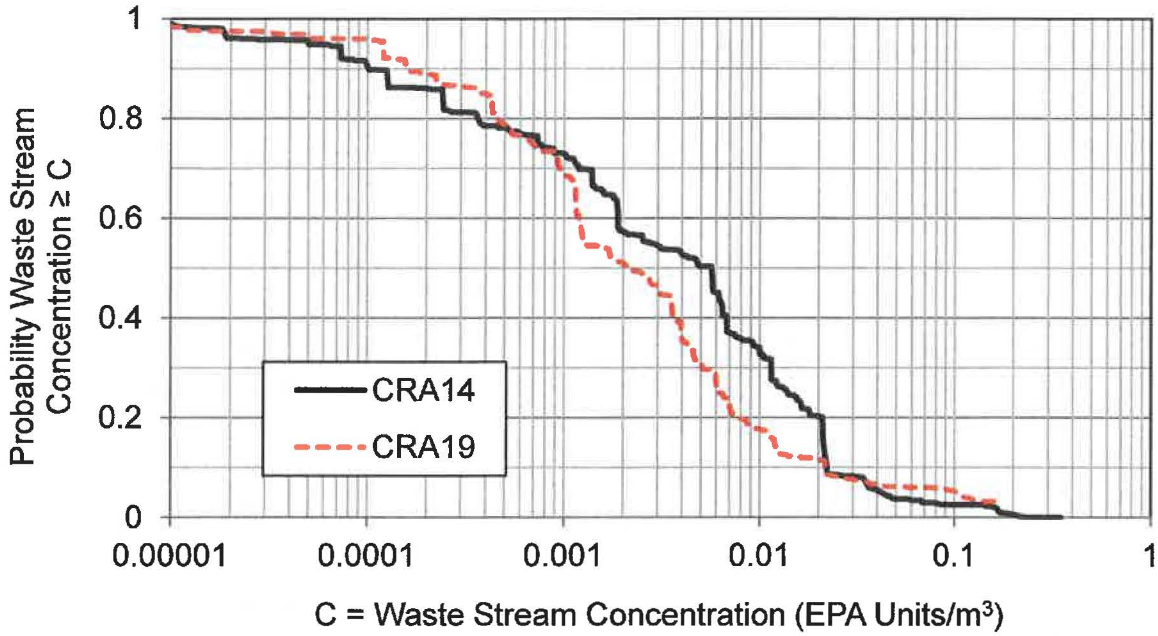
a. Activity Concentration in Ci per m^3



b. Activity Concentration in EPA Units per m^3

Source: EPAUNI output files *epu_*_ch.dia*, *epu_*_ch_activity.dia*, *epu_*_rh.dia*, and *epu_*_activity.dia*, where * is *CRA14* and *CRA19*

Figure 3 – Scatter Plots of Activity Concentration in (a) Ci/m^3 and (b) EPA Units/m^3 with Waste Volume for WIPP CH- and RH-TRU Waste Streams at Time 0 (Calendar Year 2033)



Source: EPAUNI output files: *epu_*_ch.dia* and *epu_*_rh.dia*, where * is *CRA14* and *CRA19*.

Figure 4 – WIPP CH- and RH-TRU Waste Complementary Cumulative Distribution Function for Activity Concentration; Time 10,000 (Calendar Year 12033)

Table 9 – WIPP CH- and RH-TRU Waste Streams by Total EPA Units per Volume; Time 10,000 (Calendar Year 12033) from CRA-2019 Inventory

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	Activity	Concentration	Probability		Cumulative Probability
				EPA Units	EPA Units per m^3	Stream Type	Overall	
1	SR-KAC-PuOx	CH	6.07E+03	9.77E+02	1.61E-01	3.60E-02	3.16E-02	3.16E-02
2	WP-RLRFETS.001	CH	6.45E+01	9.32E+00	1.44E-01	3.83E-04	3.35E-04	3.19E-02
3	IN-RF-361	CH	4.20E-01	5.70E-02	1.36E-01	2.49E-06	2.18E-06	3.19E-02
4	WP-RF118.01	CH	1.45E+03	1.70E+02	1.17E-01	8.61E-03	7.54E-03	3.94E-02
5	WP-RLHMOX.001	CH	1.96E+02	2.17E+01	1.11E-01	1.16E-03	1.02E-03	4.05E-02
6	WP-RF128.01	CH	2.00E+02	2.15E+01	1.07E-01	1.19E-03	1.04E-03	4.15E-02
7	WP-RF121.01	CH	4.64E+01	4.97E+00	1.07E-01	2.75E-04	2.41E-04	4.17E-02
8	WP-RLMSSC.001	CH	6.53E+01	6.99E+00	1.07E-01	3.88E-04	3.40E-04	4.21E-02
9	WP-RF141.02	CH	1.78E+02	1.87E+01	1.05E-01	1.06E-03	9.26E-04	4.30E-02
10	WP-RF009.01	CH	1.34E+03	1.39E+02	1.04E-01	7.95E-03	6.97E-03	5.00E-02
11	WP-RF032.01	CH	2.11E+02	2.17E+01	1.03E-01	1.25E-03	1.10E-03	5.11E-02
12	RL209E-01	CH	1.01E+02	1.02E+01	1.01E-01	5.99E-04	5.25E-04	5.16E-02
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
607	WC-LA-MSG04.00	CH	4.70E-01	7.68E-12	1.63E-11	2.79E-06	2.44E-06	1.00E+00
	Total:		175574	2.32E+03	1.32E-02		1.00E+00	

NOTES: 1. Total CH stream type volume = 168,494 m^3; total RH stream type volume = 7,080 m^3.

2. CH area = 111,500 m^2; RH area = 15,760 m^2; CH stream type area probability = 0.876; RH stream type area probability = 0.124; stream type probability = waste stream volume/total stream type volume; overall probability = stream type probability * stream type area probability.

3. From EPAUNI output files *epu_CRA19_ch.dia* and *epu_CRA19_rh.dia*.

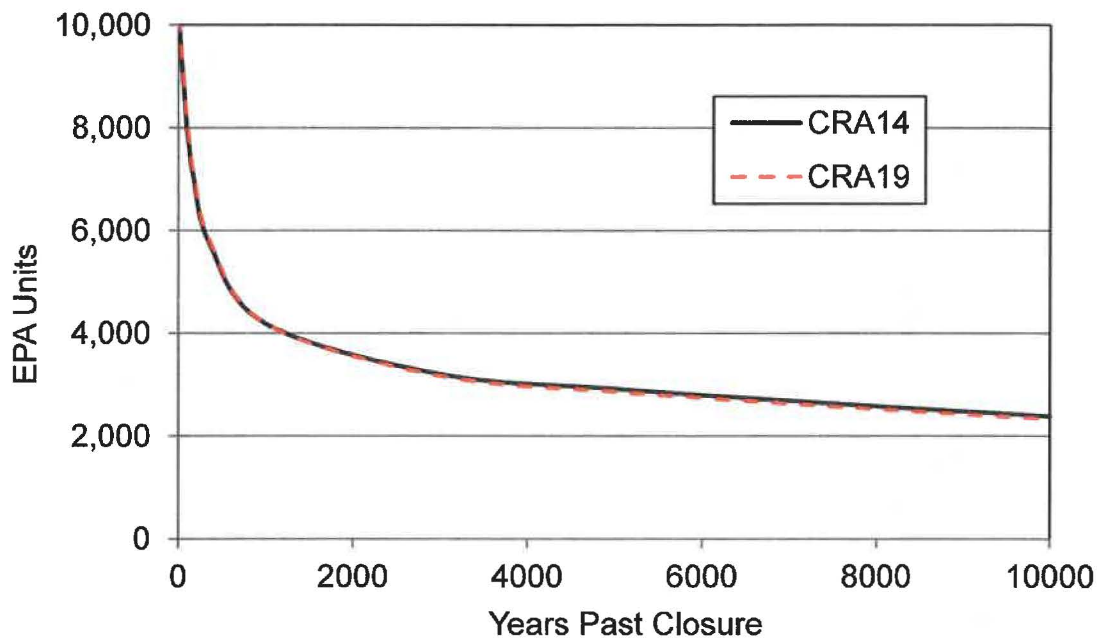
Table 10 – WIPP CH- and RH-TRU Waste Streams by Total EPA Units per Volume; Time 10,000 (Calendar Year 12033) from CRA-2014 Inventory

Rank Order	Waste Stream ID	Stream Type	Volume (m^3)	Activity	Concentration	Probability		Cumulative Probability
				EPA Units	EPA Units per m^3	Stream Type	Overall	
1	RLGEV-08	RH	6.86E+00	2.40E+00	3.50E-01	9.70E-04	1.20E-04	1.20E-04
2	WP-RLRFETS.001	CH	6.45E+01	1.49E+01	2.31E-01	3.83E-04	3.35E-04	4.55E-04
3	WP-RF118.01	CH	1.45E+03	2.72E+02	1.88E-01	8.61E-03	7.54E-03	8.00E-03
4	WP-RLHMOX.001	CH	1.96E+02	3.48E+01	1.78E-01	1.16E-03	1.02E-03	9.01E-03
5	WP-RF128.01	CH	2.00E+02	3.44E+01	1.72E-01	1.19E-03	1.04E-03	1.01E-02
6	WP-RF121.01	CH	4.64E+01	7.96E+00	1.72E-01	2.75E-04	2.41E-04	1.03E-02
7	WP-RLMSSC.001	CH	6.53E+01	1.12E+01	1.71E-01	3.88E-04	3.40E-04	1.06E-02
8	WP-RF141.02	CH	1.78E+02	3.00E+01	1.68E-01	1.06E-03	9.26E-04	1.16E-02
9	WP-RF009.01	CH	1.34E+03	2.23E+02	1.66E-01	7.95E-03	6.97E-03	1.85E-02
10	WP-RF032.01	CH	2.11E+02	3.47E+01	1.65E-01	1.25E-03	1.10E-03	1.96E-02
11	WP-RF005.01	CH	1.21E+02	1.95E+01	1.61E-01	7.18E-04	6.29E-04	2.03E-02
12	WP-RF141.01	CH	4.60E+01	7.34E+00	1.60E-01	2.73E-04	2.39E-04	2.05E-02
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
528	SA-W138M	CH	2.10E-01	2.15E-15	1.03E-14	1.25E-06	1.09E-06	1.00E+00
	Total:		175570	2.39E+03	1.36E-02		1.00E+00	

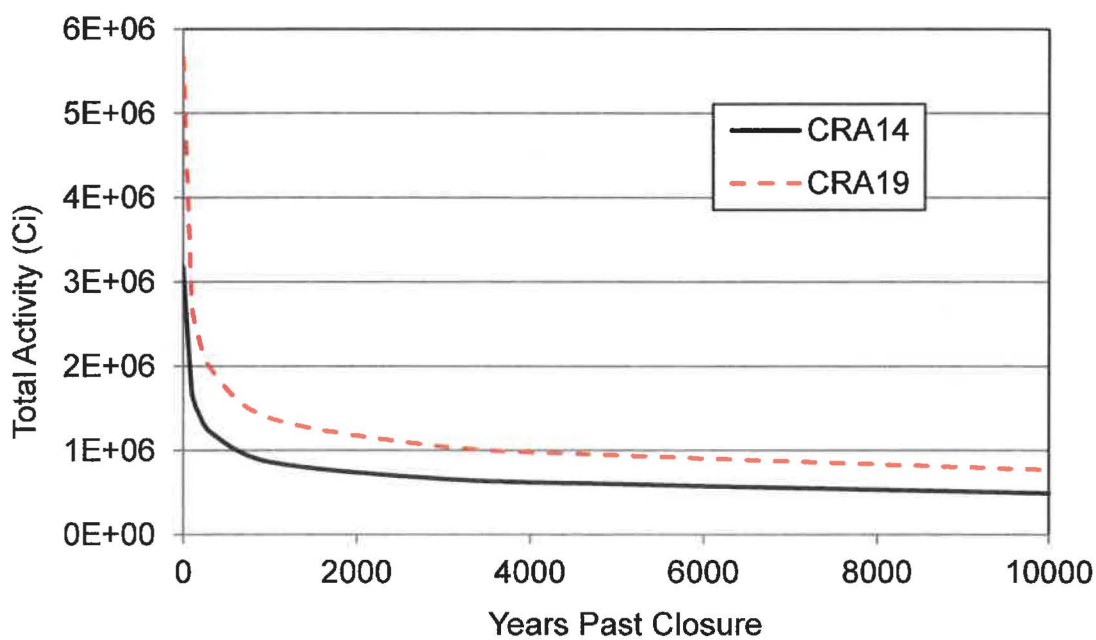
NOTES: 1. Total CH stream type volume = 168,496 m^3; total RH stream type volume = 7,074 m^3.

2. CH area = 111,500 m^2; RH area = 15,760 m^2; CH stream type area probability = 0.876; RH stream type area probability = 0.124; stream type probability = waste stream volume/total stream type volume; overall probability = stream type probability * stream type area probability.

3. From EPAUNI output files *epu_CRA14BL_ch.dia* and *epu_CRA14BL_rh.dia*.



a. EPA Units



b. Total Activity (Ci)

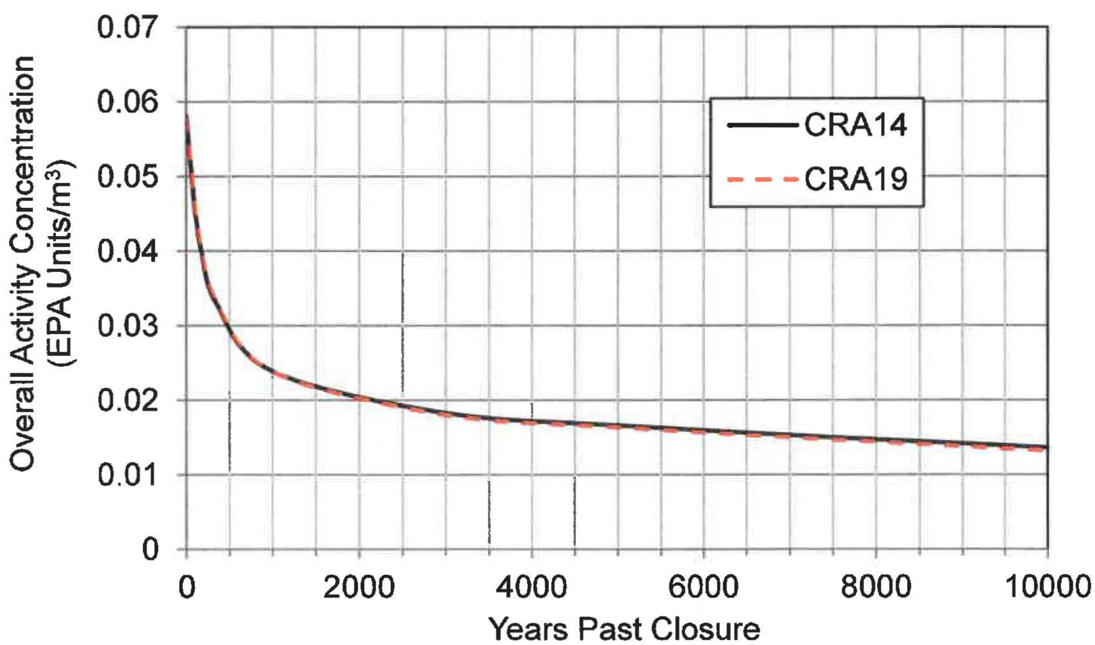
Source: EPAUNI output files *epu_*_ch.dia*, *epu_*_ch_activity.dia*, *epu_*_rh.dia*, and *epu_*_activity.dia*, where * is *CRA14* and *CRA19*

Figure 5 – Total WIPP CH- and RH-TRU Waste Activity from Closure to 10,000 Years

A comparison of the overall activity concentration as a function of time for the CRA19 and CRA14 waste inventories is shown in Figure 6. As seen in this figure, the overall activity concentration for both inventories start at similar levels, remain similar throughout the 10,000-year regulatory period.

The total activity for dominant WIPP radionuclides is shown in Table 11 at closure and at 10,000 years post-closure for both the CRA19 and CRA14 analyses. Figure 7 shows the total activity (in EPA units and Ci) as a function of time for both the CRA19 and CRA14 analyses, along with the dominant radionuclides that contribute to the overall total. As seen in Figure 7, the initial activity of the inventory is dominated by ^{241}Am, ^{238}Pu, ^{239}Pu and ^{240}Pu. The ^{241}Am and ^{238}Pu inventories decay rapidly and so the total activity of the inventory is dominated at later times (> 2,000 years) by mainly ^{239}Pu with a smaller contribution from ^{240}Pu. The ^{244}Cm, ^{137}Cs, ^{241}Pu, ^{90}Sr, ^{233}U and ^{234}U radionuclides do not appreciably contribute to the total activity at any time throughout the 10,000-year regulatory period. These trends are consistent in both the CRA19 and CRA14 analyses.

The increase seen in the CRA19 result is primarily due to an increase in ^{239}Pu inventory (5.74E+05 versus 8.74E+05 initial Ci for CRA14 and CRA19 analyses, respectively) and its relatively long half-life (Table 11 and Figure 7). Note that the ^{239}Pu inventory for CRA19 decreases in terms of EPA units compared to CRA14 (Table 11) due to the normalization process of converting Ci to EPA units (Kicker 2019). This increased ^{239}Pu inventory does not significantly impact direct solids releases for CRA-2019 PA calculations.



Source: EPAUNI output files: *epu_*_ch.dia* and *epu_*_rh.dia*, where * is *CRA14* and *CRA19*.

Figure 6 – Overall WIPP CH- and RH-TRU Waste Activity Concentration from Closure to 10,000 Years

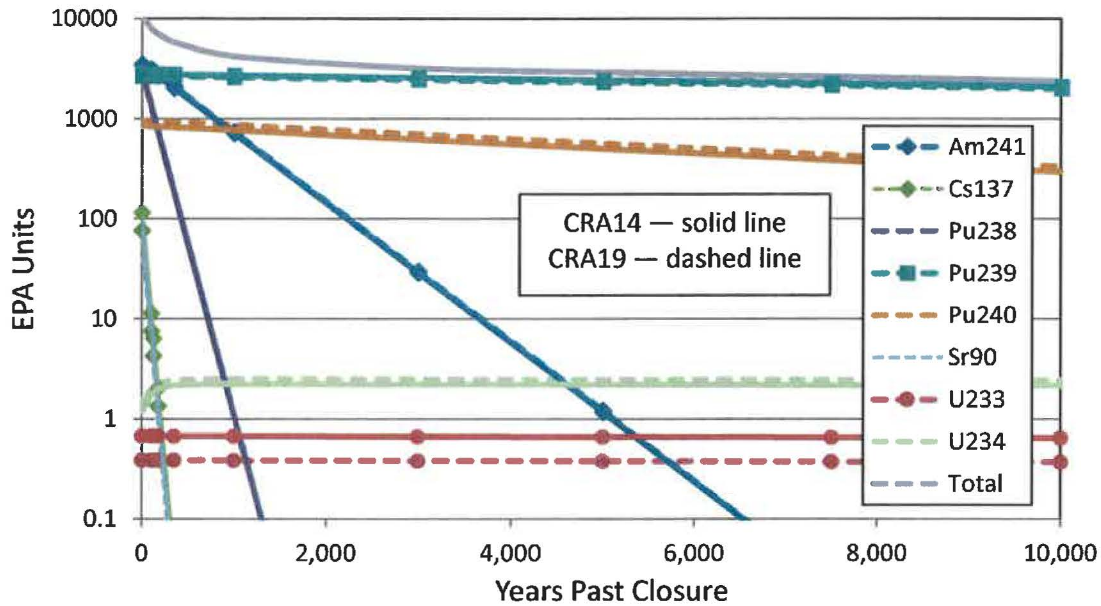
Table 11 – Total Activity for Dominant WIPP CH- and RH-TRU Waste Isotopes at Closure (Year 0) and at 10,000 Years

Radio-nuclide	Half-life (y)	Activity at 0 Years				Activity at 10,000 Years			
		Ci		EPA Units		CI		EPA Units	
		CRA14	CRA19	CRA14	CRA19	CRA14	CRA19	CRA14	CRA19
Am241	432.7	7.05E+05	1.14E+06	3.42E+03	3.46E+03	7.90E-02	1.31E-01	3.83E-04	3.97E-04
Cm244	18.1	9.97E+03	3.94E+04	—	—	0.00E+00	0.00E+00	—	—
Cs137	30.07	2.35E+05	2.51E+05	1.14E+02	7.60E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu238	87.7	6.01E+05	9.65E+05	2.92E+03	2.92E+03	2.97E-29	4.76E-29	1.44E-31	1.44E-31
Pu239	24100	5.74E+05	8.74E+05	2.79E+03	2.65E+03	4.31E+05	6.56E+05	2.09E+03	1.99E+03
Pu240	6560	1.75E+05	3.19E+05	8.51E+02	9.67E+02	6.07E+04	1.11E+05	2.95E+02	3.35E+02
Pu241	14.29	6.63E+05	1.87E+06	—	—	0.00E+00	0.00E+00	—	—
Sr90	28.8	2.09E+05	1.97E+05	1.01E+02	5.96E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	159200	1.39E+02	1.27E+02	6.73E-01	3.85E-01	1.33E+02	1.22E+02	6.45E-01	3.69E-01
U234	246000	2.42E+02	4.86E+02	1.18E+00	1.47E+00	4.45E+02	8.09E+02	2.16E+00	2.45E+00
Total:		3.17E+06	5.66E+06	1.02E+04	1.01E+04	4.92E+05	7.67E+05	2.39E+03	2.32E+03

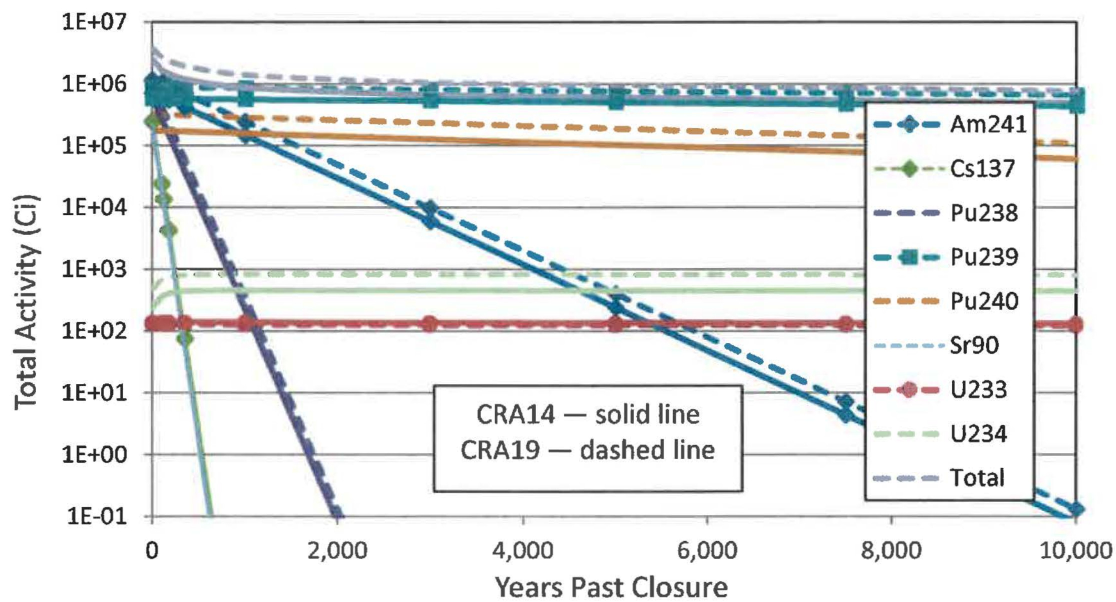
NOTES: 1. Half-life provided by Kicker (2019).

2. EPA units are calculated for each radionuclide based on EPAUNI output activity (Ci), radionuclide release limits (Kicker 2019) and the waste unit factor (Kicker 2019; Kicker and Zeitler 2013a).

3. From EPAUNI output files *epu_*_ch_activity.dia* and *epu_*_activity.dia*, where * is *CRA14* and *CRA19*.



a. EPA Units



b. Total Activity (Ci)

NOTES: The Total EPA units for each radionuclide is calculated as the sum of the CH and RH activity (in Ci) divided by the release limit (in Ci). The CH activity is from EPAUNI output file epu_*_ch_activity.dia and the RH activity is from EPAUNI output file epu_*_rh_activity.dia (where * is *CRA14* and *CRA19*). The release limit is from Kicker (2019) and Kicker and Zeitler (2013a).

Figure 7 – Dominant WIPP CH- and RH-TRU Waste Isotopes from Closure to 10,000 Years

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5.0 SUMMARY

The primary impacts to inventory from the CRA19 analysis when compared to the CRA14 analysis are as follows:

- The CRA19 inventory includes 607 CH- and RH-TRU waste streams. One waste stream, SR-KAC-PuOx, comprises almost 30% of the total EPA units at closure.
- The total EPA units for both inventories start at similar levels, and remain similar throughout the 10,000-year regulatory period (Figure 5a).
- The total activity (Ci) as a function of time for the CRA19 and CRA14 inventories are compared (Figure 5b). The total activity (Ci) for the CRA19 inventory is higher throughout the entire regulatory period. The higher activities can be attributed to increased inventory of ^{239}Pu, which has a relatively long half-life.
- The total activity concentration in EPA units/m^3 for both CRA14 and CRA19 inventories starts at similar levels and remain similar throughout the 10,000-year regulatory period (Figure 6).
- While higher activities in Ci are shown for the CRA19 inventory, the activities in EPA units (and activity concentration in EPA units/m^3) are nearly identical compared to the CRA14 inventory due to the normalization process of converting Ci to EPA units. The increased ^{239}Pu inventory does not significantly impact direct solids releases for CRA-2019 PA calculations.

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