CARD 34
Results of Performance Assessments

34.A.1 BACKGROUND

The radioactive waste disposal regulations at 40 CFR Part 191 include requirements for containment of radionuclides. The containment requirements at Section 191.13 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 40 CFR Part 191. Assessment of the likelihood that the WIPP will meet the Appendix A release limits is conducted through the use of a process known as "performance assessment" (PA). The WIPP PA essentially consists of a series of computer simulations that attempt to describe the physical attributes of the repository (site, geology, waste forms and quantities, engineered features) in a manner that captures the behaviors and interactions among its various components. The computer simulations require the use of conceptual models that represent the physical attributes of the repository. The conceptual models are expressed as mathematical relationships, which are then translated into computer code. The results of the simulations show the potential releases of radioactive materials from the disposal system to the accessible environment over the 10,000-year regulatory time frame.

The PA must include both natural and man-made processes and events that have an effect on the disposal system (61 FR 5228). It must consider all reasonable potential release mechanisms from the repository, and it must be structured and conducted in a way that demonstrates an adequate understanding of the physical conditions at the disposal system and its surroundings and shows that the future performance of the system can be predicted with reasonable assurance. Also, it must include both undisturbed conditions and human intrusion scenarios. For further discussion of disturbed performance, refer to **CARD 32 -- Scope of Performance Assessments** and **CARD 33 -- Consideration of Drilling Events in Performance Assessments**. For a discussion of undisturbed performance, refer to **CARD 54 -- Scope of Compliance Assessments** and **CARD 55 -- Results of Compliance Assessments**.

The results of the PA are used to demonstrate compliance with the containment requirements at Section 191.13. The containment requirements place limits on the likelihood of radionuclide releases from a disposal facility. A radionuclide release to the accessible environment is defined in terms of the location of the release and its magnitude. Any release of radioactivity to the ground surface, the atmosphere, or surface water is considered to be a release to the accessible environment. In addition, any subsurface transport of radioactivity beyond the boundary of the WIPP controlled area is also considered a release to the accessible environment.[1] The underground portion of the controlled area consists of the portions of the subsurface environment that directly underlie the WIPP Land Withdrawal Area boundary. Under this definition, a future drilling intrusion through the WIPP repository that brings radioactive materials to the ground surface would qualify as a release to the accessible environment. Natural horizontal flow of contaminated brine from the WIPP repository in the subsurface environment beyond the

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[1] The "controlled area" withdrawn from public use pursuant to Section 3 of the WIPP Land Withdrawal Act extends to a depth of 6,000 feet. Therefore, the complete boundary of the WIPP controlled area is represented by the vertical plane extending from the surface boundary to a depth of 6,000 feet.

vertical projection of the controlled area boundary would also constitute a release to the accessible environment. The PA evaluates both the human-initiated releases (e.g., via drilling intrusions) and releases by natural processes that would occur independently of human activities.

The restrictions on releases of radioactive materials from the WIPP are expressed in terms of “normalized releases” or “cumulative releases” (EPA and DOE use the terms interchangeably). The calculation of a normalized release, in turn, involves tabulated “release limits” and the number of “units of transuranic (TRU) waste” in the inventory:

- One unit of TRU waste is defined in 40 CFR Part 191 as that amount of radioactive waste that contains exactly one million curies (Ci) of alpha-particle-emitting TRU radionuclides with half-lives greater than 20 years. (A TRU radionuclide is defined to have a net TRU concentration of greater than 100 nCi/g.) If *C* represents the total activity, in curies, of the TRU component of the waste in the repository at closure in approximately the year 2033 (estimated in the CCA at 3.44×10^6 Ci), then the number of units of TRU waste for the WIPP is given by © Ci)/(10^6 Ci). (As will be discussed below, the correct value of this number is 3.59×10^6 Ci, but there are no adverse consequences of this small error.)

- The release limit for any (TRU or non-TRU) radionuclide, or, more precisely, the release limit per unit of TRU waste, for the j-th radionuclide, L_j, refers to the factors (in curies per unit of TRU waste) listed in Table 1 of Appendix A of 40 CFR Part 191. As the name implies, a release limit is a measure of the amount of radionuclide that may legally be released into the accessible environment. (The radionuclides of greatest importance at WIPP are isotopes of americium, plutonium, and uranium, and for all of them, L_j = 100 curies per unit of TRU waste.) Release limits account for the fact that the same activity (in curies) of different radioisotopes may have significantly different effects on human health.

If the activity of the first radionuclide escaping from the repository over 10,000 years is estimated to be Q_1 for some release scenario, and that of the second radionuclide is Q_2, and so on, then the normalized release for the scenario is defined as the sum $\{ Q_1 / (L_1 \times C \times 10^{-6}) + Q_2 / (L_2 \times C \times 10^{-6}) + ...$. That is, for each radionuclide, the predicted amount which will be released over 10,000 years is divided by the release limit for that radionuclide (adjusted for the number of waste units in the WIPP); the results are then summed over all the radionuclides in the repository (not just over the TRU radionuclides) to produce a total normalized release. The normalized release is presented in what DOE has called “EPA units,” where 1 EPA unit corresponds to a normalized release of 1. The rationale for these definitions, and the interpretation of L_j in particular, are discussed in detail in **CARD 31 -- Application of Release Limits** and in the Technical Support Document for Section 194.34: Use of the CCDF Formalism in the WIPP PA (EPA 1997d), hereafter called CCDF TSD.

The containment requirement (at Section 191.13) is expressed probabilistically in terms of normalized releases. There must be a reasonable assurance that:

> "Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon PAs, that cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:
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> (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and
>
> (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A),"

where the "calculated" quantities referred to are normalized releases, as obtained from the method described above. These requirements mean that the WIPP is *not* in compliance if there could plausibly be a greater than 10 percent probability of occurrence of a normalized release, accumulated over 10,000 years, that is greater than 1. In addition, the site is not in compliance if there is a greater than 0.1 percent probability that the normalized release exceeds a value of 10. Thus, the containment requirement is fully defined at two points. The terms "reasonable assurance" and "plausible" will be expressed more rigorously and precisely, in statistical language, below.

The Compliance Criteria require that the results of WIPP PAs be expressed as complementary cumulative distribution functions (CCDFs). A CCDF indicates the probability of exceeding various levels of cumulative release.[2] The CCDFs must be generated using random sampling techniques that draw upon the full range of values established for each uncertain parameter. Parameters of lesser sensitivity in the PA may be held constant, provided that such constant values can be justified as being sufficiently conservative (61 FR 5242). Section 194.34 imposes six specific requirements on results of the PA. Section 194.34 requires that:

- CCDFs be used to express the results of the PA;
- Probability distributions for uncertain disposal system parameters must be developed and documented in the compliance certification application;
- Computational techniques which draw random samples from across the entire range of parameter probability distributions must be used in generating CCDFs and must be documented in the compliance certification application;

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[2] The nature of the CCDF is discussed in depth in the technical support document for Section 194.34: Use of the CCDF Formalism in the WIPP PA, An EPA Background Document, EPA 1997d. For the WIPP, a probability distribution function would indicate the relative number of physical scenarios, or futures, corresponding to any particular value of the normalized release. The associated CCDF curve would show the relative number of physical scenarios with a normalized release *greater than* any particular normalized release value (as suggested by Figure 6-3 of the CCA, p. 6-25). The CCDF formalism is especially suited to the WIPP PA because the containment requirements can be expressed in essentially the same graphical format. That is, the CCDF curves of the PA and the requirements of Section 191.13 can be displayed together and compared directly.

- The number of CCDFs produced shall be large enough to ensure that certain statistical conditions on their reliability are met;
- The full range of CCDFs generated will be displayed; and
- The compliance certification application must demonstrate that the containment requirements of Section 191.13 will be met with a specified level of statistical confidence.

34.A.2 REQUIREMENT

(a) “The results of performance assessments shall be assembled into “complementary, cumulative distribution functions” (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events.”

34.A.3 ABSTRACT

DOE used selected computer codes and input parameters to generate estimates of radionuclides for a large number of release scenarios; refer to the requirements for Sections 194.23(a)(1) and (c)(1) through (4) in **CARD 23 -- Models and Computer Codes** for discussions of these codes and associated parameters. In total, 300 CCDFs (100 for each of the three replicates) were constructed and presented in Volume 1, Chapter 6 of the CCA. Three hundred realizations were needed in order to satisfy the requirements of Section 194.34(d). Normalized release results for ten thousand future simulations were used to calculate each of the 300 CCDF curves.

The results of DOE's analysis are presented in Volume 1, Chapter 6.5, p. 6-214 to 6-234. Figures 6-35, 6-36 and 6-37 of the CCA show the 100 CCDF curves generated by the CCDFGF program for each of replicates 1, 2 and 3, respectively. The figures also show EPA regulatory limits, in terms of probability limits at values of normalized release of $R = 1$ and $R = 10$. DOE concluded that all 300 CCDFs demonstrate compliance, and thus that the PA as a whole demonstrates compliance. DOE also concluded that the containment requirement of Section 191.13 was satisfied and that all requirements of Section 194.34 were met.

EPA’s analysis concluded that DOE adequately presented the PA results in CCDFs, which show the probability of exceeding various levels of cumulative releases. EPA also reviewed features, events and processes (FEPs), scenarios, conceptual models and computer codes that support CCDF generation. EPA has found that DOE adequately addressed issues associated with these aspects of the PA.

34.A.4 COMPLIANCE REVIEW CRITERIA

EPA expected DOE to:

- Demonstrate that the results of the PA were assembled into CCDFs;

- Demonstrate that the CCDFs represent the probability of exceeding various levels of cumulative release caused by all significant processes and events; and

- Demonstrate that all significant processes and events that may affect the repository over the next 10,000 years have been incorporated into the CCDFs that are presented. [Compliance Application Guidance for the Waste Isolation Pilot Plant: A Companion Guide to 40 CFR Part 194 (CAG), p. 51.]

34.A.5 DOE METHODOLOGY AND CONCLUSIONS

Information on the construction and use of CCDFs to determine compliance is contained in Chapters 6.4.13 and 6.5 of the CCA (p. 6-199 to 6-234), and Appendix CCDFGF. Chapters 6.4.13 and 6.5 present general descriptions of the risk assessment calculations performed by DOE, and also reference details provided in Appendix CCDFGF. More DOE information on CCDF construction is provided in the Analysis Package for the CCDF Construction (Docket A-93-02, Item II-G-10, WPO #40524) and the Preliminary Summary of Uncertainty and Sensitivity Analysis (Docket A-93-02, Item II-G-07). Additional explanation on CCDF construction may be found in the EPA Technical Support Document for Section 194.34: Use of the CCDF Formalism in the WIPP PA, An EPA Background Document (EPA 1997d). Significant events and processes are discussed in Chapter 6.2 (p. 6-35 to 6-61) and Appendix SCR.

Overview of Construction of WIPP CCDF Curves

The WIPP PA is designed to calculate three replicates (groups) of one hundred CCDF curves each, representing 300 plausible, but different sets of physical conditions within the WIPP. The calculation of a single CCDF curve, and the incorporation of the various relevant uncertainties into it, involve two separate but related activities: the generation of a “realization” (i.e., a mathematical simulation of the physical conditions within and around the repository) followed by the creation of 10,000 “futures” for that realization, where each future represents a series of human intrusion events over the course of 10,000 years.

The generation of a realization employs a set of values, randomly selected by a Latin Hypercube Sampling (LHS) program, for 57 parameters that describe physical conditions within and around the repository. (Chapter 6.4.11, p. 6-173 to 6-180). That is, the 100 CCDF curves of a replicate correspond to 100 different sets of parameters that together determine the flow of brine, the buildup of gas pressure, etc., over time.

In the creation of the first future of the first realization, a Monte Carlo random sampling program (which is somewhat different from, but performs the same function as, the LHS program) selects values for the six “stochastic” variables that define the first intrusion event, such as the period of dead time until it occurs, its location, etc., and estimates the normalized release for that intrusion event. (The dynamics of the event also depend on factors obtained earlier, during the running of the realization, such as gas pressure within the panels, and the degree of saturation of the waste material with brine, as functions of time.) (Chapter 6.4.12, p. 6-180 to 6-181). The second sampling leads to the simulation of the second event, and so on. Eventually, an event occurs after the 10,000 year period of regulatory concern, indicating the end of the simulation of the first future. The end result is a numerical value (in EPA units) for the normalized release associated with the first future, obtained by summing the releases from its respective intrusions. Then 9,999 more futures are produced in the same way, and the resulting 10,000 probability and consequence (i.e., normalized release) values are combined in the construction of the CCDF curve for the first realization. The other 99 CCDF curves of a replicate are produced in exactly the same way, only with 99 different sets of 57 values selected by the LHS program, and each with 10,000 new random sequences of intrusions produced with the Monte Carlo program.

The information content of the 100 CCDF curves in each replicate was consolidated into a small number of summary CCDF curves. The *mean* CCDF curve, for example, was generated point-wise by calculating an average of the 100 CCDF values at each of a large number of selected values of the normalized release. The same approach allowed construction of 10th and 90th percentile curves: At each selected value of the normalized release, there are 100 CCDF values to consider; the tenth one from the top (or bottom) was used as an estimate of the 90th (or 10th) percentile summary CCDF curve at that value of the normalized release. Thus, while one CCDF may serve as the 90th percentile curve for one value of the normalized release, a different CCDF curve may mark the 90th percentile for another. The mean CCDF curves for the three replicates were of particular interest because the containment requirements of Section 194.34(f) are phrased in terms of the mean CCDF. Note that while the PA process resulted in the generation of 300 complete CCDF curves, the actual test of compliance with the regulation requires only the evaluation of one summary curve (the 95th percent upper confidence limit on the mean) at two specific values of normalized release (at 1 EPA Unit and at 10 EPA Units).

Although it is defined at only two points, for normalized release values of 1 and 10, the containment requirement can be shown on a graph of CCDF WIPP performance curves as an exclusion area with corners at cumulative releases of one and ten, as may be seen in Figure 6-38 of the CCA (p. 6-223). The PA shows compliance with the containment requirement if the mean CCDF curve is sufficiently far below and to the left of the exclusion area. The statistical meaning of “sufficiently far” is addressed in Section 194.34(f) of this CARD.

Features, Events, Processes and Scenario Development

DOE defined a set of FEPs that could potentially affect the performance of the WIPP over the next 10,000 years. Refer to **CARD 32 -- Scope of Performance Assessments** for detail regarding the FEP development and screening process.

DOE reduced the set of FEPs to be included for consideration in the PA modeling to about 80. The PA modeling included FEPs related to the geologic conditions and processes at the WIPP site, and to the performance of the repository over time. The PA modeling included human-initiated events and processes, in particular the drilling of sequences of boreholes, some of which continue downward from the repository and intersect pockets of pressurized brine. See

Chapter 6.2 (p. 6-35 to 6-61) for all FEPs and Chapter 6.2.5 (p. 6-47 and 6-52 to 6-61) for FEPs related to human-initiated events.

Once DOE had selected the set of FEPs, it then determined how each of them could be represented in the PA. Generally, this step involved either explicitly including the feature, event, or process in one of the conceptual models, or adjusting a parameter value or group of parameter values to represent the FEP (Chapter 6.1.4, p. 6-24 to 6-31).

DOE then developed conceptual models to represent the FEPs. The conceptual models pertained to all aspects of the disposal system, and covered conditions at both the undisturbed and the disturbed repository. They dealt with issues such as the geologic stratigraphy, creep closure, gas generation, fluid flow in the geologic media, waste degradation, actinide dissolution, and effects of borehole intrusions. The conceptual models were interrelated, so as to capture the dynamic, interconnected nature of the disposal system. All of DOE's conceptual models are described in Chapter 6. See Section 194.23(a) in **CARD 23 --Models and Computer Codes** for EPA’s review of the conceptual models.

The FEPs were used, in particular, to define radionuclide release scenarios related to human intrusion. The following major scenarios were developed by DOE:

- Undisturbed performance;
- Mining scenario (M);
- Drilling scenario in which the repository (but not necessarily a waste panel) and then a pressurized brine reservoir are intersected by the same borehole (E1);
- Drilling scenario in which the repository is intersected, but *not* a brine reservoir (E2); and
- Drilling scenario in which multiple boreholes penetrate the same waste panel, at least one of which also penetrates an underlying pressurized brine reservoir (E1E2).

The FEPs were incorporated into the computational scenarios from which normalized releases were calculated. DOE presented the releases in the form of CCDFs.

Complementary Cumulative Distribution Functions

The CCDFGF model and code performed simulations related to human intrusion (i.e., stochastic uncertainty) to generate the CCDF curves for the WIPP. CCDFGF generated 10,000 futures for each LHS input vector (and realization), and a Monte Carlo program performed random sampling over the distribution functions for the six stochastic parameters. This included, but was not limited to, determining:

- The time to the next borehole intrusion;
- Where the intrusion hits the repository and, in particular, whether or not it strikes an excavated area;
- Which waste containers (i.e., what types and concentrations of radioactive waste) were intersected;
- Whether brine is hit or not after the borehole passes through the repository;
- The type and integrity of borehole plugging pattern used following the intrusion; and
- Whether or not mining is on-going.

The program incorporates the time dependence of intrusion events by means of the Poisson process model, a probability model often used to simulate the random occurrence of discrete events within a specified time interval, as is discussed in any elementary text on statistics (Chapter 6.4.12.2 , p. 6-182 to 6-183). The Poisson model requires only one parameter here, λ, the average rate of intrusion occurrences per 10,000 years.

DOE discussed intrusion events in Chapter 6.4.12 (p. 6-180 to 6-198). While simulating each future, the program keeps track of multiple intrusions into the waste panels and into the brine pocket to implement specific rules for the treatment of multiple intrusions. For example, when a borehole hits an excavated area of the repository, it is possible that the event may lead to the release of radioactive materials from the repository through any or all of four mechanisms noted above: cuttings and cavings; spallings; direct brine release at the time of intrusion; and long-term releases into the ground water by way of the Culebra dolomite and the Salado anhydrite marker beds.

DOE's set of models and computer codes are intended to allow a quantitative assessment of the consequences of any such release of radioactive materials (i.e., the magnitude of the normalized release; see **CARD 31--Application of Release Limits**). For each realization (i.e., for each LHS vector), the program keeps track of the estimates of the consequences for the 10,000 equally probable futures, and from this information generates a CCDF curve. (See the CCDF TSD). The result is a set of 100 CCDFs for each of the three replicates. The value of CCDF(R) is calculated by counting how many of the 10,000 equally probable futures resulted in cumulative normalized release greater than the specific normalized release value, R, then dividing that count by 10,000.

Selected computer codes and input parameters were used to generate a large number of release estimates; refer to sections (a)(3)(ii) through (a)(3)(iv) and (c)(1) through (c)(4) in **CARD 23 -- Models and Computer Codes** for discussions of these codes and associated parameters. The results of DOE's analysis were presented in Chapter 6.5 (p. 6-214 to 6-234). Figures 6-35, 6-36 and 6-37 of the CCA (p. 6-217 to 6-221) show the 100 CCDF curves generated by the CCDFGF program for replicates 1, 2 and 3, respectively. The figures also show EPA regulatory limits, in terms of probability limits at R = 1 and R = 10. The DOE concluded that the three replicates of 100 CCDFs each demonstrate compliance, that the containment requirement of Section 191.13(a) was satisfied, and that all requirements of Section 194.34 were also met.

34.A.6 EPA COMPLIANCE REVIEW

EPA’s compliance review regarding FEPs, scenario development, and conceptual models that lead to CCDF development is discussed in **CARD 32 -- Scope of Performance Assessment** and **CARD 23 -- Models and Computer Codes**, section (a)(1). EPA concluded that DOE appropriately considered natural processes and events, as well as human-initiated events, in its PA-related evaluations. EPA believes that all models but the spallings model are adequate for use in the CCA PA calculations, that the results from the spallings model are reasonable, and that the spallings model results may even overestimate releases (see Section 194.23(a)(3)(v) in **CARD 23 -- Models and Computer Codes**). EPA found that all significant FEPs and scenarios were included in the generation of CCDFs. The CCDFGF program also reports results of several internal diagnostic tests designed to ensure that the probabilities of events generated by the model match closely with calculated probabilities from the assigned probability distributions (Appendix CCDFGF). Also, EPA devised and successfully carried out a bilinearity test for the CCDFGF code to determine if the CCDFs generated by the CCDFGF program respond linearly to its two primary inputs, waste volume and waste radionuclide concentration (see Appendix A of EPA Technical Support Document for Section 194.23: Models and Computer Codes (EPA 1997b).

EPA examined DOE’s presentations in Chapter 6 of the CCA, and concluded that DOE appropriately presented the PA results in CCDFs showing the probability of exceeding regulatory levels of cumulative releases.

Upon reviewing models and computer codes, the Agency questioned a number of important input parameter values and distributions used in the PA. Based upon its review of the supporting information, EPA determined that such information supported values or ranges of values for certain key input parameters different from those selected by DOE. In addition, certain of the conceptual models utilized in the derivation of certain input parameters were changed by DOE or its contractors after submission of the CCA. Because of concerns that the necessary corrections of certain input parameters and conceptual models could have significant effects on the actual results of the PA, EPA required DOE to demonstrate that the combined effect of all the parameter and computer code changes required by EPA was not significant enough to necessitate a new PA (Docket A-93-02, Item II-I-17).

EPA directed DOE to demonstrate the combined effect of the parameter and code changes by conducting additional calculations in a Performance Assessment Verification Test (PAVT). The PAVT was an independent computer simulation of the WIPP's performance conducted under EPA's authority to require independent verification computer simulations (Section 194.23(d)). It implemented DOE's PA modeling, using the same sampling methods as the CCA PA, but incorporating parameter values mandated by EPA (see Docket A-93-02, Items II-I-25, II-I-27 and III-B-5). The methods used to execute the PAVT were identical, from a technical standpoint, to those used for the CCA PA. That is, DOE used the same computer codes, same sampling methodologies, etc., but changed the parameters identified by EPA and modified some of the computer codes in response to EPA's questions about the codes. DOE's results from the PAVT are found in the July 25, 1997, Summary of EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations (Docket A-93-02, Item II-G-26), and the August 8, 1997, Supplemental Summary of EPA-Mandated Performance Assessment Verification Test (All Replicates) and Comparison with the Compliance Certification Application Calculations (Docket A-93-02, Item II-G-28).

The PAVT resulted in 300 CCDF curves that verified that the combined effect of computer code changes and altered parameter values did not significantly alter the results of the PA and did not cause the predicted releases from the WIPP to violate the containment requirements. A more detailed analysis of the PAVT and its results is included in EPA Technical Support Document Overview of Major Performance Assessment Issues (EPA 1997c).

34.B.1 REQUIREMENT

(b) "Probability distributions for uncertain disposal system parameter values used in performance assessments shall be developed and documented in any compliance application."

34.B.2 ABSTRACT

DOE documented its selection of parameters and probability distributions for the key parameters in Chapter 6 of the CCA, Appendix PAR, and associated references. DOE selected 57 uncertain subjective parameters whose values were obtained through random sampling in the PA. The ultimate goal of the parameter sampling was to capture uncertainties in the parameters and show their effects on the CCDFs, which DOE discussed in Chapter 6.4.11 (p. 6-174). DOE's Sensitivity Analysis (Docket A-93-02, Items II-G-07 and II-G-30) also showed the impact of some sample parameter variations on the CCDFs. Based on the documentation provided with the CCA and associated references, DOE concluded that the requirements of Section 194.34(b) were satisfied. Refer to Section 194.23(c)(4) in **CARD 23 -- Models and Computer Codes** and the EPA Technical Support Document for Section 194.23: Parameter Report (EPA 1997a) for a detailed discussion of DOE's parameter distributions and parameter values.

EPA reviewed the parameters used in the modeling and the probability distributions for the sampled parameters, and determined that certain of the key parameter values were not supported by the relevant data and information. This review is documented in a separate report included in the reference list (see EPA Parameter Report (EPA 1997a)). As a result of the parameter review, EPA required either a demonstration that the combined effect of corrected parameter values is not significant enough to require a new PA (see **CARD 23 -- Models and Computer Codes**, Section (c)(4)).

34.B.3 COMPLIANCE REVIEW CRITERIA

EPA expected DOE to:

- Discuss the sources used and the methods by which each of the probability distributions was developed (e.g., experimental data, field data, etc.);
- Identify the functional form of the probability distribution (e.g., uniform, lognormal) used for the sampled parameters;
- Describe the statistics of each probability distribution, including the values for lower and upper ranges, mean (geometric mean when appropriate) and median;
- Identify the importance of the sampled parameters to the final releases; and
- Demonstrate that the data used to develop the input parameter probability distribution were qualified and controlled in accordance with Section 194.22 (CAG, p. 51).

34.B.4 DOE METHODOLOGY AND CONCLUSIONS

The Compliance Criteria require that the PA account for uncertainties in the modeling. DOE chose (largely for computational reasons) to partition the uncertainties in the future performance of the WIPP into two, largely non-overlapping categories: stochastic and subjective. Stochastic uncertainty is associated with the inability to predict future events involving human intrusion into the repository. Subjective uncertainty comes from an incomplete knowledge of the physical properties and attributes of the disposal system, or from quantities that do not have single, unique values, such as the permeability or compressibility of dolomite. Both types of uncertainty are incorporated into the PA by choosing ranges and probability distributions for various key parameters. For example, stochastic uncertainty in the timing of drilling intrusions is treated by assigning a random variable for the time until the next intrusion, while maintaining the desired average drilling rate. Similarly, subjective uncertainty in parameters such as the shaft permeability are randomly selected from a probability distribution that encompasses a plausible range of values.

Not every parameter in the PA has been represented by a probability distribution. DOE assigned distributions only for 57 key subjective parameters that DOE believes may have significant effects on the results of the calculations. For each of the three replicates, a Latin Hypercube Sampling program selected 100 sets of random values of these 57 variables. The result was one hundred 57-dimensional “input vectors”, $\mathbf{x}_{SU}$, representing the subjective variables. The 100 input vectors were used in the computer codes that describe the physical processes occurring within and near the repository both without and with human intrusion. One hundred output files were generated and employed as input files to the CCDFGF computer code.

For each LHS-produced input vector of parameters related to the WIPP's physical conditions, the CCDFGF code generated 10,000 multi-intrusion "futures." In doing this, it accounted for stochastic uncertainties by using a (non-stratified) Monte Carlo program to sample the distributions for six stochastic parameters listed above. For each replication, a total of 100 CCDF curves were generated, one for each LHS input vector, and with 10,000 futures for each curve.

DOE used several types of probability distributions to describe the uncertainty in the WIPP PA model input parameters, as documented in Chapter 6 of the CCA, Appendix PAR, and associated references, as discussed below. The families of probability distributions selected for possible use with the PA model input parameters by DOE included the uniform, loguniform, triangular, Student's t, cumulative, logcumulative and delta distributions (see Appendix PAR, p. PAR-2 to PAR-9). All but the delta distribution are defined for variables that have a continuous range of values; the delta distribution was used for parameters which can take only a discrete set of values (p. PAR-6). DOE indicated that the uniform, loguniform, and triangular distributions are appropriate for parameters that are assumed to lie in an interval between two known endpoints (p. PAR-3, 8, and 5 respectively). The Student's t distribution was defined for this analysis to extend only to the 1st and 99th percentiles, rather than to continue indefinitely past these extremes (p. PAR-5 and PAR-6). The logcumulative distribution uses the same method applied to the logarithms of the parameter values (p. PAR-8 and PAR-9). Section 194.23(c)(6) in **CARD 23 -- Models and Computer Codes** contains information on parameter correlations. The general methods for addressing correlation are included in Iman and Shortencarier (1984). DOE's Sensitivity Analysis also shows the impact of some sample parameter variations on the CCDFs (Docket A-93-02, Items II-G-07 and II-G-30) . See Section 194.23(c)(4) in **CARD 23 -- Models and Computer Codes** for a detailed discussion of DOE's parameter distributions and parameter values.

34.B.5 EPA COMPLIANCE REVIEW

EPA reviewed the PA as described in Chapter 6 of the CCA, all pertinent appendices provided with the CCA, and all pertinent materials referenced by DOE, to verify DOE's approach and implementation of the PA. EPA conducted a thorough review of the parameters and the parameter development process (see EPA Technical Support Document for Section 194.23: Models and Computer Codes (EPA 1997b) and EPA Parameter Report (EPA 1997a)). It reviewed parameter packages for approximately 1600 parameters used in the CCA PA calculations, including the 57 subjective parameters. The Agency found that DOE adequately documented the probability distributions in Appendix PAR, and discussed the data from which, and the method by which, the probability distribution of each of the 57 sampled variables was created. This information was augmented by Chapter 6.4 (p. 6-101 to 6-173), DOE's Analysis Packages, and parameter records in the SNL Records Center. DOE provided general information on probability distributions, data sources for parameter distribution, forms of distributions, bounds, and importance of parameters to releases.

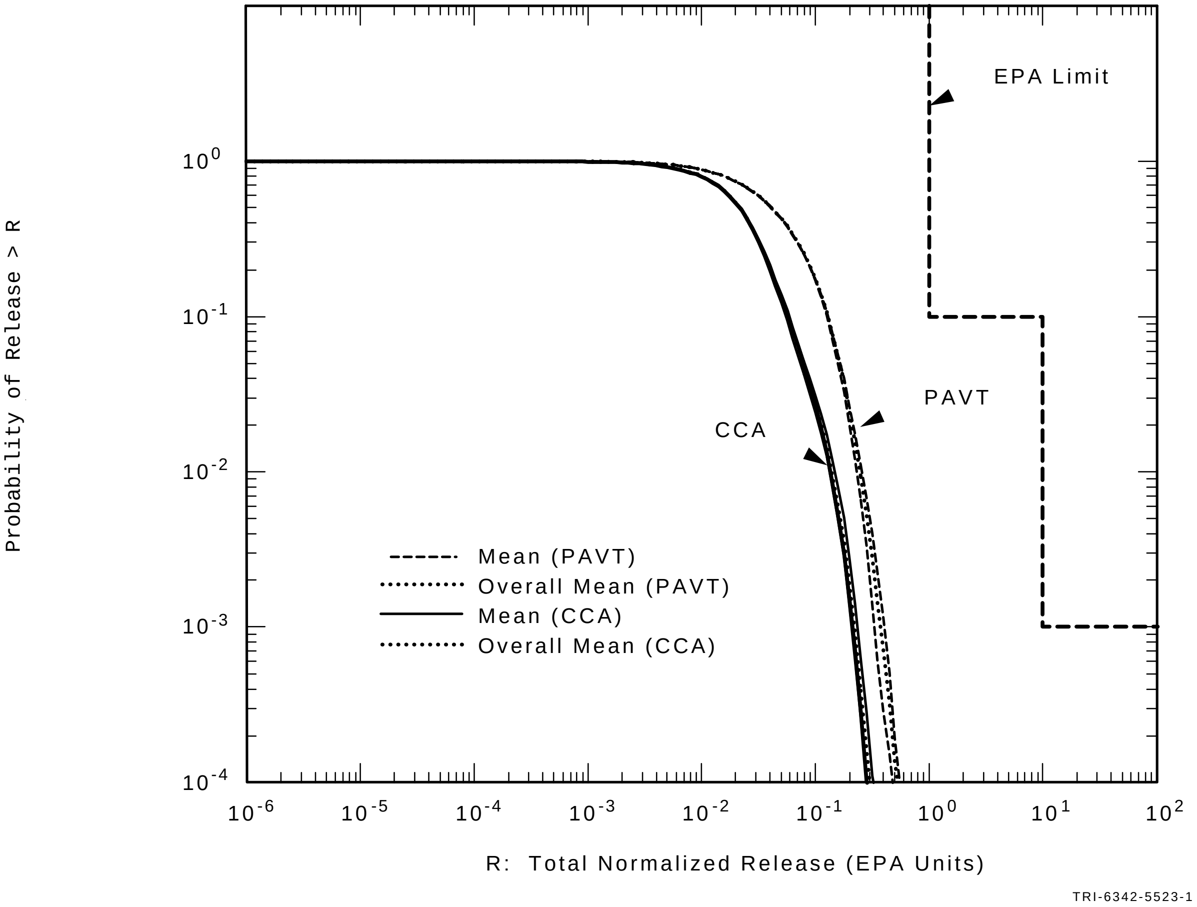
Upon reviewing models and computer codes, the Agency questioned the basis for and importance of 58 parameter values and distributions used in PA (Docket A-93-02, Item II-I-17). In response to EPA's letter, DOE provided additional documentation to support some of its parameter values (Docket A-93-02, Items II-I-24 and II-I-26). After reviewing this information and conducting further technical review, including parameter sensitivity analyses, EPA still had concerns about 24 parameters. The Agency believed that these 24 parameters -- either individually or in combination with other parameters -- might have a significant impact on the results of PAs. In addition, both EPA and DOE had identified some problems with the PA computer codes that required changes. EPA's compliance review on this topic is documented in Section 194.23(c)(4) of **CARD 23 -- Models and Computer Codes**.

EPA required DOE to demonstrate that the combined effect of all parameter and computer code changes was not significant enough to necessitate a new PA by conducting additional calculations in a Performance Assessment Verification Test (PAVT) using EPA's values or distributions for 24 parameters (Docket A-93-02, Items II-I-25 and II-I-27); see also the discussion of parameters in Section 194.23(c)(4) of **CARD 23--Models and Computer Codes**. DOE conducted the PAVT using parameters that had been changed in accordance with EPA's direction. The methods used to execute the PAVT were identical, from a technical standpoint, to those used for the CCA PA. That is, DOE used the same computer codes, same sampling methodologies, same total number of input parameters, etc., but changed the specific parameter values identified by EPA and modified some of the computer codes in response to EPA's questions about the codes. DOE conducted 300 realizations for the PAVT, resulting in 300 CCDF curves, just as for the CCA PA. As shown in Figure 1, the resulting CCDF curves show slightly higher normalized releases than the CCA PA, but they are still more than an order of magnitude below the radioactive waste containment requirements at Section 191.13. Thus, the PAVT incorporated changes that addressed EPA's concerns about the PA and demonstrated that the combined effect of the necessary modification did not require that DOE conduct a new full PA. Moreover, the results of the PAVT demonstrated that modeled resulting releases are still within the containment requirements. Because the PAVT used technical methods identical to those of the CCA PA, EPA believes that the PAVT results are numerically equivalent to those that would be obtained by performing a new PA that incorporated the same changes implemented in the PAVT. Therefore, because of the close agreement between the PA and PAVT results, EPA believes that the PAVT verifies that the original CCA PA was adequate for comparison against the radioactive waste containment requirements. For a detailed treatment of the PAVT, see July 25, 1997 Summary of EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations (Docket A-93-02, Item II-G-26); August 8, 1997 Supplemental Summary of EPA-Mandated Performance Assessment Verification Test (All Replicates) and Comparison with the Compliance Certification Application Calculations (Docket A-93-02, Item II-G-28); and Technical Support Document: Overview of Major Performance Assessment Issues (EPA 1997c).

Figure 1

Comparison of Mean CCDF Curves Resulting from CCA PA and PAVT

(After Figure 7.1 of DOE Document WPO #46702; see Docket A-93-02, Item II-G-28.)



Note: Four CCDFs are shown for both the CCA and PAVT, including three individual mean CCDFs calculated for each of the three distributions of CCDFs calculated for the three replicates and an overall mean CCDF that is the arithmetic mean of the three individual mean CCDFs.

34.C.1 REQUIREMENT

(c) “Computational techniques, which draw random samples from across the entire range of the probability distributions developed pursuant to paragraph (b) of this section, shall be used in generating CCDFs and shall be documented in any compliance application.”

34.C.2 ABSTRACT

DOE chose or developed computer codes and calculational procedures for all aspects of the PA modeling. The main computer code relevant to compliance with Section 194.34(c) is the Latin Hypercube Sampling (LHS) code, which performs sampling of the probabilistic parameters. The computer codes and their documentation are discussed in Sections 194.23(c)(1) through (c)(6) in **CARD 23 -- Models and Computer Codes**.

DOE used the LHS method instead of pure random sampling because LHS requires a smaller number of samples to achieve a given level of statistical convergence to the mean. A purely random sampling program selects independently each parameter value from its respective probability distribution function. The LHS method stratifies (divides) every probability distribution into a number (100 for the WIPP PA) of regions of equal probability. DOE contended that with LHS, the number of samples can be smaller while still maintaining a good representation of the full range of the parameter probability distributions. Based on the information presented in the CCA, particularly the LHS computer code documentation and Appendix PAR, DOE concluded that the requirements of Section 194.34(c) were met.

EPA reviewed the PA as described in Chapter 6 of the CCA and all pertinent CCA appendices and references. A major part of EPA's review dealt with the documentation of computer codes and calculational procedures, particularly the methods for sampling parameters from probability distributions. The LHS method for selecting parameter values was evaluated by EPA.

EPA agreed that it was appropriate to use the LHS method for the 57 sampled parameters described in Appendix PAR. EPA concluded that DOE adequately discussed the computational techniques and the sampling ranges.

34.C.3 COMPLIANCE REVIEW CRITERIA

EPA expected DOE to:

- Discuss the computational techniques used for random sampling; and
- Demonstrate that sampling occurred across the entire range of each parameter (CAG, p. 51).

34.C.4 DOE METHODOLOGY AND CONCLUSIONS

DOE chose or developed computer codes and calculational procedures for all aspects of the PA modeling. The main computer code relevant to compliance with Section 194.34(c) is the LHS code, which performs the sampling of probabilistic parameters. The computer codes and their documentation are discussed in Sections 194.23(c)(1) through (c)(6) of **CARD 23 -- Models and Computer Codes**.

DOE chose the LHS method, which carries out stratified random sampling, instead of pure random sampling in order to reduce the number of samples needed. Purely random sampling selects independently every parameter value from its respective probability distribution function. LHS, by contrast, first stratifies each parameter probability distribution into a number of regions of equal probability. In this case, since there are one hundred realizations in a replicate, 100 such regions were used for each distribution. The regions are selected at random without replacement, so that each region eventually contributes its value exactly once in each replication. (Equivalently, the vertical axis of the *cumulative* distribution curve for each parameter was partitioned into 100 equally tall segments, and the segments were sampled without replacement.) The 100 realizations thus give a random permutation of the 100 regions for each uncertain parameter. Finally, a single parameter value within each region is selected randomly from that region (using the conditional distribution of the parameter value given that it lies inside the region.)

DOE asserted that the stratification of the distribution before selecting a value causes the sampled parameters to better represent the full range of values from the probability distribution than would be likely with purely random sampling. With a small sample size, non-stratified random sampling would be less likely to select values from the extreme ranges of the distributions. DOE contended that with LHS, the number of samples can be smaller while still maintaining a good representation of the full range of the parameter probability distributions.

DOE's LHS computer code manual documented the LHS procedure and stated the empirical rule that the sample size to obtain representative sample vectors should be no less than about four thirds times the number of sampled parameters. Since DOE sampled 57 key parameters, DOE believed that a minimum of 76 sample vectors was adequate. Based on this criterion, DOE believed its sample size of 100 for each of three replicates was more than sufficient, as discussed further in Section 194.34(d) of this CARD. A more complete discussion of the LHS method and its application in the CCA is provided in Appendix A to The Technical Support Document for Section 194.23: Models and Computer Codes (EPA 1997b).

Six additional (stochastic) parameters related to human intrusion scenarios (rather than to the uncertain behavior of the disposal system itself) were also sampled in DOE's CCDFGF code. DOE utilized non-stratified Monte Carlo random sampling rather than LHS for these parameters, and relied on a much larger sample size to ensure a good representation of the probability distributions. Each realization in the CCDFGF code used 10,000 futures and, for each future, some number (i.e., the number of intrusion events for that future) of random samples of the set of the six stochastic variables. For a given set of values for the 57 subjective parameters (i.e., for any realization), it is the differences among the futures that determine the detailed shape of a CCDF curve.

Based on the information presented in the CCA, particularly the LHS computer code documentation and Appendix PAR, DOE concluded that the requirements of Section 194.34(c) were met.

34.C.5 EPA COMPLIANCE REVIEW

EPA reviewed the PA as described in Chapter 6 of the CCA and all pertinent appendices provided with the CCA. EPA's review covered the documentation of computer codes and calculational procedures, particularly the methods for sampling parameters from probability distributions.

EPA evaluated the LHS method that was used for the 57 sampled parameter described in Appendix PAR (see Appendix A of Technical Support Document for Section 194.23; EPA 1997b). EPA determined that this method ensures that parameter values will be selected from the entire range of the probability distributions because LHS stratifies the probability distributions into a number (100, in this case) of equal-probability regions and then samples one value from each region (see also Stein, 1987; McKay, 1979). EPA noted that the LHS sampling is appropriate for generating random samples.

Additional sampling of human intrusion parameters was done in the CCDFGF code. EPA concluded that the LHS method was not used here, but that the probability distributions for the stochastic variables were represented properly and sampled correctly with Monte Carlo sampling for each realization. The large number of samples is sufficient to ensure that the values represent the entire range of the probability distribution.

EPA required DOE to perform additional calculations in a Performance Assessment Verification Test (PAVT) to demonstrate that the combined effect of all the parameter and computer code changes required by EPA was not significant enough to require a new PA. The methods used to execute the PAVT were identical, from a technical standpoint, to those used for the CCA PA. That is, DOE used the same computer codes, same sampling methodologies, etc., but changed the parameters identified by EPA and modified some of the computer codes in response to EPA’s questions about the codes. Because the PAVT used identical sampling methods to those in CCA PA -- which EPA finds adequate for the purpose of compliance with Section 194.34(c) -- the PAVT would also be fully adequate to meet the technical criterion in Section 194.34(c).

34.D.1 REQUIREMENT

(d) “The number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability. Values of cumulative release shall be calculated according to Note 6 of Table 1, Appendix A of Part 191 of this chapter.”

34.D.2 ABSTRACT

DOE's approach to demonstrating compliance with Section 194.34(d) was presented mainly in Chapter 6.5, p. 6-214 to 6-234. DOE generated three sets of 100 CCDFs each and discussed the statistical confidence levels for the set of CCDFs and asserted that LHS probably yields better results than purely random sampling when the sample number is low. Based on the number of CCDFs generated, DOE concluded that the maximum CCDF generated exceeded the 99th percentile with at least a 0.95 probability, and thus that the statistical requirements of Section 194.34(d) were satisfied. EPA concurs with DOE's conclusion.

34.D.3 COMPLIANCE REVIEW CRITERIA

EPA expected DOE to:

- Identify the number of CCDFs generated;
- Discuss how DOE determined the number of CCDFs to be generated;
- List the probabilities of exceeding cumulative releases of 1 and 10 for each CCDF generated; and
- Demonstrate that the maximum CCDF generated, at cumulative normalized releases of 1 and 10, exceeds the 99th percentile with at least a 0.95 probability with a discussion that includes examples of calculations (CAG, p. 52).

34.D.4 DOE METHODOLOGY AND CONCLUSIONS

In Chapter 6 of the CCA, DOE presented the PA methodology and the results that it used to demonstrate compliance with the containment requirements at Section 191.13. DOE generated a total of 300 CCDFs (three replicates of 100 CCDFs each). All of the CCDFs are shown in Chapter 6, Figures 6-35, 6-36, and 6-37, of the CCA (pp. 6-217 to 6-221); mean, ninetieth, fiftieth and tenth percentile values of the CCDF curves, and upper and lower 95th percent confidence limits on the mean are displayed in Figures 6-38, 6-39 and 6-40 of the CCA (p. 6-223 to 6-227).[3]

DOE established in the User's Manual for LHS (Docket A-93-02, Item II-G-03, Vol. 8) the empirical rule that the minimum number of sample vectors required to assure representative sampling is roughly 4/3 times the number of parameters sampled. Based on this argument, a minimum of approximately 75 vectors (represented as CCDFs) would be required.

DOE used a set of three independent replicates of 100 CCDFs each and with a different LHS sample of parameter values, to ensure that its simulations would more than cover the number

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[3] Note that in the succeeding discussion, "CCDFs," "CCDF curves," and "realizations" are all used interchangeably.

indicated by the empirical rule. Only very small differences were noted among the three replicates, and DOE believed this similarity indicates that it is not necessary to use higher sample sizes.

DOE also presented a more formal probabilistic analysis to show that 300 curves are more than sufficient to ensure, with a 0.95 probability, that for any value of normalized release, the value of the maximum CCDF curve (i.e., of the top-most of the 300) exceeds the value of the 99th percentile curve of the entire, countless population of CCDF curves (Chapter 8.1.4, p. 8-8 to 8-10). At any value of normalized release, R, the value of a single CCDF curve, namely CCDF(R), will assume some value between 0 and 1. For a set of 300 such curves, there will be 300 values of CCDF(R), all of them simple numbers in the 0 to 1 range. For the hypothetical "true" population of all such possible CCDF curves for the WIPP, there will be an infinite number of such numbers. By definition, only 1 in 100 of the infinite number of rational numbers lying between 0 and 1 exceeds the 99th-percentile value of that population (i.e., 0.99). Conversely, a randomly selected number in that range would have a 0.99 probability of falling below the 99th-percentile value. If two such numbers are randomly selected, then the probability that both will lie below 0.99 is $(0.99)\times(0.99)$, or $(0.99)^2$. For n independently constructed CCDF curves, the probability that all of their values for some value of R will fall below the 99th percentile value is $(0.99)^n$. The probability that at least one of these numbers will exceed 0.99 is therefore $\{1 - 0.99^n\}$. For some value of n, the probability will be 0.95; equivalently, the sample size required for there to be a 0.95 probability that at least one sampled number will exceed 0.99 can then be obtained from $\{1 - 0.99^n\} = 0.95$. The solution to this is $n = 298$. Therefore, DOE concluded that 300 curves were sufficient to satisfy the requirements of Section 194.34(d).

34.D.5 EPA COMPLIANCE REVIEW

EPA found that DOE used the LHS method to sample the 57 key parameters. The statistical requirement at Section 194.34(d) states that the number of CCDFs shall be large enough that the maximum CCDF shall exceed the 99th percentile of the population of CCDF curves with a 0.95 confidence level. The Agency's intent for this section was for DOE to generate enough CCDFs so that the number of CCDFs "will be large enough to ensure that a full range of realizations have been generated" (60 FR 5776). EPA estimated that this would require several hundred realizations. DOE has argued that 300 curves is more than sufficient to meet this condition.

EPA found the analysis presented in CCA Chapter 8 sufficient to show that 298 (where $\{1-0.99^n\} = 0.95$; $n = 298$) CCDF curves will satisfy the statistical criterion. Therefore, the 300 CCDF curves actually computed and presented in the CCA are sufficient. DOE correctly interpreted the definition of the 99th percentile value, and applied standard mathematical expressions for deriving the probability of an outcome of multiple events (i.e., the generation of multiple CCDF curves). The probabilistic analysis is appropriate for sampling with the LHS method, which achieves better coverage than non-stratified random sampling of parameter ranges. The LHS method, the CCDFs, and their application in the CCA are presented and discussed in detail in EPA's Technical Support Documents pertaining to the CCDFGF and LHS. (See Appendix A of the Technical Support Document for Section 194.23; EPA, 1997b).

EPA also conducted a different sort of analysis of whether 300 CCDFs would adequately represent the entire population of potential CCDFs. The Agency's analysis involved fitting statistical data on CCDF curves to distributions and interpreting the dictate of the rule directly. Section 194.34(d) focuses on the 99th percentile of the "true" population distribution of estimated CCDF probabilities at normalized releases of 1 and 10. To determine the population distribution, EPA attempted to fit the values of the 300 extant CCDF curves at a number of values of the normalized release R, using several standard distribution functions. The probabilities at normalized releases of 1 and 10 were almost all below the resolving capability of the CCDF model and computer codes, which deal with probabilities in increments of 10^{-4} and treat any probability smaller than 10^{-4} as a zero.

EPA nonetheless decided to proceed with this curve-fitting exercise at values of normalized release of 1 and less, where most data on DOE's CCDF curves exist. EPA selected the beta distribution as the most appropriate model for a random variable between 0 and 1 that represents a probability. The beta distribution could be fitted to the probability values for DOE's 300 CCDF curves at the six values of normalized release shown in Table 1 below. However, the fit at the normalized release of 1 was based on too small a number of non-vanishing CCDF curves and was rejected. Table 1 also presents EPA's estimated 99th percentile value of the population distribution, derived from the cumulative distribution function of the fitted beta distributions. The table also shows DOE's 99th percentile curve (as estimated by the third highest sample value out of 300), and also the maximum observed probability value for the full set of all 300 of DOE's CCDFs at these values of R. Since only two curves exceed 10^{-4} at R=1, it is clear that the 99th percentile DOE curve has a value less than that.

The set of 300 CCDFs itself directly provides two sample statistics, the sample 99th percentile value and the sample maximum. These statistics are available at all values of the cumulative normalized release up to about R=1, beyond which the CCDF value has dropped to near 10^{-4} for every curve but two. The DOE sample 99th percentile curve (indicated with a ▽) and DOE sample maximum curve (☐) are plotted on a log-log scale in Figure 2. The vertical scale is the logarithm of the cumulative probability (that is, the line marked "−3" refers to a probability of 10^{-3}), and the horizontal axis denotes the logarithm of the normalized release. (A logarithm of 0 denotes a normalized release of 1 EPA unit; a logarithm of 1 corresponds to a normalized release of 10, and so on.) The estimated values of the 99th percentile from the fitted beta models at values of normalized release (×) less than R = 1 are also plotted. The DOE sample 99th percentile curve closely follows the 99th percentile curve estimated from the beta-fitting, which, EPA believes, provides the best estimate of the true population's 99th percentile curve. The significance of this is that at a normalized release of 1, where the beta method has too small a data base to work well, the DOE 99th percentile curve should still be a good estimator for the population 99th percentile curve; and in fact it was significantly below the value of the maximum DOE CCDF curve at that point. That is, the sample maximum clearly exceeds the sample (and, presumably, the population) 99th percentile at all values of R up to R = 1. (Both curves, incidentally, are below the regulatory requirement of $0.1 = 10^{-1}$ cumulative probability at R = 1 by several orders of magnitude.) Although these results are applicable for values of R only up to about 1.0, the fact that in each case the maximum exceeds the 99th percentile by a wide margin provides compelling additional evidence, EPA believes, that the sample size is sufficient.

Table 1
EPA’s Estimated 99th Percentile Value of the Population Distribution

Normalized Release	99th percentile		DOE Sample Maximum
	DOE	Beta	
0.05	0.9074	0.8855	0.9362
0.07	0.818	0.8011	0.8663
0.1	0.533	0.546	0.6102
0.2	0.0569	0.0463	0.0779
0.5	0.0002	0.0002	0.0005
1.0	<0.0001	N/A[4]	0.0002

Comparison of the values of the 99th percentile CCDF curves obtained directly from DOE data, and from fitting to beta distributions at six different values of normalized release, and the maximum curve from the DOE data there. Normalized releases are in EPA units, and probability values are dimensionless.

EPA concluded that there is sufficient technical support to accept DOE’s assertion that with 300 CCDF curves, it is at least 95 percent probable that DOE’s maximum CCDF curve exceeds the population 99th percentile curve.

DOE applied the same methodology to the PAVT, and produced 300 CCDF curves there as well. EPA therefore concludes that there were enough CCDF curves generated in the PAVT to show that the maximum CCDF generated exceeded the 99th percentile with a 0.95 probability; thus, the PAVT also meets the technical criterion at Section 194.34(d).

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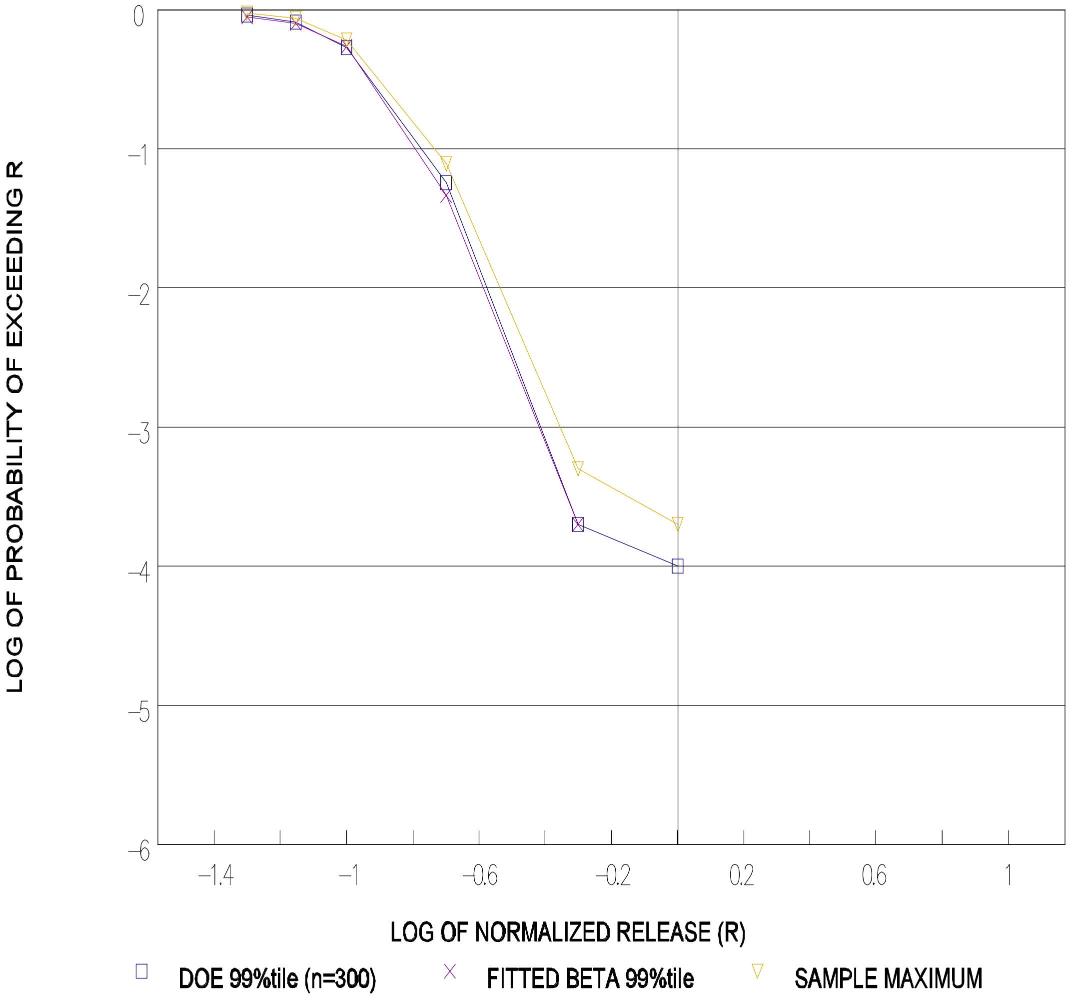
[4] This does not apply for the 99th percentile of the beta-distribution because there are insufficient values to treat statistically at a normalized release of 1.



LOG OF PROBABILITY OF EXCEEDING R
0
−1
−2
−3
−4
−5
−6
−1.4
−1
−0.6
−0.2
0.2
0.6
1
LOG OF NORMALIZED RELEASE (R)
□ DOE 99%tile (n=300)
× FITTED BETA 99%tile
▽ SAMPLE MAXIMUM

Figure 2

34.E.1 REQUIREMENT

(e) "Any compliance application shall display the full range of CCDFs generated."

34.E.2 ABSTRACT

Section 194.34(e) requires that DOE display all of the CCDFs generated in the PA. All of DOE's 300 CCDF curves are shown in Chapter 6 of the CCA; therefore, DOE concluded that the requirement of Section 194.34(e) was met. EPA concurred with this conclusion.

34.E.3 COMPLIANCE REVIEW CRITERIA

EPA expected DOE to:

♦ Display the full range of CCDFs generated;

♦ Present the appropriate information so that EPA may confirm DOE's PA analysis, including steps used to arrive at the result and data values that are represented by the CCDFs; and

♦ Include descriptive statistics such as the range, mean, median, etc., for the estimated CCDFs at cumulative releases of 1 and 10 (CAG, p. 52).

34.E.4 DOE METHODOLOGY AND CONCLUSIONS

DOE presented information pertinent to Section 194.34(e) in Chapter 6.5 (p. 6-214 to 6-234) and Appendices CCDFGF and SA. DOE employed LHS to create three independent replicates of 100 realizations each, yielding 300 CCDF curves. The range of normalized release values indicated on the horizontal axis extends from below one in a million (10^{-6}) to values above 1 (10^{0}) and 10 (10^{1}). (The latter normalized release values are the regulatory values specified in Section 191.13.) The CCDF probability values on the vertical axis range from 10^{-4} up to the highest possible probability value, namely 1 (see Figure 6-39, p. 6-225). DOE used log-log display because the values on each axis span ranges that cover many orders of magnitude.

Summary CCDF curves also indicate the range of CCDF curves. A mean CCDF curve, 95th-percentile confidence bound curves for the mean, a 10th percentile curve, a median curve, and a 90th percentile curve were generated for each replicate.

DOE concluded that it displayed the full range of CCDFs generated, including confirmatory information and descriptive statistics, and a full range of normalized release and probability values for those CCDF curves.

34.E.5 EPA COMPLIANCE REVIEW

The CCDFGF code is designed to produce estimates of the probability of exceeding various values of the cumulative normalized release. When the model is run using 10,000 futures, the lowest non-zero probability value the model can estimate is 10^{-4}. Hence, the CCDFGF code cannot estimate probabilities smaller than 10^{-4}, and it reports zero values of probability below this lower limit of resolution. EPA noted that calculations performed on these zero values may lead to spurious results when determining the mean CCDF and its associated confidence intervals.

Nonetheless, CCDF curves are by definition single-valued and non-increasing. Since all 300 curves fell significantly below a probability level of 0.001 well before approaching the regulatory exclusion region, EPA concluded that none of them could possibly come near, much less enter, the region of exclusion. EPA, therefore, determined that the CCA displays the full range of CCDF curves over the full range of CCDF values and normalized releases relevant to the determination of its compliance with Section 194.34(e). EPA also concluded that DOE applied the same methodology to the PAVT for displaying the full range of CCDF curves over the full range of probabilities and normalized releases.

34.F.1 REQUIREMENT

(f) "Any compliance application shall provide information which demonstrates that there is at least a 95 percent level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of 40 CFR 191.13."

34.F.2 ABSTRACT

DOE must show, in effect, that the mean of its 300 CCDF curves, and the 95th percentile upper confidence limit on the mean, both lie below a CCDF value of 0.1 at R=1, and below 0.001 at R=10. DOE presented the steps used in its PA to generate its 300 CCDF curves in Chapter 6.5 (p. 6-214 to 6-234). DOE identified the mean of the population of CCDFs and showed that it easily satisfies the containment requirements with the required level of confidence. DOE therefore concluded that the requirement of Section 194.34(f) was satisfied. EPA concurred with this conclusion.

34.F.3 COMPLIANCE REVIEW CRITERIA

EPA expected DOE to:

- ♦ Present the appropriate information, including steps used to arrive at the result and the data used in the analysis, so that EPA can confirm that the mean of the population of CCDFs meets the containment requirements of Section 191.13 with a 95 percent level of statistical confidence;
- ♦ Identify the mean of the sample of CCDFs generated for the cumulative releases at 1 and 10 as specified in Section 191.13; and

- Identify the values of the CCDFs associated with a 95 percent level of statistical confidence of the mean of the population for the cumulative releases at 1 and 10 as specified in Section 191.13 (CAG, p. 52).

34.F.4 DOE METHODOLOGY AND CONCLUSIONS

The requirements of Section 194.34(f) are phrased in terms of the mean CCDF curve and its associated 95 percent confidence upper bound at value of R=1 and R=10. DOE must show, in effect, that the mean of its 300 CCDF curves, and the 95th percentile upper confidence limit (UCL) on the mean, both lie below a CCDF value of 0.1 at R=1, and below 0.001 at R=10.

The frequency distribution of estimated probability values obtained from the 300 CCDF curves at the value R=10 contains only zeros. This indicates that all 300 curves are at or below the lower limit of resolution and, in any case, far below the limit specified in Section 194.34(f). At R=1, only two CCDF curves exceed the lower limit of resolution.

DOE presented graphs of the summary curves for the mean CCDF for each of the three replicates and the overall mean CCDF in Figure 6-38 of the CCA (p. 6-223). At R=1 and R=10, the mean CCDF curve is at or below the lower limit of resolution of 10^{-4}. DOE concluded that the mean CCDF and its associated upper 95 percent confidence limit are both below the lower limit of resolution of the model. This figure also shows that the mean CCDF curves for each replicate and the overall mean CCDF are outside EPA's exclusion area, defined in the standard, by several orders of magnitude.

An estimate of the variability of the mean is necessary to develop an upper confidence limit (UCL) for the estimated mean CCDF, as required in Section 194.34(f). DOE used the three mean CCDF values from the three replicates as the data for this calculation. (For a description of the method used to derive the mean curves, refer to Overview of Construction of WIPP CCDF Curves in "DOE Methodology and Conclusions" for Section 194.34(a) above.) DOE defined a 95 percent Upper Confidence Limit (UCL) on the mean as:

$$UCL_R(0.95) \quad = \quad X_R \; + \; k_{0.95} \times SE(X_R)$$

In this equation, X_R is the average of the three estimated mean CCDF values for a cumulative normalized release of R. $SE(X_R)$ represents the standard error of the estimated mean. (For the sample of three mean values, one divides their average, X_R, by the square root the number of degrees of freedom, which is two -- one less than the sample size.) The constant $k_{0.95}$ is defined as the 95th percentile value for a t-distribution for two degrees of freedom.

The overall mean, its 95 percent upper confidence limit (UCL), and 95 percent lower confidence limit also were shown in Chapter 6, Figure 6-39 (p. 6-225). DOE asserted that the 95 percent UCL for the mean is in compliance with the regulatory requirements by several orders of magnitude.

34.F.5 EPA COMPLIANCE REVIEW

The disposal regulations require that the probability of exceeding a cumulative normalized release of 1 is to be less than 10^{-1}, and the probability of exceeding a release of 10 is to be less than 10^{-3}. In addition, Section 194.34 of the Compliance Criteria requires that the 95 percent upper confidence limit for the mean be in compliance. EPA interpreted these sections to mean that a one-sided statistical test conducted at the 95 percent level of statistical confidence is appropriate at each of the two values of cumulative normalized release specified in Section 191.13. EPA found DOE's point-wise calculation of the mean CCDF curve to be appropriate and correctly executed, and similarly that the 95 percent upper confidence limit on the mean, as described by $UCL_R(0.95)$ above, was derived appropriately.

Use of the CCDFGF/CCDFSUM models with 10,000 futures yields CCDFs with 100 percent of the curves lying orders of magnitude below the 10^{-4} probability limit of resolution at R=10, and approximately 99 percent of the CCDFs below the limit of resolution at R=1. As a result, the estimated mean CCDF is also below the limit of resolution at R=1 and R=10. Based on these low values, EPA concluded that DOE demonstrated that there is a significantly greater than 95 percent level of statistical confidence that the mean of the CCDFs meets the containment requirements.

DOE applied the same methodology to the PAVT. The PAVT results yielded CCDFs with 100 percent of the curves lying below the limit of resolution at R=10, and over 90 percent of the CCDFs below the limit of resolution at R=1. The estimated mean CCDF for the PAVT is also below the limit of resolution at R=1 and R=10. The PAVT results also demonstrated that the level of statistical confidence is significantly greater than 95 percent that the mean of the CCDFs meets the Section 191.13 containment requirements. Therefore, EPA concluded that the final result of the PAVT is also in compliance with the containment requirements of Section 191.13 and that the results are presented in accordance with Section 194.34(f). (See July 25, 1997 Summary of EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations, Docket A-93-02, Item II-G-26; August 8, 1997 Supplemental Summary of EPA-Mandated Performance Assessment Verification Test (All Replicates) and Comparison with the Compliance Certification Application Calculations, Docket A-93-02, Item II-G-28; and Technical Support Document: Overview of Major Performance Assessment Issues, EPA, 1997c).

It should be noted that DOE's value of 3.44 for the waste unit factor presented in the CCA was erroneous. EPA determined that the correct value is 3.59, which is about 5 percent greater. EPA found that the error was of little consequence, however, and that it actually drives the values of normalized release downward. That is, a 5 percent increase in the estimate of the inventory of TRU radionuclides in the repository will bring about a roughly 5 percent decrease in calculated normalized releases. In effect, it shifts all CCDF curves slightly to the left. Thus, the correction of the error shows that the WIPP is marginally more capable of preventing releases than had been thought previously. EPA therefore accepts the correction, and requires no further action regarding it. This issue is discussed in detail in **CARD 31 -- Application of Release Limits**.

34.F.6 REFERENCES

DOE, 1997a. Summary of EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations. July 25, 1997. [Docket A-93-02, Item II-G-26]

DOE, 1997b. Supplemental Summary of EPA-Mandated Performance Assessment Verification Test (All Replicates) and Comparison with the Compliance Certification Application Calculations - WPO#46702. August 8, 1997. [Docket A-93-02, Item II-G-28]

EPA, 1997a. U.S. Environmental Protection Agency. Technical Support Document for Section 194.23: Parameter Report. 1997. [Docket A-93-02, Item III-B-12]

EPA, 1997b. U.S. Environmental Protection Agency. Technical Support Document for Section 194.23: Models and Computer Codes. 1997. [Docket A-93-02, Item III-B-6]

EPA, 1997c. U.S. Environmental Protection Agency. Technical Support Document: Overview of Major Performance Assessment Issues. 1997. [Docket A-93-02, Item III-B-5]

EPA, 1997d. U.S. Environmental Protection Agency. Technical Support Document for Section 194.34: Use of CCDF Formalism in the WIPP PA, An EPA Background Document. 1997. [Docket A-93-02, Item III-B-23]

Helton, 1996. “Probability, Conditional Probability, and Complementary Cumulative Distribution Functions in Performance Assessment for Radioactive Waste Disposal.” Sandia National Laboratories. SAND95-2571. 1996.

Iman and Shortencarier, 1984. A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use With Computer Models. SAND83-2365. Sandia National Laboratories, Albuquerque NM. 1994. [Docket A-93-02, Item II-G-01, CCA Reference 327]

McKay, M.C., Beckman, R.J. and Conover, W.J., 1979. “A Comparison of Three Methods for Selecting Values of Input Variable in the Analysis of Output from a Computer Code.”*Technometrics*, Vol. 21, p. 239 to 244. May 1979.

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Results of Performance Assessment -- Section 194.34

Issue A: Sandia's analysis shows the WIPP to be safe.

1. In summary, Sandia believes that the WIPP is a safe facility for the permanent disposal of transuranic waste. As well, our analyses indicate the overall estimates and performance are well within the quantitative limits set by the EPA and that the potential for human exposure to radioactivity is extremely small. Sandia believes that the system is well understood and that our modeled estimates of future performance should be trusted. Sandia believes that we, through the EPA's regulatory framework, have considered scenarios that span the range of reasonable future events that could affect the future. (136) (C-15)

2. Sandia's analyses indicate that the potential for significant human exposure to radioactivity at the waste site is extremely small and that the overall estimates to performance are well within quantitative limits set by the EPA. (213) (A-47)

Response to Issue A:

EPA concurs that DOE's PA indicated that calculated releases comply with EPA release limits. The WIPP LWA, however, mandates that EPA conduct an independent evaluation of whether DOE has demonstrated that the WIPP will comply with the radioactive waste disposal regulations at 40 CFR Part 191. Therefore, it would be inappropriate for EPA to rely on DOE's modeled estimates of future performance, and not perform an independent analysis . In its evaluation of DOE's PA, EPA identified several critical input parameters that were not supported by the available information. EPA identified what it believes to be more appropriate parameter values, and it required DOE to demonstrate that the combined effect of changing the input parameter values and making necessary corrections to DOE's computer codes did not adversely alter the results of the PA (i.e., did not move the mean CCDF curve into the area excluded by the containment requirements of Section 191.13). The PA verification test demonstrated that incorporating EPA's parameter values in the models and correcting computer codes did not cause the predicted releases to exceed EPA's limits. Refer to Section 194.34 above for further discussion of EPA's analysis.

Issue B: Predicted releases to the accessible environment are cause for concern.

1. The fact that the application states that under some of the CCDFs there would be releases into the accessible environment is of substantial concern, given the flaws in the application. (411) (II-H-02.42)

Response to Issue B:

EPA's containment requirements limit the likelihood of releases at specific levels, but do not require DOE to demonstrate that no releases of any magnitude will occur. The CCDFs presented in Chapter 6, Figures 6-35 to 6-37, show no CCDFs above the EPA containment requirement. Although individual releases calculations indicate that a few realizations (e.g. 9 out of 300 realizations in the undisturbed scenario) resulted in actinide release, the released quantity is exceptionally low and the cumulative release is still well within the EPA limits. EPA recognized that some parameters used in PA were questionable, and required DOE to perform a performance assessment verification that included revised parameter values. See Response to Issue A, above. Results of this analysis indicate that all CCDF curves are still well below the EPA release limits. EPA therefore concludes that while individual possible releases may be calculated to be finite, the probabilities of such releases (represented by all CCDFs presented in the PA and PAVT) are still well below EPA release limits.