CARD No. 31
Application of Release Limits

31.A.1 BACKGROUND

The radioactive waste disposal regulations at 40 CFR Part 191 include requirements for containment of radionuclides. The containment requirements specify that releases from a disposal system to the accessible environment must not exceed the release limits set forth in Appendix A, Table 1, of Part 191. To calculate the applicable release limits for the WIPP, information is needed on the potential total curie content in the repository. However, because the curie content of the waste inventory in the repository will alter over time as a result of natural decay and ingrowth of radionuclides, EPA must establish when the curie content of waste should be fixed for purposes of calculating the release limits. Section 194.31 specifies that release limits should be calculated based on the curie content at time of disposal (that is, after the end of operational period, when the shafts of the repository has been backfilled and sealed). This CARD describes EPA's evaluation of DOE's calculation of release limits in the Compliance Certification Application (CCA).

The disposal regulations 40 CFR 191.13 set forth performance requirements on the ability of the WIPP to contain transuranic (TRU) waste: There must be "reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years . . . shall:

- Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and
- Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."

The calculated quantity referred to here, called the "normalized release," is described in Appendix A of 40 CFR Part 191. The normalized release reflects how all the radionuclides at the WIPP, taken as a group, relate to EPA's standards for containing radioactivity. The normalized release, and a number of related issues, are discussed in detail in EPA Technical Support Document: Use of the CCDF Formalism in the WIPP PA (EPA 1998a).

Normalized releases are calculated by comparing the calculated activities (from mathematical modeling) of all radionuclides released or escaping from the repository (both TRU and non-TRU elements) to the release limit for each radionuclide. These results are then mathematically combined into a single quantity that provides a measure of overall system performance.

The release limit for each radionuclide is derived by multiplying the values in Table 1, Appendix A, of 40 CFR Part 191 by a waste unit factor, which constitutes a measure of the amount of waste intended for disposal. As described in Appendix A of 40 CFR Part 191, the method used to determine the waste unit factor depends on the type of waste intended for disposal. For waste intended to be disposed of at the WIPP, in particular, the waste unit factor depends solely on the TRU component of waste. Section 194.31 requires that the release limits must be calculated based on the radioactivity present in the waste at WIPP at the time of disposal. EPA has defined the time of disposal as the time when the shafts at the WIPP will be backfilled and sealed.

Although the waste unit factor depends solely on the activity of TRU elements, the waste unit factor and Table 1 release limits are used to calculate release limits for all radionuclides present in the WIPP waste at the time of disposal. That is, all radionuclides escaping from the WIPP are considered to contribute to the normalized releases used to determine compliance with the containment requirements. Thus, DOE's ability to demonstrate compliance with Section 194.31 is dependent on the accurate determination of the activities of the radionuclides emplaced in the repository at the time of disposal, both TRU radionuclides (as reflected in the waste unit) and other radionuclides as well. DOE must identify the total emplacement inventory, and account for isotopic decay and/or ingrowth up to and beyond the time of disposal. Proper identification of the isotopic inventory is regulated under Section 194.24(a) (see **CARD 24—Waste Characterization**). This CARD discusses the calculation of normalized releases from estimates of releases and estimates of the radionuclide inventory of the WIPP, as defined by 40 CFR Part 191, Appendix A, and from corrections for radionuclide decay and ingrowth.

31.A.2 REQUIREMENT

"The release limits shall be calculated according to part 191, appendix A of this chapter, using the total activity, in curies, that will exist in the disposal system at the time of disposal."

31.A.3 ABSTRACT

The containment requirements for the WIPP at Section 191.13 are expressed in terms of normalized releases. Normalized releases, in turn, are computed from estimates of radionuclide releases (in terms of activity in curies), the estimated waste unit factor (based on TRU components of the total WIPP inventory), and the tabulated values of the release limits from Appendix A of 40 CFR Part 191. The purpose of Section 194.31 is to ensure that these calculations are carried out correctly, and that they make use of the correct input information.

Based upon waste emplacement and decay information, DOE concluded that the waste unit factor would be 4.07 if disposal ceased in 1995 (Appendix WCA, Table WCA-5, p. WCA-21). To account for decay and ingrowth of radionuclides, DOE used the EPAUNI computer code (Version 1.01). DOE thereby obtained a revised waste unit factor of 3.44 at the time of disposal.

DOE confirmed and verified the validity of EPAUNI by modeling four test cases with both EPAUNI and either hand calculations or ORIGEN2 (Oak Ridge Isotope Generation and Depletion Code, Version #2). ORIGEN2 is an accepted computer code in the nuclear industry for radionuclide buildup, decay, and nuclear fuel burn-up calculations.

DOE used the revised waste unit factor as of the year 2033 (3.44) to prepare sample calculations, to determine the release limits for radionuclides, to express the WIPP inventory and projected releases in “EPA units,” and to present the relative contribution of each radionuclide to a normalized release. Of the 47 contributing radionuclides within the Transuranic Waste Baseline Inventory Report (TWBIR), plutonium and americium isotopes were present in greatest abundance.

EPA reviewed Appendices WCA and WCL and confirmed DOE’s testing of the EPAUNI code using both hand calculations and verification computer runs. EPA found an error in DOE’s calculation of the waste unit factor, but determined that the error was both small (5 percent impact on the computation of normalized releases) and in the direction that indicated more effective confinement of waste by the WIPP than had been thought previously. EPA also evaluated whether DOE appropriately calculated release limits and identified the relative contribution of each radionuclide to normalized releases. Finally, EPA reproduced the first three of DOE’s tests of EPAUNI, checked the fourth, and added a fifth EPA test. All of these supported the conclusion that EPAUNI works properly.

31.A.4 COMPLIANCE REVIEW CRITERIA

As stated in the Compliance Application Guidance (CAG, p. 42), EPA expected the CCA to:

- Estimate curies of each radionuclide in the disposal system at the time of disposal.
- Describe the process used to determine the activity of each radionuclide.
- Estimate the activity (in curies) of each radionuclide.
- Estimate the upper limit of the activity (in curies) of each radionuclide.
- Describe the procedure used to estimate the units of waste proposed for disposal (according to the TRU waste described in Note (1) of Appendix A to 40 CFR Part 191).
- Provide sample calculations of release limits.
- Identify the relative contribution of each radionuclide to the normalized release.

The first four and the seventh items listed above are discussed under Section 194.24(a) in **CARD 24—Waste Characterization**. The fifth and sixth items are discussed in this CARD. EPA must find the information presented in the CCA to be accurate, consistent, and traceable. To demonstrate consistency, DOE must calculate the waste unit factor, as of the time of disposal, using inventory data for all alpha-emitting TRU radionuclides placed in the WIPP. DOE must also document the traceability of the waste unit factor and other calculations by presenting sample calculations.

31.A.5 DOE METHODOLOGY AND CONCLUSIONS

Regulatory Definitions and Discussion of Normalized Releases

The disposal regulations are expressed in terms of normalized release of radionuclides, and the components of Table 1 of 40 CFR Part 191, Appendix A, are presented in terms of "release limits" and of the number of "units of TRU waste" in the repository. Related terms are explained below:

One unit of TRU waste is defined as that amount of radioactive waste that contains exactly one million curies of alpha-particle-emitting TRU radionuclides (with half-lives greater than 20 years) with a net TRU concentration of greater than 100 nCi/g, regardless of the amounts of other radionuclides present.[1] The term transuranic radioactive waste is defined as "waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for: (1) High-level radioactive wastes. . ." (40 CFR 191.02(i)).

Let C represent the total activity in curies of the TRU component of the waste in the WIPP repository at the time of disposal.[2] Preliminary studies by DOE indicated that the total activity would be 4.07 million curies, if 1995 was the end of the operational period of the repository, and 3.44 million curies of TRU materials if operations ceased in 2033 (Chapter 4.2.1, Table 4-8, p. 4-28). DOE calls the dimensionless entity (C Ci)/(10^6 Ci) the number of units of TRU waste, or the waste unit factor for WIPP; the estimate in the CCA for it is 3.44. The complex method for determining the value of C for WIPP and the waste unit factor is summarized below. Finally, the release limit or, more precisely, the release limit per unit of TRU waste, for the j-th radionuclide, L_j, refers to the normalizing factors (in curies per unit of TRU waste) listed in Table 1 of Appendix A, reproduced here in Table 1 of this CARD.

The disposal regulations at 40 CFR Part 191 are expressed in terms of "normalized releases," and these, in turn, are calculated from three factors:

- Estimates (from mathematical modeling) of the calculated activities of *all* radionuclides released or escaping from the repository, both TRU and non-TRU.
- The release limit (per unit of TRU waste) for each of these TRU and non-TRU released nuclides.

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[1] EPA specifies that release limits are to be determined based on total activity, in curies, of TRU waste present at the time of disposal (61 FR 5228). DOE interprets this to mean that only the TRU component of the waste is to be included in the determination of the number of units of waste in the WIPP (Appendix WCA.3.1, 3.2). *All* radionuclides escaping from the WIPP, however, are considered to contribute to the normalized release. EPA believes that this approach leads to more stringent release requirements and is therefore more protective of public health.

[2] The time of disposal is the time when the mine shafts at the WIPP will be backfilled and closed. In the CCA, DOE identified the year 2033 A.D. as the estimated time of disposal.

◆ The waste unit factor, which refers only to the total activity of the TRU component of the waste.

First, consider a simplified, hypothetical situation in which the WIPP contains exactly one unit of TRU waste, and the radioactive material present consists only of the j-th TRU radionuclide. Suppose a future or scenario of interest that has a projected release from the repository of magnitude Q_j curies over 10,000 years. By the requirements of 40 CFR Part 191, there would have to be a reasonable expectation that the probability of exceeding the release limit for the j-th radionuclide, (L_j Ci per unit of TRU waste)(1 unit of TRU waste), by the projected release for the j-th radionuclide, Q_j, will be less than 0.1. In mathematical notation, this is expressed as:

$$P[\, Q_j > L_j \,] \;<\; 0.1 \;, \qquad \text{[Section 191.13(a)(1)]}$$

where P[X] denotes the probability that event or condition "X" will occur. Likewise, Section 194.13 requires that there be less than a one in one thousand (0.001) chance that the projected release for the j-th radionuclide, Q_j, will be greater than ten times the release limit:

$$P[\, Q_j > 10{\times}L_j \,] \;<\; 0.001 \qquad \text{[Section 191.13(a)(2)]}$$

That is, the WIPP definitely would not be in compliance with 40 CFR Part 191 if there were a probability greater than 0.1 (1 in 10) that a total release that is greater than L_j would accumulate over 10,000 years. This would be also true if there were a greater than a 0.001 chance that $Q_j > 10{\times}L_j$.

To deal with the more general situation in which the WIPP contains other than exactly one unit of TRU waste, the rule introduces an adjusted release limit for the j-th radionuclide, RL_j. The adjusted release limit (in curies) is defined as the product of the release limit for the j-th radionuclide and the number of units of TRU waste in the repository:

$$RL_j \;\equiv\; L_j \times (C \text{ Ci} / 10^6 \text{ Ci})$$

RL_j, like L_j, is sometimes referred to as a release limit, but any possible confusion should be dispelled through consideration of the context. Values of RL_j are displayed in the third column of Table 1 below. It is to the calculation of these adjusted release limits that Section 194.31 refers. Then, with an estimated repository TRU inventory of C Ci from only one radionuclide, the first containment requirement of Section 191.13(a)(1) is expressed as:

$$P[\, Q_j > RL_j \,] \;<\; 0.1$$

or, equivalently, as:

$$P[\, nR_j > 1 \,] \;<\; 0.1$$

where:

$$nR_j \;=\; Q_j / RL_j \;=\; Q_j / (L_j \times C/10^6)$$

is called the normalized release for the j-th radionuclide for the future under consideration, regardless of whether it is a TRU or a non-TRU radionuclide.

With multiple radionuclides, this is readily generalized by summing the normalized releases for all the radionuclides:

$$P[\ nR > 1\ ] < 0.1$$

and

$$P[\ 10 \times nR > 1\ ] < 0.001$$

where

$$nR \equiv \sum_{j} nR_j$$

Normalized release is expressed in what DOE calls "EPA units." EPA units is used to quantify an amount of radioactivity, X_j, for a radionuclide (in curies), either from released waste, in terms of the release limit for the radionuclide, L_j, or from stored waste, as in the TRU inventory, $C/10^6$. The number of EPA units associated with the amount X_j of the j-th radionuclide is determined exactly the same way as is the normalized release, namely, by computing $X_j / (L_j \times C/10^6)$. EPA units are used not only for normalized releases (for which $X_j = Q_j$, the projected release for the j-th radionuclide), but also to quantify the WIPP's inventory of radioactive waste. Then X_j represents the activity of the j-th radionuclide held in the repository, rather than the activity of its estimated release. DOE reports, for example, that WIPP will contain 7.85×10^5 Ci of contact handled Pu239 at time of disposal (Table WCA-5 of Appendix WCA, p. WCA-21). From Table 1 of the present document, it is seen that RL_j for that radionuclide is 344, so that the repository will hold

$$X_j / RL_j = X_j / (L_j \times C/10^6) = (7.85 \times 10^5 \text{ Ci}) / (344 \text{ Ci}) = 2{,}282 \text{ EPA units}$$

of the radionuclide. (Note that the example worked out on page 6 of Appendix WCA to the CCA uses an outdated value of 4.07 curies for the waste unit factor, based upon an estimated 1995 end of disposal at the WIPP). EPA 1998a presents three examples of the calculation of normalized release.

DOE described the procedure used to estimate the units of waste proposed for disposal in Appendix WCA.3.1 (p. WCA-16). DOE included sample calculations of the release limits in Appendix WCA.1.4.2 (p. WCA-6), and Appendix WCL. Information and calculations for the EPA unit are contained in "WIPP PA Analysis Report for EPAUNI: Estimating Probability Distribution of EPA Unit Loading in the WIPP Repository for Performance Assessment Calculations," versions 1.00 and 1.01 (DOE 1996 and DOE 1997).

DOE used radionuclide activity information on a waste stream[3] level from the Transuranic Waste Baseline Inventory Database (TWBID). Per 40 CFR Part 191, Appendix A, DOE calculated the waste unit factor using the curie content of alpha-emitting TRU radionuclides with half-lives longer than 20 years at the time of disposal. DOE stated that it used 15 TRU radionuclides to calculate the waste unit factor of 3.44, based upon a total inventory at disposal of 3.44×10^6 curies (Chapter 4.2.1, pp. 4-26 to 4-28). DOE then multiplied the release limits presented in Appendix A by 3.44 to obtain the WIPP release limits. DOE presented WIPP release limits for 42 radionuclides in Table 4 of Appendix WCA 8.2. These 42 radionuclides also include radionuclides that were not used to calculate the waste unit factor because either they are not alpha-emitting, they are not TRU, or they have half-lives of twenty years or shorter. It should be noted that Appendix WCA and Chapter 4 do not present the same waste unit factor; Appendix WCA indicates that the obsolete waste unit factor is 4.07, while Chapter 4 uses a waste unit factor of 3.44. DOE used the 3.44 value in performance assessment calculations.

DOE used the computer code EPAUNI to process the data from the TWBID and obtain the waste unit factor above; see Appendix A of EPA Technical Support Document for 194.23: Models and Computer Codes (EPA 1998b). EPAUNI ultimately builds a data set for the probability distribution of volumetric EPA units (EPA units divided by the total volume of the waste being considered). EPAUNI develops the volumetric EPA units for each of the radionuclides in the Contact Handled-Transuranic (CH-TRU) waste streams and for the Remote Handled-Transuranic (RH-TRU) waste streams identified in the TWBID. Contact-handled waste emits primarily alpha particles, resulting in relatively low doses of radioactivity (less than 200 millirem/hr) and it may be handled with minimal shielding. Remote-handled waste emits primarily gamma radiation, resulting in high doses of radioactivity (greater than 200 millirem/hr), and it requires handling in shielded casks with special remote handling equipment.

EPAUNI performs radionuclide buildup and decay calculations for time periods past the year of disposal and up to 10,000 years into the future. EPAUNI performs these calculations in two phases. The first phase performs radionuclide buildup and decay calculations using analytical solutions to the Bateman equations for the key radionuclides in the TWBID, including parent radionuclides. EPAUNI uses seven key radionuclides for CH-TRU waste and ten key radionuclides for RH-TRU waste. The parent radionuclides contribute to the buildup of dominant radionuclides for both CH-TRU and RH-TRU waste. The second phase performs simple bookkeeping-type calculations to determine the EPA Unit values associated with the computed activities of the key radionuclides examined in the first phase (seven for CH-TRU waste, and ten for RH-TRU waste).

DOE designed EPAUNI to satisfy the requirements and quality assurance acceptance criteria for WIPP QAP9-1. DOE tested the overall accuracy of its EPAUNI analysis by also running ORIGEN2, which is considered the premier computer code in the nuclear industry for radionuclide buildup, decay, and nuclear fuel burn-up calculations. ORIGEN2 requires significant

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[3] A waste stream is defined as a flow of waste material with specific definable characteristics that remain the same throughout the life of the process generating the waste. A single process generates a particular waste stream.

amounts of information in order to perform numerical integration of complex decay chains, such as full branching of decay chains. In addition, the ORIGEN2 input files are complicated by the requirement that inputs be in units of mass (grams) rather than of activity (curies); therefore, additional computations are performed to convert activity to mass.

DOE Methodology for Estimating the Waste Unit Factor

An important factor in the calculation of release limits is the total inventory of TRU radionuclides, *C*, in the TRU waste. The value used in the CCA is 3.44×10^6 Ci. This section reviews the way in which DOE arrived at this number. This process was not presented in a straightforward manner in one place in the CCA. EPA prepared the following outline by extracting the necessary information out of Chapter 4.1.3.1, Appendices BIR, WCA, and WCL of the CCA, and an updated version of the Transuranic Waste Baseline Inventory Report (TWBIR)(Docket A-93-02, Item II-A-25). For further information on EPA's review of the TWBIR and waste characterization, see **CARD 24—Waste Characterization**.

Certain boundary conditions must be considered in the determination of *C* because of statutory requirements. Pursuant to Section 7(a)(2)(C) of the WIPP Land Withdrawal Act, the total capacity by volume of WIPP is limited to 6.2×10^6 cubic feet (approximately 175,600 m^3). By a separate Agreement for Consultation and Cooperation between DOE and the State of New Mexico, the volume of RH alone must be under 7,080 m^3. Thus the maximum capacity, or disposal volume, for CH is approximately 168,500 m^3.

If there were reliable values for the average volume concentrations, c^{TRU}, of the TRUs in CH and RH wastes, then these would immediately yield an upper bound on *C*:

$$C \leq (168{,}500 \text{ m}^3) \times c^{TRU}{}_{CH} + (7{,}080 \text{ m}^3) \times c^{TRU}{}_{RH}$$

In the CCA, DOE used a more refined determination on the upper bound on *C*, by means of the following process:

- Determine the volume of TRU wastes stored at each waste generator site, and the activities of all the significant TRU radionuclides in that waste.
- Calculate each TRU radionuclide's volume concentration (specific activity) in Ci/m^3 from the stored activity of each TRU radionuclide at a waste generator site and the volume of stored waste.
- Project the volume of waste yet to be generated at each site.
- Find the scaling factor required to expand the total projected volume, for all waste generator sites combined, to what the volume would be if the WIPP were filled to capacity.

- Multiply each site-specific projected volume by this single scaling factor, and add this larger projected volume to the waste generator site's stored volume, yielding the site-specific disposal volume.

- Obtain the maximum possible site-specific disposal activity for each radionuclide from the disposal volume (m^3) and TRU radionuclide concentration (Ci/m^3) at each waste generator site.

- Sum these activities over all waste generator sites and over all TRU radionuclides to calculate the value of *C*.

For contact handled waste, DOE knows the volume of retrievable CH-TRU waste already collected and stored for each site, $V_{stor,s}$, where the index *"s"* designates the site; see Table 2 below. DOE has also projected the volume still to be generated, $V_{proj,s}$ (TWBIR, Rev. 3, Table 2.1). The total "stored" and "projected" volumes of CH TRU for all generator sites combined are:

$$\sum_{s} V_{stor,s} = V_{stor} = 58{,}000 \text{ m}^3$$

and

$$\sum_{s} V_{proj,s} = V_{proj} = 54{,}000 \text{ m}^3$$

where the sums extend over values of s , i.e., over all generator sites. But the total "anticipated volume" of CH TRU, $V_{stor} + V_{proj} = 112{,}000 \text{ m}^3$, is considerably less than the CH maximum disposal volume of $V_{disp} = 168{,}500 \text{ m}^3$ legally permitted for the WIPP. To account for the possibility that the projected volume might increase before the time of disposal, DOE took the conservative step of scaling it upward by multiplying it by a site-wide average scaling factor, *sf*, until the WIPP reaches the maximum possible volume of CH waste allowed by law. The scaling factor is defined in terms of the DOE-wide volumes of stored and projected wastes, and the legal maximum, as follows:

$$V_{disp} = V_{stor} + sf \times V_{proj}$$

The scaling factor can thus be obtained directly from tabulated volumes through the rearrangement of this equation as:

$$sf = (V_{disp} - V_{stor}) / V_{proj}$$

In the CCA, DOE calculated the scaling factor to be 2.05:

$$sf = (168{,}500 \text{ m}^3 - 58{,}000 \text{ m}^2) / (54{,}000 \text{ m}^3) = 2.05$$

This average scaling factor leads to one way of estimating the contribution of every site to the total disposal volume. The site-specific, maximum waste disposal volume that might conceivably come from the *s*-th site (if the WIPP were to be filled to capacity), $V_{disp\,,\,s}$, can be estimated from the scaling factor and site-specific volumes through:

$$V_{disp\,,\,s} = V_{stor,\,s} + sf \times V_{proj,\,s}$$

The total maximum waste disposal volume for all waste generator sites can then be determined by summing the site-specific, maximum waste disposal volumes:

$$\sum_{s = 1} V_{disp,\,s} = V_{disp}$$

Of primary interest is the activity of the TRU component of the radioactive waste at the *s*-th site. This is obtained from $V_{disp\,,\,s}$ and from the average concentration of the waste there, $c^{TRU}_{disp\,,\,s}$:

$$A^{TRU}_{disp\,,\,s} = V_{disp\,,\,s} \times c^{TRU}_{disp\,,\,s}$$

Assuming that the concentration of waste is uniform throughout the site (that is, the same in the scaled projected wastes as in the stored), then $c^{TRU}_{disp\,,\,s}$ is estimated from the known activity and volume of the stored material as follows:

$$c^{TRU}_{disp\,,\,s} = A^{TRU}_{stor,\,s} / V_{stor,\,s}$$

Then the value of *C*, the total waste activity for CH TRU at the WIPP, is obtained from the known activity of the stored waste, the scaled projected volume of waste, and the stored volume of waste. C_{CH} can be calculated by the following equation:

$$C_{\mathrm{CH}} = \sum_{s} \mathrm{A}^{\mathrm{TRU}}_{\mathrm{disp},\, s} = \sum_{s} \mathrm{V}_{\mathrm{disp}\,,\, s} \times \mathrm{c}^{\mathrm{TRU}}_{\mathrm{disp}\,,}$$

$$= \sum_{s} (\mathrm{V}_{\mathrm{stor},\, s} + sf \times \mathrm{V}_{\mathrm{proj},\, s}) \times (\mathrm{A}^{\mathrm{TRU}}_{\mathrm{stor},\, s} / \mathrm{V}_{\mathrm{stor},\, s})$$

The RH activity is handled the same way, using stored and projected volumes of waste and the concentration of waste. However, the RH projected volume requires no scaling *(i.e.*, $sf_{\mathrm{RH}} = 1$) since the stored (3.6×10^{3} m^{3}) plus projected (2.3×10^{4} m^{3}) RH waste already exceeds the 7,080 m^{3} limit. Note that only a total volume of 7,080 m^{3} RH waste may be stored at the WIPP.

$$C_{\mathrm{RH}} = \sum_{s} \mathrm{A}^{\mathrm{TRU}}_{\mathrm{disp},\, s} = \sum_{s} \mathrm{V}_{\mathrm{disp}\,,\, s} \times \mathrm{c}^{\mathrm{TRU}}_{\mathrm{disp}\,,} =$$

$$\sum_{s} (\mathrm{V}_{\mathrm{RH}\,,\ \mathrm{stor},\, s} + \mathrm{V}_{\mathrm{RH}\,,\ \mathrm{proj},\, s}) \times \mathrm{c}^{\mathrm{TRU}}_{\mathrm{RH},\, s}$$

Finally, it is necessary to add in the *stored* activities from waste from two additional sources, residues at Rocky Flats and off-site wastes at Savannah River. There is no projected future waste from these sources to be emplaced in the WIPP; thus, no scaling of projected activities is necessary. The CH waste activity from these two sources, C_{RFSR}, could be added directly to the estimated C_{CH} for the other seven sources. Because the activities from residues at Rocky Flats and off-site wastes at Savannah River are not multiplied by a scaling factor, they are represented separately here.

The total inventory can be determined by summing the inventories of CH and RH waste and additional CH waste from Rocky Flats and Savannah River:

$$C = C_{\mathrm{CH}} + C_{\mathrm{RH}} + C_{\mathrm{RFSR}}$$

The time at which C is to be determined is important. EPA noted in the preamble to 40 CFR Part 194: “Section 194.31 now specifies that the release limits are to be determined based on total activity . . . present at the time of disposal (as defined in Section 191.2). If the activity of a waste container is assayed prior to this time, then the known rates of decay for the radionuclides in the container should be used to calculate the activity of the waste as it will exist at the anticipated time of disposal” (61 FR 5228). “Time of disposal” is defined as the time of repository closure.

The CH scaling factor and the activities listed in Appendix C of the TWBIR together yield a value for the total waste inventory, C, of 4.07×10^{6} Ci, taken as of the end of 1995. This number would apply in 2033 as well, if all the TRU radionuclides of interest had long life-times. However, of the four TRU isotopes that make up most (more than 99.9 percent) of the TRU waste, namely ^{241}Am, ^{238}Pu, ^{239}Pu, and ^{240}Pu, only three are relatively long-lived (see Table 3). The half-life of ^{238}Pu is 87.7 years, and the amount of this isotope present declines significantly during the 38 year period between 1995 and 2033. (The relatively small amount of ingrowth of

^{241}Am from ^{241}Pu over this period also is accounted for.) When the decay of ^{238}Pu was considered, C became 3.44×10^6 Ci, the value used in performance assessment calculations in the CCA.

Use of the Code EPAUNI

DOE documented its calculations of the waste unit factor using inventory data for all alpha-emitting TRU radionuclides, including results of decay, as of the time of disposal. DOE also documented the traceability of the waste unit factor and EPA unit calculations by presenting sample calculations. DOE used the following five steps in conducting the EPAUNI analysis:

- Calculate the number of units of TRU waste for the inventory.
- Calculate the radionuclide release limits.
- Calculate the activities of stored and released wastes, in EPA units, at nine reference times.
- Calculate the volumetric releases of radionuclides at nine reference times.
- Maintain the inventory information in a form that is amenable for use in construction of complementary cumulative distribution functions (CCDFs), cuttings/cavings scenarios only.[4]

Radionuclide activity information on a waste stream level is available from the TWBID in two forms. In the first form, inventory data are reported for all CH-TRU and RH-TRU radionuclides. In the second, waste stream level inventory data are reported for only CH-TRU radionuclides (these data correspond to 569 waste streams). Figure 1 below illustrates the level of information available in the TWBID.

DOE limited the number of radionuclides relative to the more than 135 radionuclides present in WIPP inventory, noting that the TWBID data to be used in the PA calculations are dominated by only a few key radionuclides. Table 3 presents the inventories, in curies and EPA units, and some parameters of interest for the key radionuclides evaluated by DOE. DOE examined the ten radionuclides contributing the most radioactivity to the inventory. Together, these ten radionuclides accounted for more than 99.99 percent of the EPA units of waste in inventory. The top five radionuclides contribute to greater than 99.9 percent of the unit of waste value, and to 99.4 percent of the initial EPA units for CH-TRU and RH-TRU waste. The dominant CH-TRU radionuclides are: ^{241}Am, ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{234}U. The two parent

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[4] "Cuttings" refers to material that is actually cut by a drill bit during drilling, including any waste that may be intersected in the repository. "Cavings" refers to material that falls from the borehole walls as a drill bit penetrates. For these two types of possible releases, it is only necessary to know the average concentration of radionuclides, rather than a complete inventory. This is not the case for other kinds of releases due to human intrusion, such as a direct brine release through a borehole or spallings, in which pressurized solid waste is pushed up through a borehole.

radionuclides ^{241}Pu and ^{244}Cm that produce ^{241}Am and ^{240}Pu, respectively, are also used in the calculations (^{238}Pu is also a parent to ^{234}U). For RH-TRU, three additional key radionuclides are apparent: ^{137}Cs, ^{90}Sr, and ^{233}U.

DOE modeled temporal changes by predicting the decay of the activity inventories of these radionuclides as functions of time. The model predicted decay with the use of the analytical solution to the Bateman equations, the systematic set of ordinary differential equations that describe the radioactive buildup and decay of isotopes in a radioactive decay chain. The Bateman equations and their solutions are discussed in any standard text on health physics. At each of the selected time frames (i.e., time of disposal, time of disposal + 100 years, + 125 years, + 175 years, + 350 years, + 3,000 years, + 5,000 years, + 7,500 years, and +10,000 years), DOE calculated the activities for each of the 569 CH-TRU waste streams in the TWBID. The calculated activities in EPA units, along with the waste volumes from all of the CH-TRU waste streams and the RH-TRU waste streams, tracked through each of the selected time frames.

DOE's Tests of EPAUNI

DOE conducted four test cases to demonstrate that the data on the inventory of waste to be disposed of at the WIPP and its activity, expressed in EPA units, meet the data quality requirements used in WIPP PA calculations. The first three tests simply compared the results of running EPAUNI with those from direct computation with a hand calculator. The two approaches employ the same standard analytical solutions to the Bateman equations that model the decay and ingrowth of radionuclides in decay chains such as

$$N_1 \xrightarrow[\lambda_1]{} N_2 \xrightarrow[\lambda_2]{} \text{Stable Progeny}$$

$N_1(t)$ refers to the quantity present of the first radionuclide (the "parent") in the chain at time t, and λ_1 to its decay constant, and likewise for subsequent generations. Note that the decay constant and the half-life, $t_{1/2}$, of any radionuclide are related through $\lambda \times t_{1/2} = 0.693$, and that the activity (in curies (Ci) at any given time, $A(t)$, is related to the amount of it present through $A(t) = \lambda \times N(t)$.

The first test case followed the decay (only) of key radionuclides in CH-TRU (^{241}Am, ^{239}Pu, ^{240}Pu, and ^{234}U) and RH-TRU (^{137}Cs, ^{90}Sr, and ^{233}U) for specific periods up to 10,000 years into the future, assuming no ingrowth into the initial inventory. That is, it focused on the decline of parent activity, $A_1(t)$, over time. DOE compared the results of running the relevant subcode, RDECAY, of the code EPAUNI, with those of hand calculations. DOE found complete agreement, as discussed in Appendix A of EPA Technical Support Document for Section 194.23: Models and Computer Codes (EPA 1998b).

The second test case performed radioactive decay plus buildup calculations for three decay chains, those of ^{244}Cm, ^{238}Pu, and ^{241}Pu, with the subroutine BUILD of EPAUNI and by hand. The calculation of $A_2(t)$, the activity over time for radionuclide #2, involves both its decay over time and its buildup from the decay of its parent. The forms of the Bateman equation used for

DOE's hand calculation are presented in DOE's WIPP PA Analysis Report for EPAUNI (DOE 1996 and DOE 1997). DOE states that this second test was also successful.

The third test case used data on all 569 CH-TRU waste streams for both buildup and decay calculations of the seven key CH-TRU radionuclides. The activities calculated for each waste stream were summed to obtain a "derived WIPP-Scale" activity value where the volume and activity of projected waste were scaled to fill the volume of the WIPP. DOE compared the derived "WIPP-Scale" activity to those activity values previously calculated in Test Cases #1 and #2, resulting in a precision test that proved successful.

The fourth test case involved decay and buildup calculations for the entire inventory of 135 radionuclides identified in the TWBID. The EPA unit values calculated by EPAUNI using the key radionuclides for CH-TRU and RH-TRU waste were then compared to those computed by the ORIGEN2 program. DOE determined that the error at the various decay times of interest was no greater than five parts in one hundred (5 percent relative error). This was true both for activities and for EPA units.

31.A.6 EPA COMPLIANCE REVIEW

Calculation of the Waste Unit Factor, *C*

The waste unit factor, *C*, plays a pivotal role in the ability of the WIPP to comply with the containment requirements of Section 191.13. It is essential that its value be established with assurance.

EPA was not able to corroborate DOE's waste unit factor value of 4.07 for 1995 (Appendix WCA, p. WCA-21). EPA's analysis of DOE's data led to the conclusion that the value should instead be 4.28, which is about 5 percent greater. DOE reviewed their work and stated that they had resolved the discrepancy (Chakraborti 1997). However, DOE subsequently identified an oversight in which the contribution of TRU waste at an off-site facility of the Savannah River Site was not included in the total waste (Sanchez 1997). DOE agreed that a waste unit factor of 4.28 is correct. When processed by the code EPAUNI so as to apply to a closure date of 2033, the TRU waste factor becomes 3.59. To avoid confusion between what was done in the CCA versus what resulted from DOE's correction of the error, EPA displays here the values used in the CCA and the corrected values for the two dates of relevance, i.e., 1995 and 2033:

	CCA	**Corrected**
1995	4.07	4.28
2033	3.44	3.59

EPA found the error to be of low consequence. Using the correct waste unit factor value of 4.28 drives the values of normalized release downward. If a scenario leads to the prediction that the activity Q_j of the j-th radionuclide may be inadvertently released from the repository, then the normalized release will be given by $Q_j / (L_j \times C/10^6)$, where the release limit per unit of TRU waste, L_j, has been defined above. A 5 percent *increase* in C will bring about a roughly 5 percent *decrease* in the normalized release. That is, the correction of the error shows that the WIPP will comply with the radioactive waste disposal regulations by a wider margin than had been thought previously. EPA therefore accepts the correction and requires no further action regarding it.

DOE interpreted the requirements of Appendix A of 40 CFR Part 191 to mean that only the TRU component of the waste is to be included in the determination of the number of units of waste in the WIPP, while all radionuclides are considered to contribute to the normalized release. EPA concurs with this approach because it is a reasonable interpretation of the regulation and leads to more stringent release requirements than would other interpretations. EPA therefore considers DOE's approach to be protective of public health. EPA found that DOE used the correct method for calculating the release limits and identified the relative contribution of radionuclides to the normalized release.

EPA performed an independent analysis of DOE's EPAUNI report to check its conclusions and calculations, and the results may be found in Appendix A of EPA Technical Support Document for Section 194.23: Models and Computer Codes (EPA 1998b). Specifically, EPA ran the EPAUNI model to duplicate DOE's analyses conducted in Test Cases 1-4, and then performed spot-check, hand calculations to duplicate DOE's hand calculations conducted in Test Cases 1-3. EPA concurred with DOE's finding that EPAUNI performed as expected.

Due to the complexity of the ORIGEN code (which requires computer time to run) and the number of test radionuclides, it was not possible to verify the fourth test case directly. Rather, EPA elected to perform a fifth test case to verify, by waste stream, that DOE correctly calculated releases in EPA units. This approach also served to demonstrate that the calculation could be performed at the waste container-level for a particular waste stream. EPA selected waste stream IN-W375-827 for this analysis; according to the TWBIR, Rev. 3, Appendix P, its volume is 7.09 m^3. As shown below, EPA calculated the number of drums and total activity (steps i and ii, respectively), and then found the curie content by drum (step iii). The stored waste in EPA units (iv) was obtained by dividing the average curie content by the adjusted release factor used in PA calculations (3.44×100):

i. $(7.09 \text{ m}^3)/(0.208 \text{ m}^3/\text{drum}) = 34$ drums -- Volume from TWBIR, Appendix P

ii. $(7.09 \text{ m}^3) \times (2.22 \text{ Ci/m}^3) = 15.74$ Ci -- Total activity for this waste stream

iii. 15.74 Ci/34 drums = 0.463 Ci/drum

iv. $(0.463 \text{ Ci/drum})/344 = 1.34\times10^{-3}$ EPA units per drum of IN-W375.827.

As a result of EPA's independent EPAUNI modeling analysis and four spot-check calculations, EPA concluded that the DOE's EPAUNI modeling analysis (which DOE also checked through hand calculations) performed accurate decay and buildup calculations necessary to determine WIPP radionuclide activity at the completion of disposal and at various times up to 10,000 years. Specifically, the relative error between volumetric EPA units calculated by the EPAUNI model and by hand calculations was found to be not greater than one part in ten thousand (0.01 percent) for any of the key radionuclides for any of the time frames examined by DOE in test cases 1-3 (DOE 1997). In addition, the relative error between volumetric EPA units calculated by the EPAUNI and ORIGEN2 models was found to be not greater than 1.75 percent for any of the key radionuclides for any of the time frames examined by DOE in test case 4. The relative errors for CH-TRU Waste, RH-TRU Waste, and TOTAL TRU Wastes in test case 4 were as follows (DOE 1997):

- CH-TRU Waste—0.186 percent (Yr. 175) to 1.03 percent (Yr. 10,000)
- RH-TRU Waste—0 percent (Yr. 175) to 1.75 percent (Yr. 10,000)
- Total-TRU Waste—0.149 percent (Yr. 100) to 1.02 percent (Yr. 10,000).

31.B REFERENCES

EPA 1998a. U.S. Environmental Protection Agency. Technical Support Document: Use of the CCDF Formalism in the WIPP PA, An EPA Background Document. 1998. (Docket A-93-02, Item v-B-23)

EPA 1998b. U.S. Environmental Protection Agency. Technical Support Document for Section 194.23: Models and Computer Codes. 1998. (Docket A-93-02, Item V-B-6)

DOE 1996. U.S. Department of Energy. WIPP PA Analysis Report for EPAUNI: Estimating Probability Distribution of EPA Unit Loading in the WIPP Repository for Performance Assessment Calculations (Version 1.00), WPO39259. June 14, 1996. (CCA Reference #401)

DOE 1997. U.S. Department of Energy. WIPP PA Analysis Report for EPAUNI: Estimating Probability Distribution of EPA Unit Loading in the WIPP Repository for Performance Assessment Calculations (Version 1.01), WPO43843. February 17, 1997.

Chakraborti, S. Memorandum to M. Chu re: Assumptions and Methodology Involved in the Estimation of the WIPP Disposal Radionuclide Inventory in the CCA, WPO46766. August 8, 1997.

Sanchez, L. Memorandum to M. Chu re: Recalculations of Waste Unit Factor with the Corrected Radionuclide Inventory, WPO47544. September 10, 1997.

Table 1

40 CFR Part 191 Release Limits for the Containment Requirements (from Table 1 of Appendix A, 40 CFR Part 191 and CCA, Appendix WCA)

Radionuclide	**L_j**	**RL_j^***
Americium-241 or -243	100	344
Carbon-14	100	344
Cesium-135, -137	1,000	3,440
Iodine-129	100	344
Neptunium-237	100	344
Plutonium-238, -239, -240, -242	100	344
Radium-226	100	344
Strontium-90	1,000	3440
Technetium-99	10,000	34,400
Thorium-230, -232	10	
Tin-126	1,000	3440
Uranium-233, -234, -235, -236, -238	100	344
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100	344
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000	3440

*Assumes $C = 3.44 \times 10^6$ Ci of TRU radionuclides emplaced in WIPP as of the time of disposal. EPA determined that this value should instead be C=3.59x10^6 Ci of TRU radionuclides.

Table 2

Calculation of WIPP Disposal Radionuclide Activity (as of 1995)

					$A_{stor,s}$ - Decayed to 1995 (2)						
Sites: CH-TRU Wastes	$V_{stor,s}$ (m3) (1)	$V_{proj,s}$ (m3) (1)	V_{scaled} proj,s (m3)	$V_{disp,s}$ (m3)	Am-241	Pu-238	Pu-239	Pu-240	Pu-242	A TRU stor,s	A TRU $_{disp,s}$
daho Nat. Eng. Lab	2.86e+04	0.00e+00	0.00e+00	2.86e+04	9.01e+04	5.98e+04	4.01e+04	9.82e+03	9.45e-01	2.00e+05	2.00e+05
Lawrence Livermore	2.30e+02	7.11e+02	1.49e+03	1.72e+03	1.44e+02	7.65e+01	1.58e+02	6.44e+01	2.02e-02	4.43e+02	3.31e+03
Los Alamos Nat. Lab	1.11e+04	7.35e+03	1.54e+04	2.65e+04	9.11e+03	1.15e+05	7.69e+04	1.00e+02	4.85e+02	2.02e+05	4.83e+05
Mound Plant	2.74e+02	0.00e+00	0.00e+00	2.74e+02		1.53e+03	2.98e+01			1.56e+03	1.56e+03
Nevada Test Site	6.19e+02	8.98e+00	1.88e+01	6.38e+02	2.84e+02	1.95e+02	2.76e+03	1.88e+01	8.70e-02	3.26e+03	3.36e+03
Oak Ridge Nat. Lab	1.30e+03	2.56e+02	5.37e+02	1.84e+03	1.61e+03	3.50e+03	1.01e+03	9.48e+02	2.37e-01	7.07e+03	9.98e+03
Rocky Flats Env. Tech.	7.06e+02	4.40e+03	9.23e+03	9.93e+03	1.10e+04	3.43e+02	9.98e+03	7.22e+03	9.63e-05	2.85e+04	4.02e+05
Hanford (RL)	1.23e+04	3.32e+04	6.97e+04	8.19e+04	4.73e+03	8.05e+04	2.63e+04	6.15e+03	3.80e-01	1.18e+05	7.85e+05
Savannah River - Onsite	2.82e+03	6.77e+03	1.42e+04	1.70e+04	3.58e+03	2.86e+05	9.13e+03	2.21e+03	3.75e-01	3.01e+05	1.81e+06
Savannah River - Offsite	6.00e+01	0.00e+00	0.00e+00	6.00e+01	1.20e+02	2.01e+05	1.58e+02	7.97e+01		2.01e+05	2.01e+05
Sub-Total:	5.79e+04	5.27e+04	1.11e+05	1.68e+05	1.21e+05	5.47e+05	1.66e+05	2.65e+04	4.87e+02	8.61e+05	3.90e+06
Rocky Flats - Residue	--	--	--	--	1.19e+05	8.09e+03	1.84e+05	4.22e+04	5.33e+00	3.53e+05	3.53e+05
Grand Total:	5.79e+04	5.27e+04	1.11e+05	1.68e+05	1.29e+05	5.55e+05	3.50e+05	6.87e+04	4.92e+02	1.21e+06	4.26e+06

					A stor,s - Decayed to 1995						
Sites: RH-TRU Wastes	V stor,s (m3)	V proj,s (m3)		V ant,s (m3)	Am-241	Pu-238	Pu-239	Pu-240	Pu-242	A TRU stor,s	A TRU disp,s
Energy Tech. Eng. Cent.	8.9e-01	0.0e+00		8.9e-01	5.85e-02		4.00e-01			4.59e-01	1.30e-01
Hanford	2.0e+02	2.2e+04		2.2e+04	1.93e+02	4.67e+01	3.35e+02	1.67e+02	4.92e-03	7.42e+02	2.25e+04
daho Nat. Eng. Lab	2.2e+02	0.0e+00		2.2e+02	4.68e+01	6.09e+01	2.98e+01	1.13e+01	1.01e-03	1.49e+02	4.20e+01
Los Alamos Nat. Lab	9.4e+01	9.9e+01		1.9e+02		3.90e+00	9.28e+01			9.67e+01	5.59e+01
Oak Ridge Nat. Lab	2.5e+03	4.5e+02		2.9e+03	2.41e+02	2.82e+01	9.86e+01	1.07e+00		3.69e+02	1.23e+02
TOTAL:	2.99e+03	2.21e+04		2.53e+04	4.81e+02	1.40e+02	5.57e+02	1.79e+02	5.93e-03	1.36e+03	2.28e+04

C=CCH+CRH: 4.28e+06
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(1) Waste stream volumes from Table 2-4 and Table 2-5, pages 2-7 and 2-8 of "Transuranic Waste BaselineInventory Report," Rev. 3, (DOE/CAO-95-1121, June 1996

(2) Site specific stored radionuclide inventories are from Appendix C of "Transuranic Waste Baseline Inventory Report, Rev. 3, (DOE/CAO-95-1121, June 1996.

(3) The RH volume limit (7,080 m3), was divided by V ant, and mulitiplied by A TRU

Table 3
Inventories and Parameters of Interest for the Key Radionuclides to be Sent to the WIPP(a)

Radionuclide	Parameter(b)		Inventory (Ci)(c)			Inventory (EPA Units)(d)			
	Decay Mode	Half-Life (Yrs.)	CH	RH	Total	CH	RH	Total	Cumulative (%)
Pu-238	α,γ,*SF*	87.7	1.93E+06	1.08E+03	1.94E+06	5.61E+03	3.14E+00	5.64E+03	56.0
Pu-239	α,γ,*SF*	2.41E+04	7.85E+05	1.03E+04	7.95E+05	2.28E+03	2.99E+01	2.31E+03	79.0
Am-241	α,γ,*SF*	432.7	4.78E+05	9.43E+03	4.88E+05	1.39E+03	2.74E+01	1.42E+03	93.2
Pu-240	α,γ,*SF*	6.56E+03	2.09E+05	5.05E+03	2.14E+05	6.08E+02	1.47E+01	6.22E+02	99.4
Cs-137	β,γ	30.17	3.35E+03	8.98E+04	9.31E+04	9.74E-01	2.61E+01	2.71E+01	99.6
Sr-90	β^-	29.1	2.77E+03	8.45E+04	8.73E+04	8.05E-01	2.46E+01	2.54E+01	99.9
U-233	α,γ,*SF*	1.592E+05	1.79E+03	1.58E+02	1.95E+03	5.20E+00	4.59E-01	5.67E+00	>99.9
Pu-242	α,β^-,γ	14.4	1.17E+03	1.50E-01	1.17E+03	3.40E+00	4.36E-04	3.40E+00	>99.9
U-234	α,γ,*SF*	2.46E+05	7.08E+02	4.29E+01	7.51E+02	2.06E+00	1.25E-01	2.18E+00	>99.9
Np-237	α,γ	2.14E+06	6.19E+01	2.95E+00	6.49E+01	1.80E-01	8.58E-08	1.89E-01	>99.99
Cm-244	α,γ,*SF*	18.1	7.36E+03	7.36E+01	7.43+03	N/A(e)	N/A(e)	N/A(e)	>99.99

Table 3 Endnotes

(a) Radionuclide inventory information taken from the Transuranic Waste Baseline Inventory Database (TWBID), ref. BIR-3 (in total, 135 radionuclides are in the TWBID). The inventory is based upon disposal in 2033.

(b) Decay mode and half-life information taken from the Chart of the Nuclides, 14th ed., ref. GE-1.

(c) Total inventory (curie) data taken from BIR-3. Values have been scaled to the volume of the WIPP.

(d) Note that the EPA unit (calculated to four significant figures) is the same, whether the calculated using all available information in the TWBID (ref. BIR-3) or using the limited data within the WIPP PA database. Also, only 4 radionuclides (Pu-238, Pu-239, Am-241, and Pu-240) make up 99.4% of the EPA unit. Six radionuclides (adding Cs-137 and Sr-90) make up 99.9%. The top 10 radionuclides make up 99.99% of the EPA unit.

(e) Cm-244 has a half-life of less than twenty years and is not included in Table 1 as a radionuclide with a required release limit. Thus, Cm-244 does not contribute to the EPA unit of waste. Cm-244 is included in this table because it is the parent to Pu-240.

Figure 1
Levels of Information Available in the TWBID