GUIDANCE FOR DISPLAYING INFORMATION NECESSARY FOR DEMONSTRATING COMPLIANCE WITH THE POSTCLOSURE PUBLIC HEALTH AND ENVIRONMENTAL STANDARDS—LETTER REPORT

Prepared for

U.S. Nuclear Regulatory Commission
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ABSTRACT

Prelicensing interactions between the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) on the performance assessment of a potential repository after permanent closure have been conducted for the four main subissues identified in NRC (2002, Section 4.2.1). This report focuses on the fourth subissue, Demonstration of Compliance with the Postclosure Public Health and Environmental Standards (NRC, 2002, Section 4.2.1.4). Evaluation of compliance is not part of the prelicensing interactions between DOE and NRC. To date, prelicensing interactions between DOE and NRC about the fourth subissue have been limited to discussions about the DOE methodology, and less attention has been given to the presentation of results. The report discusses ways for presenting results in graphs and tables, which would make a detailed review of the demonstration of compliance with the postclosure public health and environmental standards easier.

The objective of this report is to provide guidance on the presentation of results only. Such guidance neither replaces nor augments the requirements of the regulation at 10 CFR Part 63 (NRC, 2001). Within the subissue on Demonstration of Compliance with the Postclosure Public Health and Environmental Standards, NRC (2002, Section 4.2.1.4) identified numerous items that are not within the scope of this report (e.g., information for which graphical display is not clearly beneficial). Graphical and tabular examples are presented in this report for illustration purposes only. This report makes no conclusions about what would be sufficient for satisfying the regulatory requirements and makes no determinations about regulatory compliance.

References:

NRC. NUREG–1804. “Yucca Mountain Review Plan. Draft Report for Comment.” Rev. 2. Washington, DC: NRC. March 2002.

———. “Disposal of High-Level Radioactive Wastes in a Proposed Geological Repository at Yucca Mountain, Nevada.” Final Rule. 10 CFR Part 63. *Federal Register*. Vol. 66. No. 213. pp. 55732–55815. Washington, DC: U.S. Government Printing Office. November 2, 2001.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under Contract No. NRC–02–02–012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Waste Management. The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

The authors wish to thank S. Mohanty for his technical review and B. Sagar for his programmatic review. Thanks are also expressed to A. Woods and C. Cudd for their editorial reviews and to R. Mantooth for secretarial support.

QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: This report does not present new data.

ANALYSES AND CODES: This report presents example illustrations. The example illustrations do not show actual code results. Some example illustrations were derived from previous CNWRA analyses. Where appropriate, references are made to the original CNWRA analyses conducted under the quality assurance program.

1 INTRODUCTION

Prelicensing interactions between the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) about the performance assessment of a potential repository after permanent closure have been conducted for the four main subissues identified in NRC (2002a, Section 4.2.1): (i) system description and demonstration of multiple barriers, (ii) scenario analysis and event probability, (iii) model abstraction, and (iv) demonstration of compliance with the postclosure public health and environmental standards. The status of prelicensing interactions between DOE and NRC has been documented (NRC, 2002b). This report focuses on the fourth subissue, Demonstration of Compliance with the Postclosure Public Health and Environmental Standards (NRC, 2002a, Section 4.2.1.4). Evaluation of compliance is not part of the prelicensing interactions between DOE and NRC. The prelicensing interactions between DOE and NRC about the fourth subissue have been limited to discussions about the DOE methodology[1], and less attention has been given to the presentation of results—especially graphical display. In general, documentation of the methodology and technical bases for calculations and assumptions should be transparent and traceable so a competent analyst could reproduce and verify the calculations. In this report suitable methods for displaying information in graphs and tables are presented. Use of such displays will make the Demonstration of Compliance with the Postclosure Public Health and Environmental Standards easier.

It is expected that if the recommendations are followed, the likelihood of requests for additional information about this subissue would be reduced. This report includes some acceptable approaches for the graphical display of a performance assessment. The recommendations presented in this report neither replace nor augment the requirements of the regulation in 10 CFR Part 63 (NRC, 2001). Even within the subissue, Demonstration of Compliance with the Postclosure Public Health and Environmental Standards, NRC (2002a, Section 4.2.1.4) identifies numerous items that are not within the scope of this report (e.g., information for which graphical display is not clearly beneficial). Graphical and tabular examples presented in this report are for illustration purposes only. This report makes no conclusions about what would be sufficient for satisfying the regulatory requirements and makes no determinations about regulatory compliance.

It is important that all results be presented in a clear and understandable fashion to reduce the likelihood of misunderstandings and avoid an inefficient review. Complex ideas should be communicated with clarity, precision, and efficiency. The basic premise, as described by Tufte (2001), is to provide "the greatest number of ideas in the shortest time with the least ink in the smallest space." Following this premise would allow the NRC review to focus on substance rather than on interpreting graphic design. Each display of results should have a purpose and it should be clearly and intuitively evident what that purpose is. It has been noted that "assessments of change, dynamics, and cause and effect are at the heart of thinking and explanation. To understand is to know *what cause provokes what effect, by what means, at what rate*. How then is such knowledge to be represented?" (Tufte, 1997). The following

[1]Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6–10, 2001)." Letter (August 23) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

guiding principles from Tufte (2001) for producing quality graphic designs, if adopted by the DOE where practicable, would benefit the NRC for reviewing a potential license application and its supporting documents.

- Reveal the data at several levels of detail, from a broad overview to the fine structure, using multiple displays, if necessary.

- Integrate graphical displays with their associated statistical and verbal descriptions.

- Improve graphics by showing the data, maximizing the data-ink ratio, and revising and editing.

- Eliminate moiré vibration through use of shaded fill in charts rather than cross-hatch and other design fills; eliminate or mute grid lines; and eliminate clutter that is not related to the data such as graphics, pictures, colors, and three-dimensional effects.

- When possible, avoid the use of abbreviations, obscure coding, and legends because going back and forth between legend and graphic is inefficient; preferably, place labels on the graphic itself.

- Be sensitive to color-deficient and color-blind readers. Red, green, and brown should be avoided for essential contrasts. Blue is a suitable contrast for most color-deficient people.

- Interpretation of data should be clear, this can be accomplished by adding brief messages to explain data; avoid the use of all capitals; text should read from left to right.

The guiding principles have not been universally applied to all of the example figures in this report. This report followed the guiding principles to the extent that they were clearly beneficial. Because legends are common to engineering and scientific figures, it is not necessary to replace all legends with descriptions near their corresponding curves (especially when little space is available between curves).

The main body of this report, Section 2, is structured to be parallel in format with the acceptance criteria from Section 4.2.1.4, Demonstration of Compliance with the Postclosure Public Health and Environmental Standards, of NRC (2002a).

2 DISPLAY OF INFORMATION FOR DEMONSTRATING COMPLIANCE WITH THE POSTCLOSURE PUBLIC HEALTH AND ENVIRONMENTAL STANDARDS

According to the three types of postclosure standards specified in Subpart L of 10 CFR Part 63 (NRC, 2001) and Section 4.2.1.4 of NRC (2002a), this section is divided into three parts:

- Demonstration of Compliance with the Postclosure Individual Protection Standard
- Demonstration of Compliance with the Human Intrusion Standard
- Analysis of Repository Performance that Demonstrates Compliance with the Separate Groundwater Protection Standards

Recommendations are made for the presentation and display of information as graphs or tables for each of the three types of postclosure standards.

2.1 Demonstration of Compliance with the Postclosure Individual Protection Standard

NRC (2002a, Section 4.2.1.4.1.3) organizes a review of a potential license application according to three acceptance criteria for the postclosure individual protection standard:

Acceptance Criterion 1 Scenarios Used in the Calculation of the Annual Dose as a Function of Time Are Adequate.

Acceptance Criterion 2 An Adequate Demonstration is Provided That the Annual Dose to the Reasonably Maximally Exposed Individual in Any Year During the Compliance Period Does Not Exceed the Exposure Standard.

Acceptance Criterion 3 The Total System Performance Assessment Code Provides a Credible Representation of Repository Performance.

This section of the report is divided into three subsections, which directly correspond to the three acceptance criteria for the postclosure individual protection standard: (1) Scenarios Used in the Calculation of the Annual Dose, (2) Demonstration of Compliance for the Annual Dose to the Reasonably Maximally Exposed Individual, and (3) Credible Representation of Repository Performance.

2.1.1 Scenarios Used in the Calculation of the Annual Dose

This subsection relates to Acceptance Criteria 1 for the Postclosure Individual Protection Standard (NRC, 2002a, Section 4.2.1.4.1.3).

As specified in Acceptance Criterion 1 of Section 4.2.1.4.1.3 of NRC (2002a), the contribution from each of the disruptive event scenarios must be appropriately summed for calculating the annual dose curve as a function of time. The effects on the contribution to the annual dose from each scenario class should be verified so the timing of the disruptive event is properly accounted for. The sum of the probabilities for all scenario classes, which could not be screened from the

total system performance assessment analyses, equals one. The annual probability of occurrence for the events is consistent with the results of the scenario analysis. The remainder of this subsection presents example plots generated from the TPA Version 4.1 code and have been presented in a recent sensitivity study (Mohanty, et al., 2002, Section 3.7). The figures, tables, and other key information are presented for illustration purposes only.

There are three scenarios in the TPA Version 4.1 code: (i) basecase with seismicity, (ii) faulting, and (iii) igneous activity. In general, seismicity is not required to be considered with the basecase scenario. These three scenarios are assumed to be exhaustive, and their probabilities sum to one. Figure 2-1 presents the annual dose curves from the three scenarios. Figure 2-1a depicts a minor change from the basecase conditioned by the occurrence of the faulting scenario. Presentation of the conditional expected dose is benefical for those scenarios that do not differ significantly from the basecase expected dose as a function of time (as was done in Figure 2-1a). Figure 2-1b depicts the contributions to the total annual dose curves from the basecase and igneous activity scenarios. From Figure 2-1, it is clear that the annual dose is dominated by the contribution from the igneous activity scenario. In addition to the contributions from the scenarios, the total annual dose curve should also be calculated from the sum of the probability-weighted scenario contributions and plotted separately.

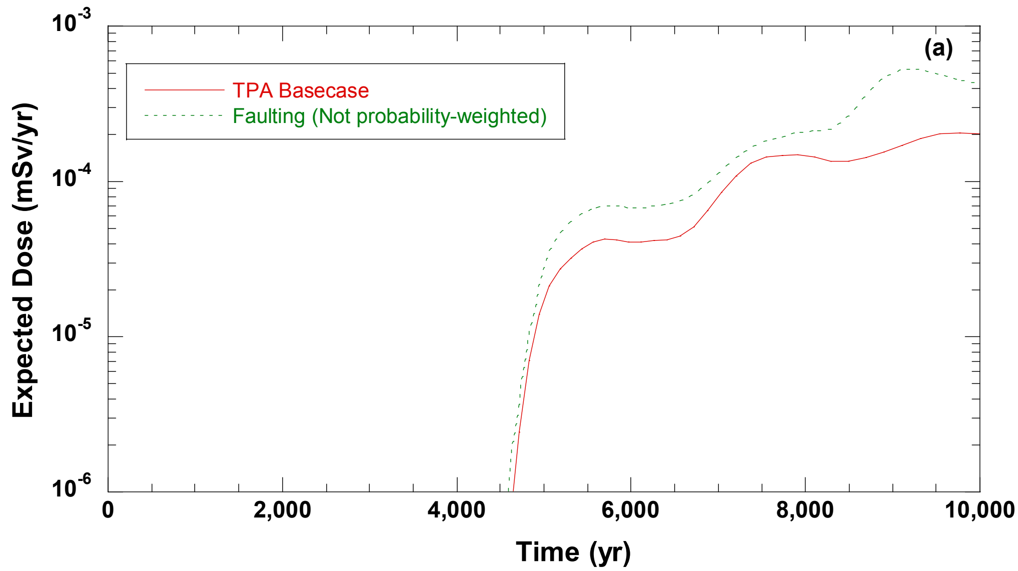
Details of the overall risk calculation from igneous activity, obtained by combining the conditional risks for several different times of the disruptive event, is documented in a previous sensitivity study using the TPA Version 4.1 code (Mohanty, et al., 2002, Section 3,7). For low probability events of short duration compared to the compliance period, the risk curve is determined from the convolution of the conditional mean dose curves for event times occurring before the year of interest. Figures should also be presented to display important method-specific intermediate results. Figures 2-2 and 2-3 are example presentations of method-specific intermediate results. Figure 2-2 shows conditional dose curves generated assuming the igneous events occur at different predetermined times using the TPA Version 4.1 code based on 400 realizations. Using an annual probability of occurrence of 10^{-7}, Figure 2-3 presents the resulting probability-weighted expected dose curve from igneous activity, which represents the contribution of an igneous activity disruptive scenario to the total annual dose curve.

2.1.2 Demonstration of Compliance for the Annual Dose to the Reasonably Maximally Exposed Individual

This subsection relates to Acceptance Criterion 2 for the Postclosure Individual Protection Standard (NRC, 2002a, Section 4.2.1.4.1.3).

2.1.2.1 Statistical Stability of Calculations

Dose to the receptor as a function of time is calculated for each realization of the performance assessment code. The expected dose is computed by averaging the doses at each time from all realizations. The peak expected dose within the compliance period of 10,000 years is identified as a performance objective in 10 CFR Part 63 (NRC, 2001). The peak expected dose is the maximum expected dose obtained from the expected dose versus time curve within the 10,000-year compliance period. Acceptance Criterion 2 of Section 4.2.1.4.1.3 of NRC (2002a)



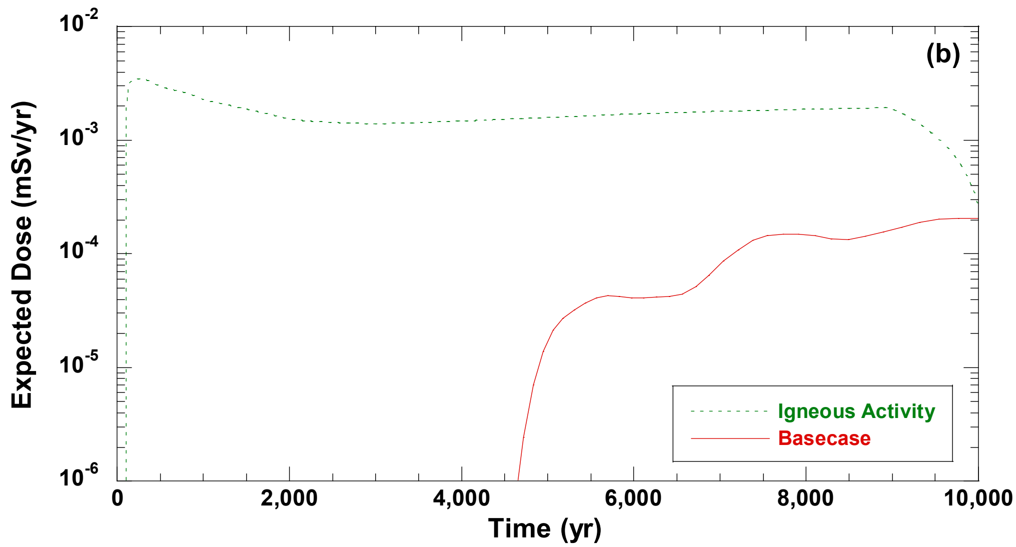


Figure 2-1. Example Annual Expected Dose Curves from the TPA Version 4.1 Code Showing the Basecase Scenario with the Disruptive Event Scenarios (a) Conditional Expected Dose from Faulting and (b) Probability-Weighted Expected Dose from Igneous Activity.

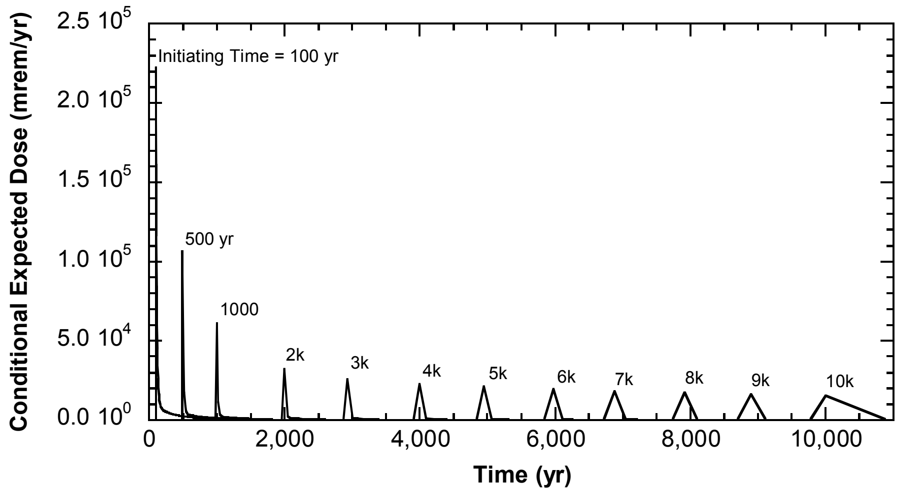


Figure 2-2. Expected Dose Assuming Extrusive Igneous Activity Occurs at Different Times

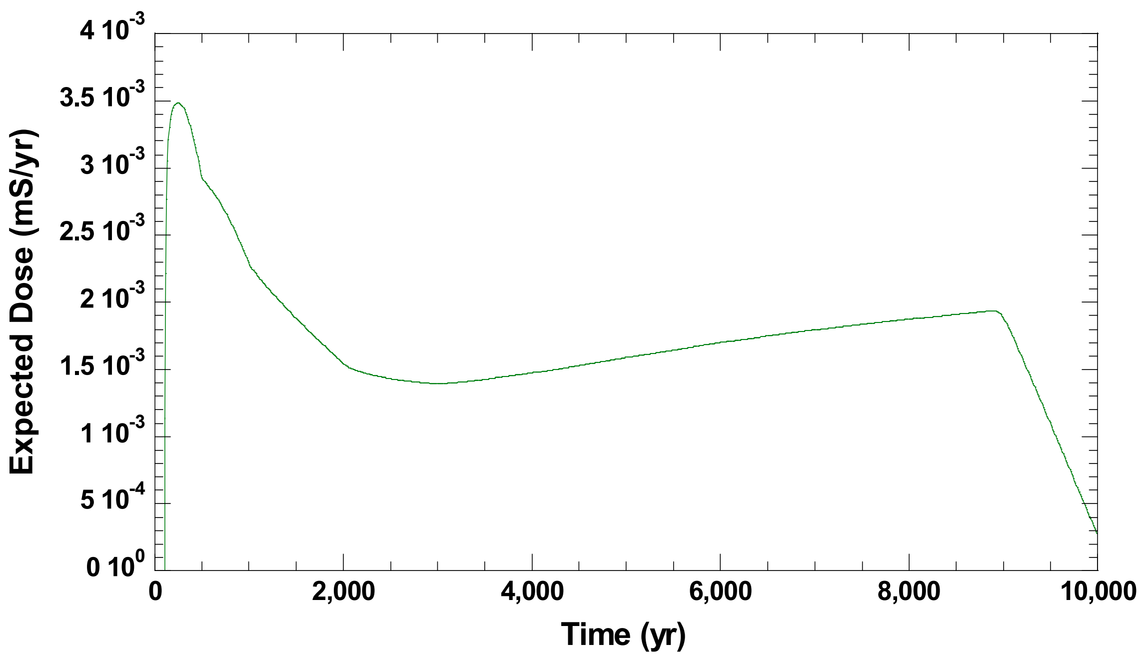


Figure 2-3. Probability-Weighted Expected Dose from Igneous Activity

states that the results of the total system performance assessment code must be statistically stable. The results for peak expected dose are considered stable at some number of realizations only when the change in calculated peak expected dose is acceptably small as a result of increases in the sample size (i.e., increases in the number of realizations).

Agreement TSPAI.4.03 states the U.S. Department of Energy (DOE) must document the method for demonstrating that the overall results of the total system performance assessment are stable[2]. As discussed previously in Section 2.1.1, the total annual dose curve consists of contributions from the basecase and disruptive event scenarios. Stability must, therefore, be demonstrated for the basecase and all disruptive event scenarios.

2.1.2.1.1 Stability of Basecase Scenario Calculation

An example for stability of the peak expected dose is taken from Appendix H of a previous sensitivity study (Mohanty, et al., 2002, Table H-1), where independent runs of the TPA Version 4.1 code were compared for different numbers of realizations. The results are displayed in Table 2-1. Table 2-1 shows that the peak expected dose has not converged after 4,000 realizations because fluctuations in the peak expected dose are within approximately 30 percent.

Selection of different random number seeds is also important when considering statistical stability. Figure 2-4 shows the hypothetical results for the basecase scenario with 400 realizations and displays an illustration of expected dose as a function of time for three different random seeds. From this example figure, it is quite clear that convergence has not been reached at 400 realizations, and a much larger sample size (i.e., number of realizations) is required to reach convergence. Similar figures were presented in Appendix H of a previous sensitivity study using the TPA Version 4.1 code (Mohanty et al., 2002, Figures H-1 and H-2) and showed large fluctuations because of the number of realizations and random seed selected. An actual demonstration of statistical convergence would require selecting more than three different random number seeds. A discussion of adequate sampling from the parameter distributions is presented in Subsection 2.1.3.1 of this report.

Table 2-1. Peak Expected Dose from the Basecase Scenario as a Function of the Number of Realizations Using the TPA Version 4.1 Code

Number of Realizations	Peak Expected Dose (mSv/Year)	Time of Peak Expected Dose (Year)
500	2.48×10^{-4}	10,000
1,000	3.05×10^{-4}	8,490
2,000	3.24×10^{-4}	10,000
3,000	2.46×10^{-4}	10,000
4,000	2.94×10^{-4}	10,000

[2]Reamer, C.W. “U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6–10, 2001).” Letter (August 23) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

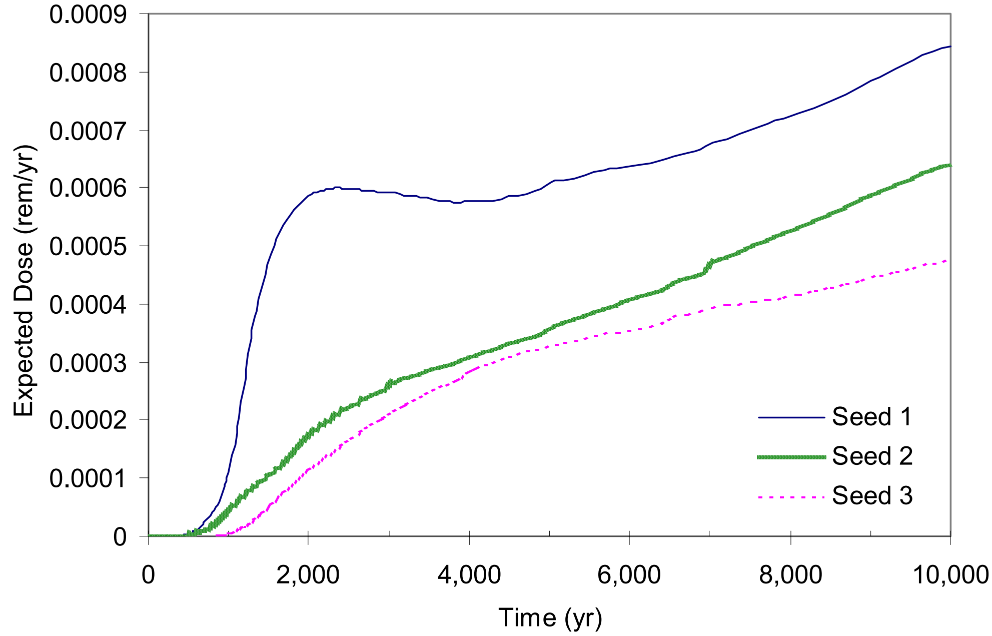


Figure 2-4. Illustration from the Nominal Scenario Showing Expected Dose as a Function of Time. (This Figure Does Not Show Actual Results from the TPA Version 4.1 Code But Shows Hypothetical Results for 400 Realizations that Differ by the Random number Seed.)

2.1.2.1.2 Stability of Disruptive Event Scenario Calculations

Similar to the basecase scenario, stability for disruptive scenario calculations should be demonstrated by considering different numbers of realizations (Table 2-1) and random seeds. Although stability must be demonstrated for all credible disruptive scenarios in the total system performance assessment, this subsection presents an example for the igneous activity scenario only.

As documented in a previous sensitivity study using the TPA Version 4.1 code (Mohanty, et al., 2002, Section 3.7),[3] the overall risk from igneous activity is calculated by combining the conditional risks for several different times of the disruptive event. Stability must be achieved in the probability-weighted peak expected dose from igneous activity. Hypothetical results for the igneous activity scenario are presented for different random seeds with 400 realizations, where the time of the igneous event is fixed at 500 years. For the method described above, actual demonstration of stability would require that stability is achieved in the results for each of event times used in the calculation of the overall risk from igneous activity (e.g., at 100 years, 500 years, 1,000 years, 2,000 years, and such).

Hypothetical results are shown in Figure 2-5 for the igneous activity scenario with different random seeds. Figure 2-5 displays an illustration of the expected dose as a function of time.

[3] Mohanty, S. and R.B. Codell. "Ramifications of Risk Measures in Implementing Quantitative Performance Assessment for the Proposed Radioactive Waste Repository at Yucca Mountain, Nevada, USA." Risk Analysis. To be Published. 2003.

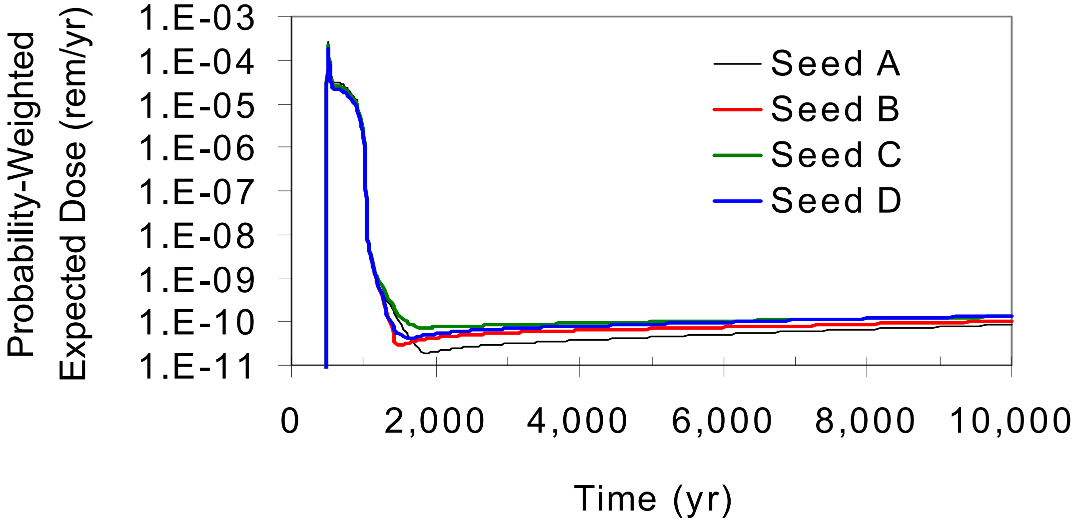


Figure 2-5. Illustration from the Igneous Disruptive Scenario for an Igneous Event Occurring at 500 Years Showing Probability-Weighted Expected Dose as a Function of Time. (This Figure Does Not Show Actual Results from the TPA Version 4.1 Code but Shows Hypothetical Results that Differ by the Random Number Seed.)

Because of the many orders of magnitude plotted in Figure 2-5, the differences in the probability-weighted peak expected dose are not clearly visible. Table 2-2 displays the probability-weighted peak expected dose for each of the random seeds. Table 2-2 clearly shows that convergence has not been reached at 400 realizations because of fluctuations in the probability-weighted peak expected dose of more than 30 percent. Similar to example results for the basecase scenario, a much larger sample size (i.e., number of realizations) is required to reach convergence for the igneous activity disruptive scenario. Actual demonstration of statistical convergence should involve selecting more than four different random number seeds.

Table 2-2. Hypothetical Probability-Weighted Peak Expected Doses from the Igneous Activity Disruptive Scenario for Different Random Seeds and 400 Realizations

Random Seed	Hypothetical Probability-Weighted Peak Expected Dose (mSv/year)
A	2.45×10^{-3}
B	1.99×10^{-3}
C	2.22×10^{-3}
D	1.79×10^{-3}

2.1.2.2 Submodel Stability

As stated in part of Agreement TSPAI.4.03, DOE will document that submodels (including submodels used to develop input parameters and transfer functions) are numerically stable[4]. Although a submodel quantity for which stability is being assessed differs from the total system quantity (e.g., radionuclide release rate from the waste package versus peak expected dose), the requested analyses and their graphical presentations from the Subsection 2.1.2.1 on Statistical Stability of Calculations, should also be applied to submodels. In particular, for submodels that involve stochastic sampling, the dependence of the submodel results on the sample size of stochastic inputs should be plotted. The degree of proof required for submodel stability can be commensurate on the effect the submodel result has on the results of the total system inclusive of uncertainty.

2.1.2.3 Discretization Stability

As stated in Agreement TSPAI.4.04, DOE will conduct the appropriate analyses and provide documentation that demonstrates the results of the performance assessment are stable with respect to discretization (e. g., spatial and temporal) of the Total System Performance Assessment model.[5] Clear presentations should be provided for the effects of spatial and temporal discretization on the performance assessment results (i.e., risk and its uncertainty) and on appropriate intermediate outputs. For example, graphics could show the effect of different grid sizes (used in the unsaturated zone modeling) on the water flux at some horizon in the unsaturated zone, on the radionuclide release rate from the waste package, and on the dose to the reasonably maximally exposed individual. Similarly, the effect of different time step sizes also could be presented for water seepage rate into the drifts, radionuclide release rate from the waste package, and dose to the reasonably maximally exposed individual.

The representation of heterogenieties should be discussed. The discussion should highlight differences among the scale of measured data, the size of grid spacings used in the simulations, and the scale of repository simulations and include estimates of effect of these differences on risk and its uncertainty.

2.1.2.4 Presentation of Uncertainty in the Annual Dose Curve

As suggested in Acceptance Criterion 2 of Section 4.2.1.4.1.3 of the NRC (2002a), the annual dose time curve should include 5^{th} and 95^{th} percentiles to represent the uncertainty in the dose calculations. The mean, 5^{th} percentile, and 95^{th} percentile of the total annual dose curve should be plotted as a function of time. The total annual dose curve refers to the summation of scenario contributions to annual dose (contributions of the three scenarios are shown in Figure 2-1). To better convey the propagation of uncertainty, the 5^{th} and 95^{th} percentiles for each of the

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[4]Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6–10, 2001)." Letter (August 23) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

[5]Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6–10, 2001)." Letter (August 23) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

contributions from the disruptive event scenarios to the basecase scenario should be plotted as a function of time for those disruptive event scenarios whose uncertainty contributes significantly to the uncertainty in the total annual dose. Other suggestions for the presentation of uncertainties have been made by reporting the chance of exceeding the dose limit.[6]

In line with a Nuclear Waste Technical Review Board priority,[7] a clear and systematic quantitative presentation of uncertainty and conversatism in the performance assessment is very important information for a regulator. The Board also recommended[8] that the DOE representation of performance uncertainty include: "...a description of critical assumptions, an explanation of why particular parameter ranges were chosen, a discussion of possible data limitations, an explanation of the basis and justification for using expert judgments (whether or not they are elicited formally), and an assessment of confidence in the coneptual models used."

2.1.2.5 Presentation of Results from Alternative Conceptual Models

As stated in Agreement TSPAI.4.01, DOE will document the methodology that will be used to incorporate alternative conceptual models into the performance assessment.[9] The documentation of the methodology's implementation must be sufficient to allow a clear understanding of the potential effect of the alternative conceptual models and their associated uncertainties on the performance assessment results. DOE should also ensure and sufficiently document that the representation of alternative conceptual models does not result in an underestimation of risk.

For example, the alternative conceptual models for the basecase scenario in the TPA Version 4.1 code are divided into three types: (i) fuel dissolution models, shown in Figure 2-6, (ii) fuel wetting assumptions, shown in Figure 2-7, and (iii) transport alternatives, shown in Figure 2-8. Figures 2-6, 2-7, and 2-8 show different performance assessment results for each alternative conceptual model selected but do not directly show the uncertainty contributions from the alternative conceptual models. To account for the contributions of alternative conceptual models to the uncertainty of the results, additional plots are recommended from full stochastic simulations that show the 5^{th} and 95th percentile doses for each alternative conceptual model.

Treatment of alternative conceptual models in Total System Performance Assessment–License Application has been discussed in a previous DOE report (Bechtel SAIC Company, LLC, 2002a). In addition to approaches that either involve full total system performance assessment simulations with each alternative conceptual model or use of the most conservative alternative

[6] Cohon, J.L. Comments on Performance Assessment (March 20, 2002). Letter to I. Itkin, DOE. Arlington, Virginia: Nuclear Waste Technical Review Board. 2000.

[7] Cohon, J.L. Board Comments on May 2002 Meeting (June 20, 2002). Letter to M.S.Y. Chu, DOE. Arlington, Virginia: Nuclear Waste Technical Review Board. 2002.

[8] Cohon, J.L. Comments on Performance Assessment (March 20, 2002). Letter to I. Itkin, DOE. Arlington, Virginia: Nuclear Waste Technical Review Board. 2000.

[9] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Departent of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6–10 August 23) to S. Brocoum, DOE. Washington, DC: MRC. 2001.

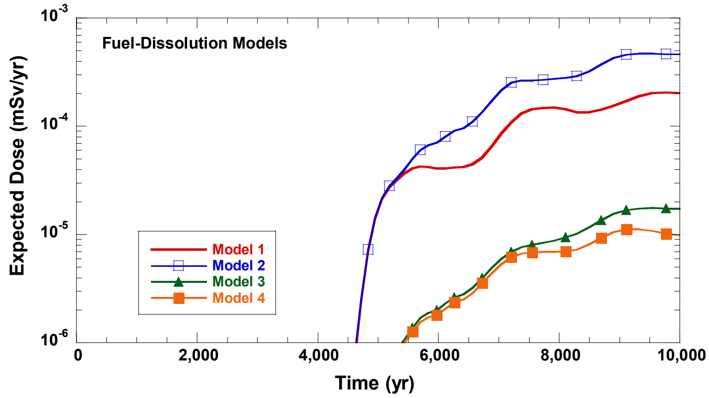


Figure 2-6. Illustration of Groundwater Dose from Different Fuel Dissolution Models

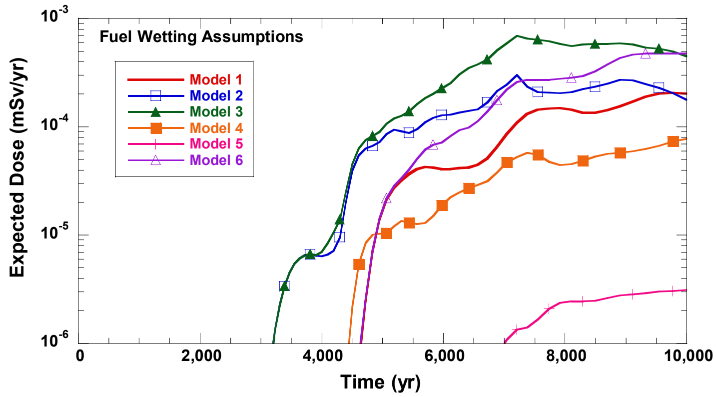


Figure 2-7. Illustration of Groundwater Dose from Different Fuel Wetting Models

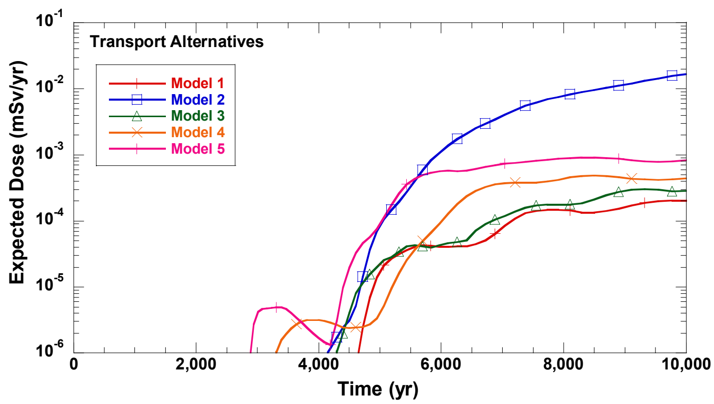


Figure 2-8. Illustration of Groundwater Dose from Different Transport Models

conceptual model with a supporting basis, DOE proposed weighting parameters may be assigned to multiple alternative conceptual models for their inclusion in the performance assessment. In accordance with NRC staff concerns, this report does not endorse the weighting of multiple alternative conceptual models. If DOE, however, assigns weights to alternative conceptual models, it is recommended that the contributions from each alternative conceptual model to the mean dose should be plotted as a function of time. The uncertainties propagated with each contribution also should be plotted as a function of time. For example, the weighted contributions from each alternative conceptual model could be plotted as three figures for the mean, 5^{th} percentile, and 95^{th} percentile dose curves.

2.1.2.6 Appropriate Use of Mean or Fixed Values

The maximum of the mean annual dose curve within the compliance period should be used to demonstrate compliance with the postclosure individual protection standard of 10 CFR 63.311 (NRC, 2001). The computation of the annual dose curve for demonstrating compliance with the individual protection standard must account for uncertainty and variability in the parameters used in the total system performance assessment. The full range of parameter values should be covered in the validation and verification of individual models used in the total system performance assessment code, so validation and verification based solely on the analysis of mean or median input parameters is insufficient in general.

In addition to the information that specifies the parameter distribution, mean values should be reported for all sampled parameters (see examples in Mohanty, et. al., 2002). As required by 10 CFR 63.114(b), a technical basis must be provided for parameter ranges, probability distributions, or bounding values used in the total system performance assessment (NRC, 2001). Rationale justifying the use of constants or fixed values should be given for all nonsampled parameters. The mean values of intermediate outputs (e.g., transport times through the geosphere) should also be presented with their ranges. Presenting a metric related to the second moment of the input and output distributions (e.g., standard deviation) would also be useful.

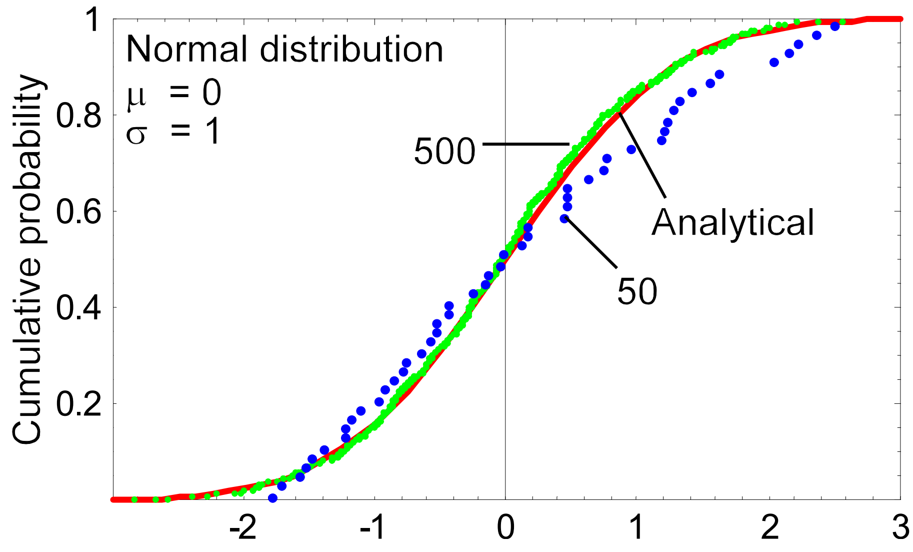
A single-realization case using the mean values for all parameter inputs can be used to more clearly show how trends in the intermediate results lead to the total system performance assessment results. Mean-value simulations were performed and analyzed in a previous sensitivity study using the TPA Version 4.1 code (Mohanty, et al., 2002).

2.1.3 Credible Representation of Repository Performance

This subsection relates to Acceptance Criterion 3 for the Postclosure Individual Protection Standard (NRC, 2002a, Section 4.2.1.4.1.3).

2.1.3.1 Sampling Across the Full Range of Parameter Uncertainty

Software verification and validation documents of the total system performance assessment model should include comparisons of analytical distributions to distributions generated with the Latin Hypercube Sampling methodology outlined in CRWMS M&O (1999) for sampling parameter uncertainty. Latin hypercube distributions should converge to the analytical distributions in the limit when a large number of samples is drawn. An example of how such a convergence trend could be displayed is shown in Figure 2-9. Convergence can also be demonstrated in a



(a)

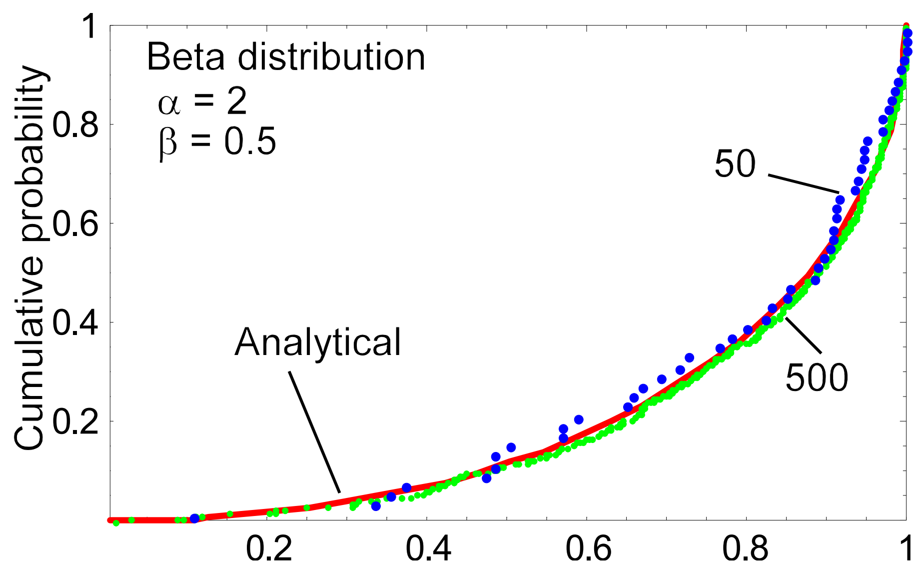


Figure 2-9. Comparison of Distributions of Populations (50 to 500 Elements) Drawn from the Latin Hypercube Sampling Methodology to Analytical Distribution Functions: (a) Normal Distribution with Mean Equal to 0 and Standard Deviation Equal to 1 and (b) Beta Distribution with Shape Parameters Equal to 2 and 0.5

(b)

quantitative manner using, for example, significance tests, such as the Kolmogorov-Smirnov test, or by computing the distance between the analytical and the sampled distribution. Convergence tests will provide confidence that the sampling code is properly implemented and that risk dilution is not likely to arise from incorrect sampling. Checks on the convergence of parameter sampling should be focused on influential parameters.

The DOE proposed a methodology to document parameter uncertainty in Section 3.5 of the Total System Performance Assessment-License Application Methods and Approach document (Bechtel SAIC Company, LLC, 2002b). According to this document, Parameter Entry Forms will provide the rationale for parameter ranges and distributions and will be attached to Analysis and Model Reports. In addition, the Total System Performance Assessment-License Application Model Document will identify model input data, parameters, and references to documents detailing parameter uncertainty (Bechtel SAIC Company, LLC, 2002b). When parameter distributions are based on data, it is highly recommended that all data be plotted with the distribution so the appropriateness of the distribution for representing the data can be easily evaluated.

It is anticipated that NRC staff will review the GoldSim implementation of the Total System Performance Assessment–License Application model. The GoldSim implementation facilitates tracing the flow of model computations. To enhance traceability, however, it is highly recommended to include references into the GoldSim implementation next to fields defining parameter ranges. Currently, it is contemplated that such references will be listed only in the Total System Performance Assessment–License Application Model Document (Bechtel SAIC Company, LLC, 2002b). Adding references also into the GoldSim implementation would streamline the review process. Besides being able to readily locate documents with rationale for parameter ranges, reviewers will simultaneously verify the consistency among License Application documentation and data used in the total system performance assessment analyses.

The Total System Performance Assessment-License Application Model Document should include sufficient descriptions of model parameters. For example, in the GoldSim implementation of the Total System Performance Assessment–Site Recommendation and in the CRWMS M&O, (2000b) there exist input parameters without text labels or sufficient description (e.g., WAPDEG_Inputs) for an independent reviewer to evaluate the adequacy of the information.

In summary, software verification and validation documentation should compare distributions of populations drawn with the Latin hypercube sampling methodology to analytical distributions to ensure the sampling code is properly implemented. Parameter Entry Forms attached to Analysis and Model Reports, references in the Total System Performance Assessment–License Application Model Document, and recommended embedded references in the GoldSim implementation of the total system performance assessment model should allow for a detailed evaluation of whether parameters have been sampled across their ranges of uncertainty.

2.1.3.2 Display of Repository Performance

To gain understanding of dose estimates, NRC staff will review the intermediate outputs. Some examples of intermediate outputs of interest include the amount of water available for radionuclide release, the fraction of waste package and drip shield surfaces breached by multiple mechanisms, the radionuclide release rates at reference model interfaces (engineered barrier subsystem, unsaturated zone, and saturated zone), radionuclide breakthrough curves, dose

conversion factors, and such. Enough information should be available to understand the repository system abstraction and modeled performance.

Without being comprehensive, Figures 2-10, 2-11, 2-12, 2-13, and 2-14 show examples of diagrams displaying the modeled repository performance. Figure 2-10 displays the flux of water available for radionuclide release. Figure 2-11 shows the average fraction of breached waste packages and drip shields versus time. Figure 2-12 summarizes radionuclide release rates away from the engineered barrier subsystem, the unsaturated zone, and the saturated zone. It is important to describe the role of and graphically display the radionuclides with dominating contributions to the dose as well as those uninfluential radionuclides in release rate versus time curves to appreciate the retardation effect of the saturated and unsaturated zones. Figure 2-13 shows mean-dose-versus-time curves. In this example, the dose is dominated by Np-237, Tc-99, and I-129. Although Tc-99 displays the highest release rates from the unsaturated zone into the biosphere, the dose associated with Np-237 is higher. Figure 2-14 is a box and whiskers representation of biosphere dose conversion factors for the crop ingestion pathway during the pluvial period. Note the approximately four orders of magnitude difference between Tc-99 and Np-237 dose conversion factors and that other radionuclides have equally large or larger dose conversion factors than Np-237. Similar representations to Figure 2-14 could be used for the other dose pathways. The pathway contributing the most to the dose should be identified. One objective of the proposed graphical representation of dose conversion factors is the visual depiction of the effect of the biosphere abstraction on dose estimates.

2.1.3.3 Links Between Results and Values of Input Parameters and Intermediate Outputs

It is very important that clear distinctions be made between inputs and outputs (e.g., one model's output may be another model's input). To enhance the understanding of the total system behavior, it is recommended that the sampled values from selected parameter inputs and intermediate outputs be presented with the results from individual realizations or groups of realizations. The analysis can be conducted separately for different simulation times (e.g., 10,000 years and 100,000 years). In this proposed analysis, statistics are gathered from full stochastic simulations of the computed values for the intermediate outputs and used to generate cumulative distribution functions for intermediate output. Ultimately, the percentiles of selected input parameters and intermediate outputs are compared to the results from an individual realization or a group of realizations. In these examples, results are the realization peak dose, time of peak realization dose, and the contribution to the peak mean dose. Example intermediate outputs are drip shield failure time, waste package failure time, and the total releases from the engineered barrier subsystem, unsaturated zone, and saturated zone (total release refers to the released activity integrated over the simulation time, in percent of the entire repository inventory). Other intermediate outputs could also be investigated (e.g., submodel outputs). An example of this linkage of information is presented in Table 2-3 for individual realizations. Similarly, Table 2-4 presents an example for groups of realizations ranked by their contribution to the total peak mean

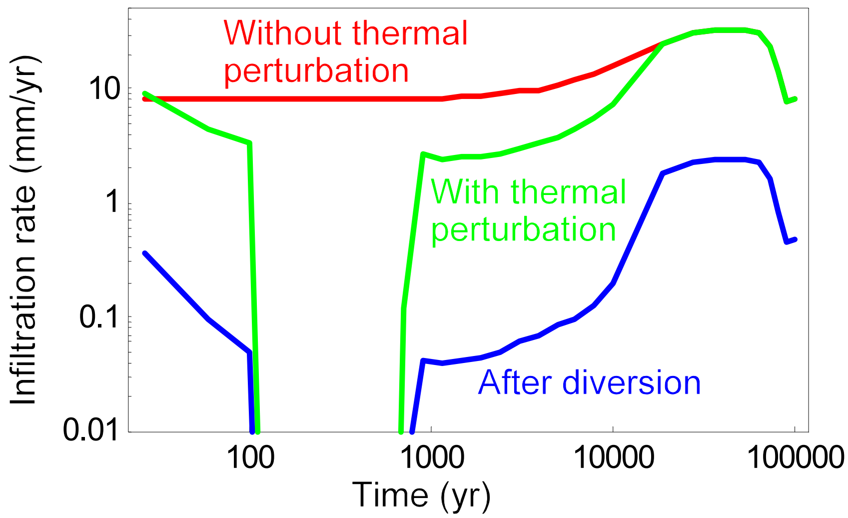


Figure 2-10. Illustration of Infiltration Rate, Flow into the Drift, and Amount of Water Hitting the Drip Shield (Or the Waste Package after Failure of the Drip Shield) (Example Does Not Represent Performance of the Proposed Repository.)

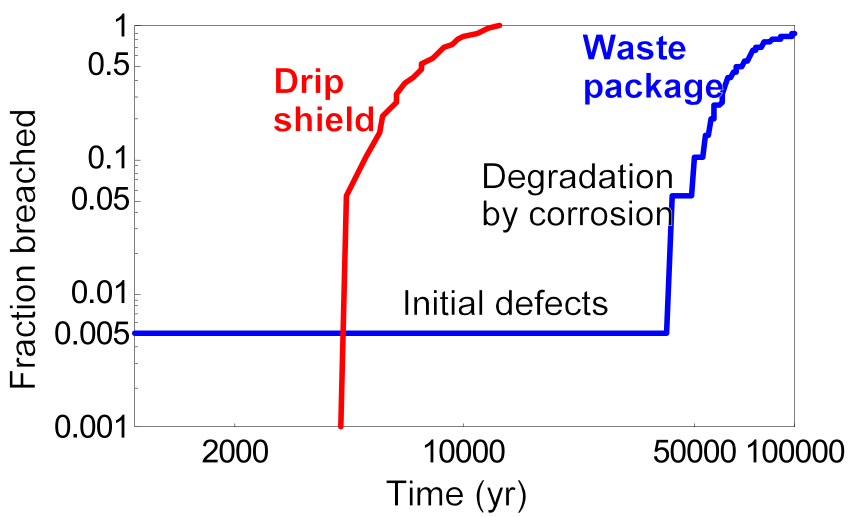


Table 2-11. Illustration of the Average Fraction of Waste Packages Breached Versus Time (Example Does Not Represent Performance of the Proposed Repository.)

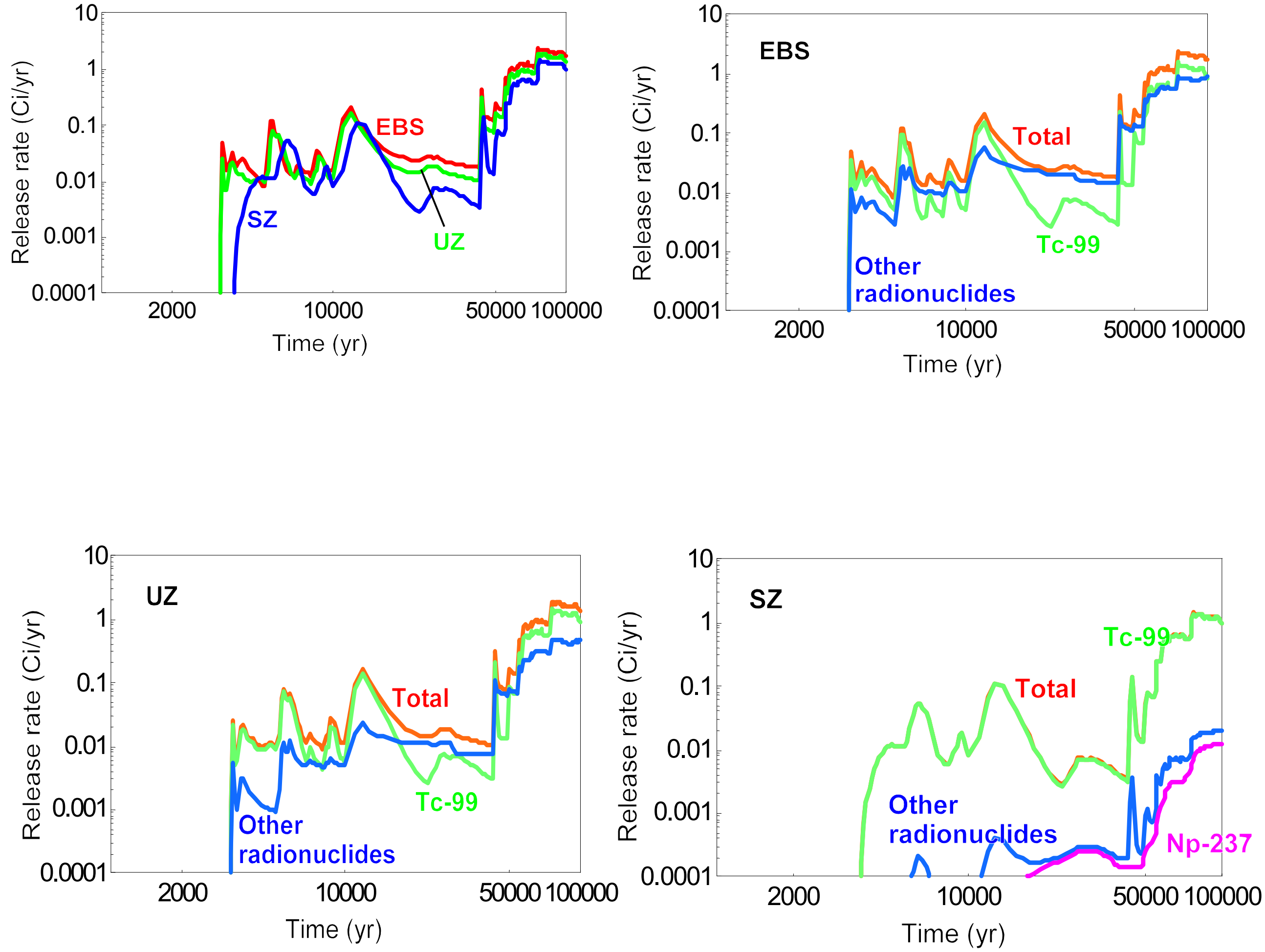


Figure 2-12. Illustrations of Radionuclide Release Rate Versus Time from the Engineered Barrier Subsystem (EBS), Unsaturated Zone (UZ), and Saturated Zone (SZ) (Example Does Not Represent Performance of the Proposed Repository.)

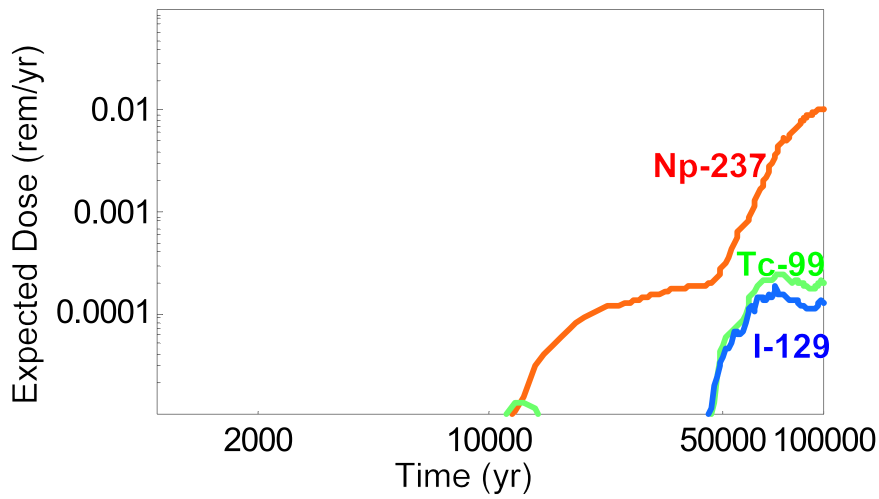


Figure 2-13. Illustration of Expected Dose Versus Time

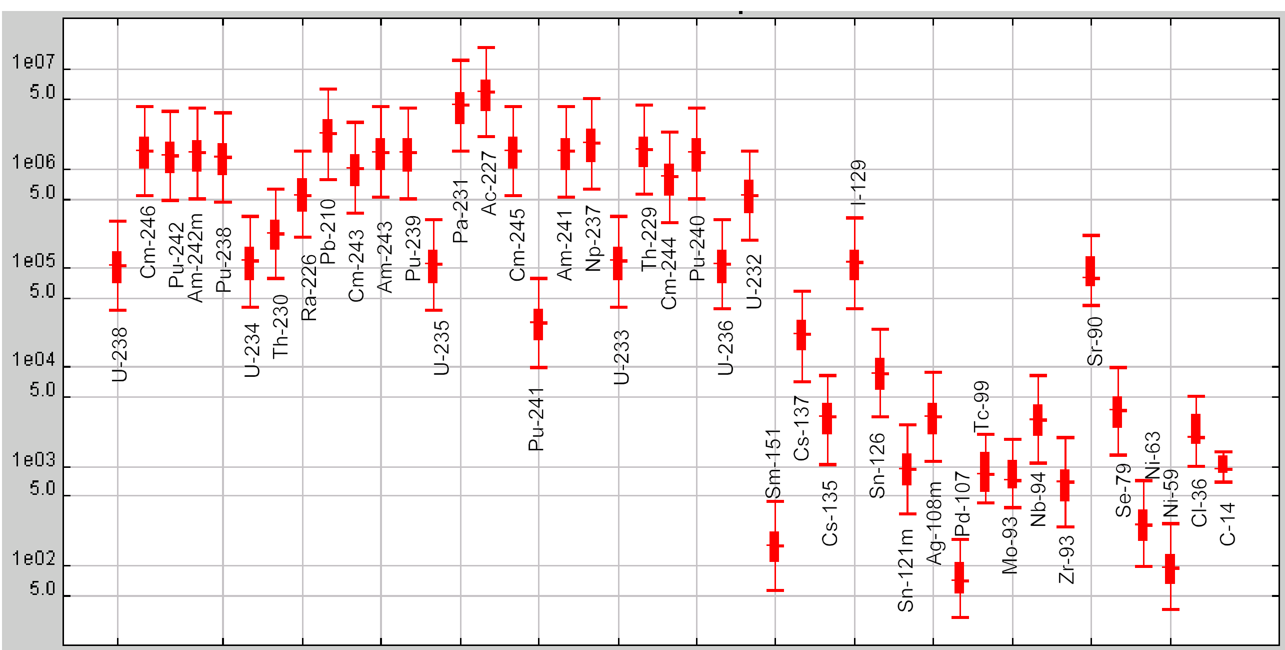


Figure 2-14. Box and Whisker Illustration of Dose Conversion Factors (Arbitrary Units) for Crop Ingestion Pathway During the Pluvial Period. Ends of the Rectangles Correspond to 20th and 80th Percentiles, the Middle Lines Crossing the Rectangles Represent the 50th Percentiles, and the End Whiskers Correspond to Minima and Maxima

Table 2-3. Linkage of Hypothetical Results to Input Parameter and Output Values for Individual Realizations Ranked by Peak Dose. Percentiles Listed for an Intermediate Output or Input Relate to Its Value for a Particular Realization with Respect to the Entire Distribution of Values from All Realizations.			
	Realization 1	**Realization 2**	**Realization 3**
Results			
Peak Dose (generic dose unit)	3.2	1.5	0.9
Time of Peak Dose (year)	8,000	9,200	10,000
Intermediate Outputs			
Waste Package Failure Time (percentile)	3	12	9
Drip Shield Failure Time (percentile)	20	16	13
Total Release from Engineered Barrier Subsystem (percentile)	99	98	96
Total Release from Unsaturated Zone (percentile)	99	97	98
Total Release from Saturated Zone (percentile)	99	98	97
Inputs			
Sensitive Parameter 1 (percentile)	95	93	97
Sensitive Parameter 2 (percentile)	5	10	7
Sensitive Parameter 3 (percentile)	85	75	50

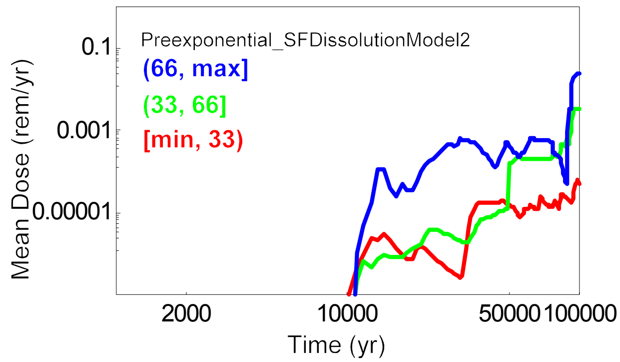
Table 2-4. Linkage of Hypothetical Results to Input Parameter and Output Values for Groups of Realizations (Quantile) Ranked by Their Contribution to the Peak Mean Dose (Not All Quantiles Are Shown). Percentiles Relate to the Arithmetic Mean of the Values for an Intermediate Output or Input Corresponding to a Particular Quantile of Realizations with Respect to the Entire Distribution of Values from All Realizations.			
	Quantile 1	**Quantile 2**	**Quantile 3**
Result (percent)			
Contribution to the Peak Mean Dose	77	12	5
Intermediate Outputs (percentile of mean)			
Waste Package Failure Time	9	18	21
Drip Shield Failure Time	11	17	34
Total Release from Engineered Barrier Subsystem	93	88	79
Total Release from Unsaturated Zone	94	84	81
Total Release from Saturated Zone	95	86	76
Inputs (percentile of mean)			
Sensitive Parameter 1	95	93	97
Sensitive Parameter 2	5	10	7
Sensitive Parameter 3	85	75	50

dose, where percentiles of the mean values for the influential input parameters and intermediate outputs are reported. In addition to the information presented in Tables 2-3 and 2-4, correlations among the inputs, intermediate outputs, and results may also be calculated and reported. Generally speaking, these tables show the relationships between the specific results and values of input parameters and intermediate outputs. These tables and calculated correlations can identify what conditions (i.e., values of sampled parameters) lead to large doses. In addition to analyses that consider the composite of all radionuclides in the repository, it would be beneficial to present these relationships for individual radionuclides as well.

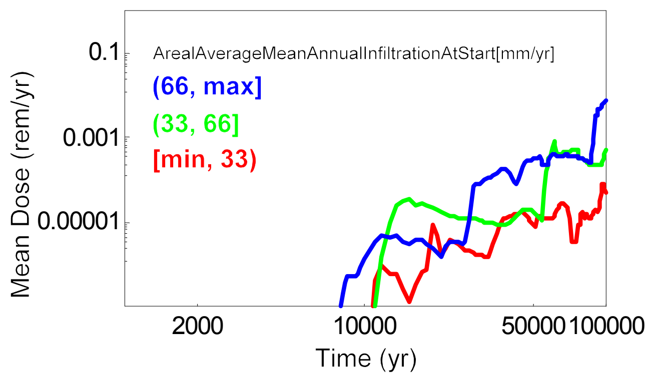
Uncertainty and importance analyses are usually completed to identify the input parameters controlling the model output and its uncertainty. After identification of important input parameters, it would be desirable to design a graphical display to highlight the effect a parameter has on the total dose or any other intermediate output of interest. An example of a proposed graphic display is discussed as follows. Realizations can be classified according to rank ranges of an input parameter. For instance, a bin could include those realizations having input parameters ranging from the minimum to its 33rd percentile value; a second bin could enclose the 33rd percentile to the 66th percentile, and a third bin, those realizations with input parameter ranging from the 66th percentile to the maximum value. The mean (or any other appropriate statistic) of the dose (or any other intermediate output) for the set of realizations in the first, second, and third bins can be computed, and displayed in the same plot. Figure 2-15 shows mean dose versus time curves derived in this manner. Figure 2-15a shows the effect of a parameter controlling the magnitude of the spent fuel dissolution rate on the dose. An increasing trend is noted: those realizations with high dissolution rates are also the realizations with high doses. Figure 2-15b shows the effect of a parameter regulating the amount of water available for radionuclide release from the engineered barrier subsystem. In this case, a less pronounced increasing trend is noted: realizations with large amounts of water display relatively high doses. Figure 2-15c shows a noninfluential variable related to failure of the waste package by seismicity (there were no seismic failures in the Monte Carlo realizations for this example). Although differences are noted between the three dose curves, no clear trend is distinguished in this latter case.

Other diagrams to display or highlight influences could be proposed. Influence diagrams allow a visualization of the relative influence of parameters. The influence diagrams should enhance appreciation of the effect of influential and noninfluential parameters on the estimated dose or other intermediate outputs. For instance, in the example in Figure 2-15, it is clearly apparent that the parameter Preexponential_SFDissolutionModel2 has more influence than the parameter ArealAverageMeanAnnualInfiltrationAtStart[mm/yr].

Influence diagrams also could be used to communicate the effect of uncertainty propagation. For example, realizations could be classified by the magnitude of an intermediate output, and the time integral of the Tc-99 release rate versus time function (see Figure 2-16). Clearly, those realizations having high releases of Tc-99 also display high doses. Therefore, in this example, identifying the controlling factors of the magnitude and uncertainty of the release rate of Tc-99 from the engineered barrier subsystem will also indicate factors potentially important to dose estimates, which might be overlooked by standard sensitivity analyses performed on dose metrics.



(a)



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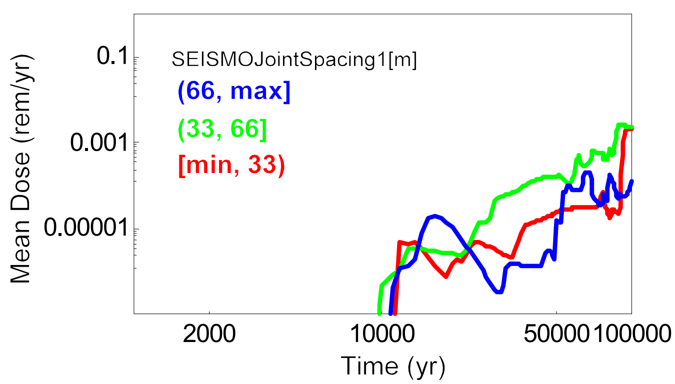


(c)

Figure 2-15. Illustrations of Mean Dose Versus Time Curves (Example Diagrams Proposed to Highlight the Influence of Input Parameters of the Dose. See Description in Section 2.1.3.3)

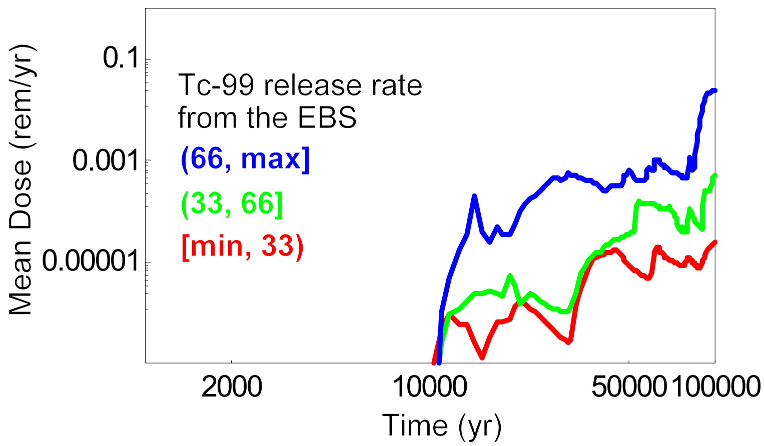


Figure 2-16. Illustration of Mean Dose Versus Time Curves (Example Diagram Proposed to Highlight the Relationship Between an Intermediate Output and the Dose. See Description in Section 2.1.3.3)

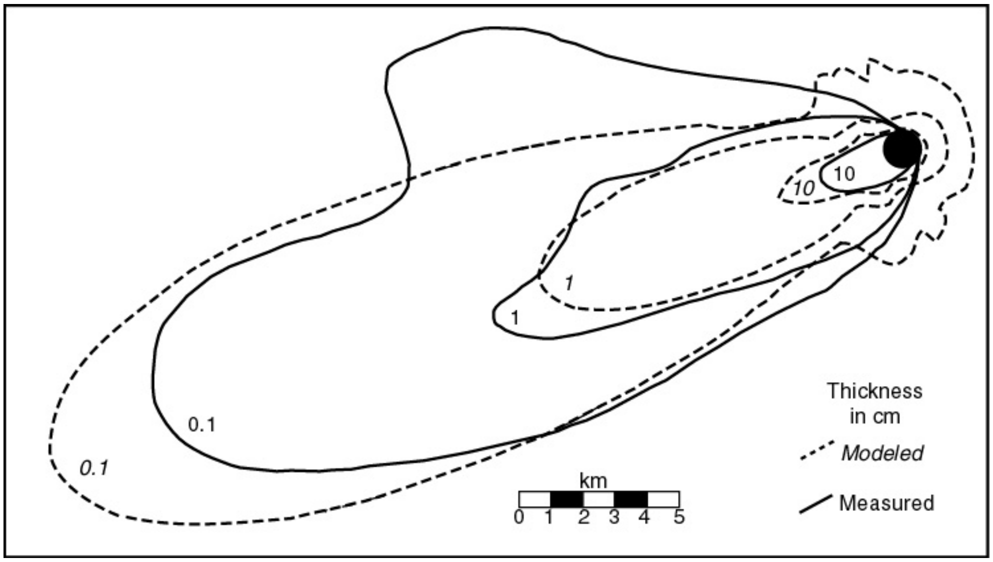
2.1.3.4 Presentation of Results Beyond 10,000 Years

The regulation in 10 CFR Part 63 specifies a compliance period of 10,000 years (NRC, 2001). Results should be presented beyond 10,000 years for the evaluating uncertainty in the total system performance assessment to enable a better understanding of the total system behavior. The time frames should be sufficiently large to establish the range of failure times for the drip shield and waste package, transport time in the geosphere, and accumulation in the biosphere. The requirement for demonstrating the function of multiple barriers also should be considered in the presentation of results. Uncertainties in the barrier capabilities to isolate waste must be taken into account. The capability for barriers to isolate waste during the compliance period may result in the masking of the capability of certain individual barriers because of the effectiveness of a redundant barrier. A presentation of results for longer time periods may be necessary to show the effectiveness of the barriers to isolate waste.

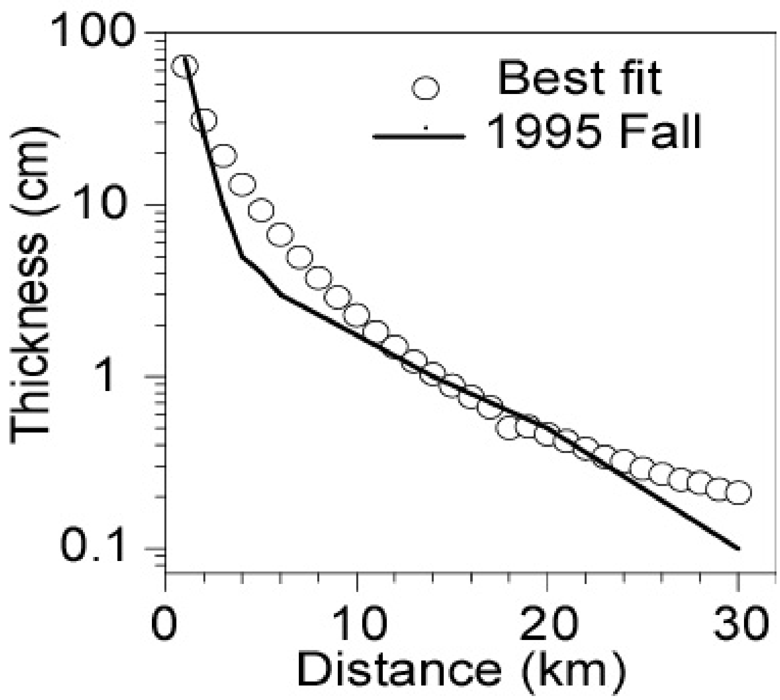
2.1.3.5 Verification and Validation

Verification of the total system performance assessment code is needed to provide confidence that the code is correctly modeling the physical processes of the repository. Because the total system performance assessment code consists of several submodels, the combination of submodel validation and verification of data transfer between the submodel and total system performance assessment code is needed to provide confidence in the results of the total system performance assessment code.

An example of submodel validation for the transport and deposition of ash following an igneous eruption is presented next. Figure 2-17 clearly shows reasonably good agreement between modeled ash thicknesses with measured data. In fact, as depicted by Figure 2-17b, some of the best agreement is realized at distances between 8 and 20 km [5 and 12 miles] from the source of the volcanic eruption, which include the location of reasonably maximally exposed individual. A more detailed presentation of this benchmarking work is available (Hill, et al., 1998).



(a)



(b)

Figure 2-17. Comparison of Modeled Ash Thicknesses with Measured Data from the 1995 Eruptions of the Cerro Negro Volcano, Nicaragua, (a) Isopach Comparison and (b) Comparison by Distance from the Vent

2.2 Demonstration of Compliance with the Human Intrusion Standard

Compliance with the human intrusion standard requires a demonstration that the repository performance is not substantially degraded as a result of inadvertent human intrusion. Regulations in 10 CFR 63.321–63.322 and acceptance criteria found in Section 4.2.1.4.2 of NRC (2002a) outline requirements and expectations of the approaches for including an analysis of limited human intrusion in total system performance assessment abstractions.

NRC (2002a, Section 4.2.1.4.2.3) organizes a review of a potential license application according to three acceptance criteria for the human intrusion standard:

Acceptance Criterion 1	Evaluation of the Time of an Intrusion Event.
Acceptance Criterion 2	Evaluation of an Intrusion Event Demonstrates That the Annual Dose to the Reasonably Maximally Exposed Individual in Any Year During the Compliance Period Is Acceptable.
Acceptance Criterion 3	The Total System Performance Assessment Code Provides a Credible Representation of the Intrusion Event.

This section of the report is divided into three subsections, which directly correspond to the three acceptance criteria for the human intrusion standard: (1) Evaluation of the Time of an Intrusion Event, (2) Evaluation of the Annual Dose to the Reasonably Maximally Exposed Individual from an Intrusion Event, and (3) Credible Representation of the Intrusion Event.

2.2.1 Evaluation of the Time of an Intrusion Event

This subsection relates to Acceptance Criterion 1 for the Human Intrusion Standard (NRC, 2002a, Section 4.2.1.4.2.3).

The individual protection standard for human intrusion in 10 CFR 63.321 is a two-step process. The first step requires DOE to provide the analyses and technical bases used to determine the earliest time after disposal that the waste package would degrade sufficiently so a human intrusion could occur without recognition by the drillers. The second step, which will be explained in more detail in Subsections 2.2.2 and 2.2.3 of this report, requires that an assessment be performed if a waste package is projected to be penetrated at or before 10,000 years after disposal.

Uncertainty should be propagated through the calculation for the time of occurrence of inadvertent human intrusion. Parameters and assumptions influencing the calculation of the intrusion time and its uncertainty should be identified and presented. The uncertainty in the intrusion time should be presented (e.g., mean value, 5^{th} percentile, and 95^{th} percentile) with the actual value selected for the calculations. The NRC would find it useful if the technical basis included information about the level of confidence in the results, by presenting the 5^{th} and 95^{th} percentiles to represent the uncertainty in the calculations. This information, along with a sound basis and clear presentation, is necessary for NRC to conduct a detailed review. The NRC (2002b) previously reported that any analyses and technical basis related to determining the earliest time after disposal that the waste package would degrade sufficiently so a human intrusion could occur without recognition by the driller may not be required if the event was assumed to occur 100 years

after closure, as assumed in CRWMS M&O (2000a). Staff found that assuming the human intrusion event occurs 100 years after closure of the repository is conservative and acceptable. It should be noted, however, if DOE elects to modify this approach by using a different time of occurrence of the human intrusion event, DOE must provide, as required by 10 CFR 63.321, the analyses and technical bases used to justify the new time of occurrence.

2.2.2 Evaluation of the Annual Dose to the Reasonably Maximally Exposed Individual from an Intrusion Event

This subsection relates to Acceptance Criterion 2 for the Human Intrusion Standard (NRC,2002a, Section 4.2.1.4.2.3).

It was introduced in Subsection 2.2.1 of this report that, if the waste package is projected to be penetrated at or before 10,000 years, the resulting annual dose to the reasonably maximally exposed individual must be evaluated. This evaluation must be performed separately from the basecase performance assessment, but would be similar to the total system performance assessment required by 10 CFR 63.113(b) and subject to specific requirements for evaluation of human intrusion specified at 10 CFR 63.321–63.322 and 63.342 and the performance objectives specified in 10 CFR 63.113(d). The performance assessment for human intrusion is different because it includes the human intrusion event as described in 10 CFR 63.322 and excludes unlikely natural processes and events. Since the human intrusion performance assessment must meet the same regulatory requirements and expectations as outlined in 10 CFR 63.113(b) and the Yucca Mountain Review Plan for the basecase total system performance assessment, no new information is required by the NRC beyond those discussed in Subsection 2.1.2 of this report for the basecase total system performance assessment.

2.2.3 Credible Representation of the Intrusion Event

This subsection relates to Acceptance Criterion 3 for the Human Intrusion Standard (NRC, 2002a, Section 4.2.1.4.2.3).

As in Section 2.2.2 of this report, this acceptance criterion has no special requirement beyond those required for the basecase total system performance assessment. Since the human intrusion performance assessment must meet the same regulatory requirements and expectations as outlined in 10 CFR 63.113(b) and the Yucca Mountain Review Plan for the basecase total system performance assessment, no new information needs are required by the NRC beyond those discussed in Subsection 2.1.3 of this report for the basecase total system performance assessment.

2.3 Analysis of Repository Performance that Demonstrates Compliance with the Separate Groundwater Protection Standards

The groundwater protection standards in 10 CFR Part 63 (NRC, 2001) include two concentration limits and a dose standard. These standards are separate from the individual protection standard in 10 CFR 63.311. For the staff to conduct a detailed review of any potential license application, it is necessary to have sufficient documentation of the total system performance assessment calculations for demonstrating compliance with the groundwater protection limits.

NRC (2002a, Section 4.2.1.4.3.3) organizes a review of a potential license application according to three acceptance criteria for the groundwater protection standard:

Acceptance Criterion 1	An Adequate Demonstration is Provided That the Expected Concentration of Combined Radium-226 and Radium-228, Expected Concentration of Specified Alpha-emitting Radionuclides, and Expected Whole Body or Organ-specific Doses from any Photon- or Beta-emitting Radionuclides at Any Year During the Compliance Period Do Not Exceed the Separate Ground-Water Protection Standards.
Acceptance Criterion 2	The Methods and Assumptions Used to Determine the Position of the Representative Volume of Ground Water are Credible and Consistent, and the Representative Volume of Ground Water Includes the Highest Concentration Level in the Plume of Contamination in the Accessible Environment.
Acceptance Criterion 3	The Methods and Assumptions Used to Calculate the Physical Dimensions of the Representative Volume of Ground Water are Credible and Consistent.

This section of the report is divided into three subsections, which directly correspond to the three acceptance criteria for the groundwater protection standard: (1) Separate Groundwater Protection Standards, (2) Positions of the Representative Volume of Groundwater and the Highest Concentration Level in the Plume of Contamination in the Accessible Environment, and (3) Physical Dimensions of the Representative Volume of Groundwater.

2.3.1 Separate Groundwater Protection Standards

This subsection relates to Acceptance Criterion 1 for the Groundwater Protection Standards (NRC, 2002a, Section 4.2.1.4.3.3)

Groundwater protection standards in 10 CFR 63.331 require DOE to demonstrate that there is a reasonable expectation that releases of radionuclides into the accessible environment will not cause the level of radioactivity in the representative volume of groundwater to exceed specified limits for 10,000 years of undisturbed performance after disposal. The specified limits include the following:

- Combined activity concentration for Ra-226 and Ra-228 of 0.185 Bq/L [5 pCi/L]

- Gross alpha activity concentration (including Ra-226 but excluding radon and uranium) of 0.555 Bq/L [15 pCi/L]

- Combined annual dose from beta- and photon-emitting radionuclides of 0.04 mSv/yr [4 mrem/yr] to the whole body or any organ (based on drinking 2 liters [0.53 U.S. gallons] of water per day from the representative volume)

Documentation of the following information is necessary to allow for a detailed review:

- Expected value of combined radium (Ra-226 and Ra-228) activity concentration in the representative volume plotted as a function of time (see Figure 2-18). Times from 0 to 10,000 years after disposal should be displayed. The 5th and 95th percentiles and the 0.185-Bq/L [5-pCi/L] limit should also be included.

- Specification of the natural background activity concentration for combined radium and the technical basis for the value.

- Expected value of the gross alpha activity concentration in the representative volume (including Ra-226 but excluding radon and uranium) plotted as a function of time (see Figure 2-18). Times from 0 to 10,000 years after disposal should be displayed. The 5th and 95th percentiles and the 0.555-Bq/L [15-pCi/L] limit should also be included.

- Specification of the natural background concentration for gross alpha activity and the technical basis for the value.

- A listing of all radionuclides considered in the gross alpha activity category and technical justification and criteria for their selection including any exclusions or exceptions.

- Expected values of estimated annual whole body and all organ doses, from combined beta- and photon-emitting radionuclides in the representative volume, plotted as a function of time based on drinking 2 L/day [0.53 U.S. gallons/day] from the representative volume (see Figures 2-19, 2-20, and 2-21). Times from 0 to 10,000 years after disposal should be plotted. The organ doses with the highest 5th and 95th percentiles and the 0.04-mSv/yr [4-mrem/yr] limit should also be presented. Although not plotted in Figures 2-19, 2-20, and 2-21, the 5th and 95th percentiles for all other organs may also be presented.

- A listing of all radionuclides considered in the beta and photon categories and technical justification and criteria for their selection including any exclusions or exceptions.

The calculated concentrations and doses used for comparison with the limits in 10 CFR 63.331 are based on the attributes of the representative volume. Information needs regarding the representative volume are discussed in Subsections 2.3.2 and 2.3.3.

2.3.2 Positions of the Representative Volume of Groundwater and the Highest Concentration Level in the Plume of Contamination in the Accessible Environment

This subsection relates to Acceptance Criterion 2 for the Groundwater Protection Standards (NRC, 2002a, Section 4.2.1.4.3.3).

Requirements in 10 CFR 63.332 specify assumptions for the representative volume used to estimate groundwater concentrations of radionuclides for comparison with the limits specified in 10 CFR 63.331. These assumptions include: (i) the representative volume includes the highest concentration level in the plume of contamination in the accessible environment; (ii) the position and dimensions of the representative volume in the aquifer are determined using average hydrologic characteristics which have cautious, but reasonable, values representative of the aquifers along the radionuclide migration path from the Yucca Mountain repository to the accessible environment as determine by site characterization; and (iii) the representative volume contains approximately 3,714,450,000 liters [3,000 acre-ft] of water. The groundwater modeling

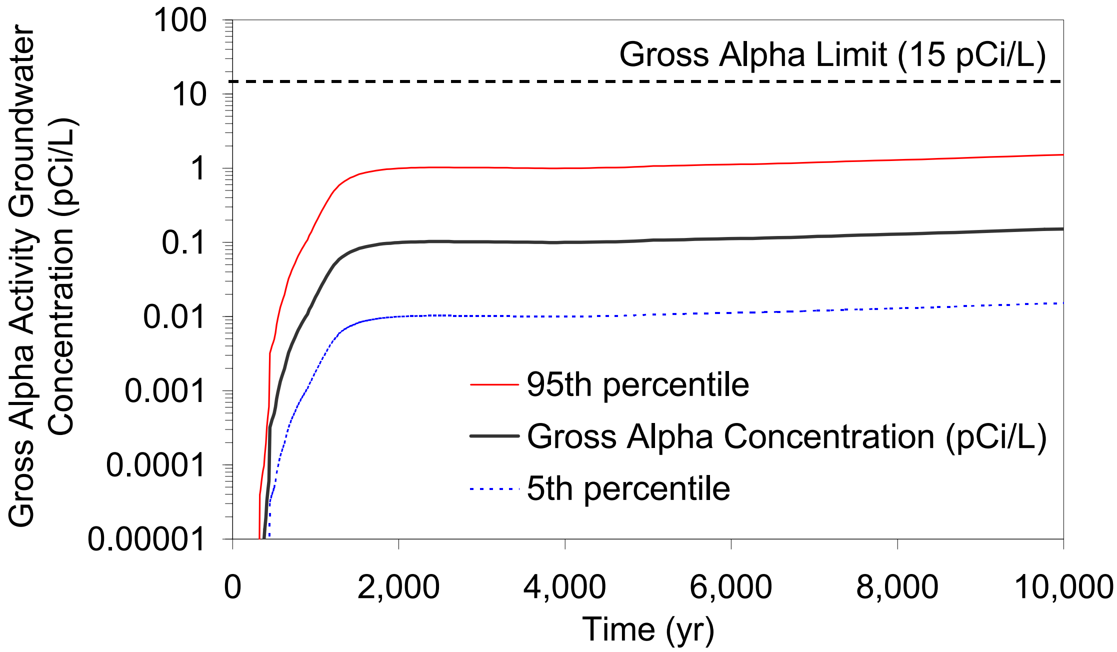


Figure 2-18. Illustration Displaying Estimated Mean Gross Alpha Concentrations and Selected Percentiles for Groundwater Protection (This Figure Does Not Show Actual Results from the TPA Version 4.1 Code but Shows Hypothetical Results.)

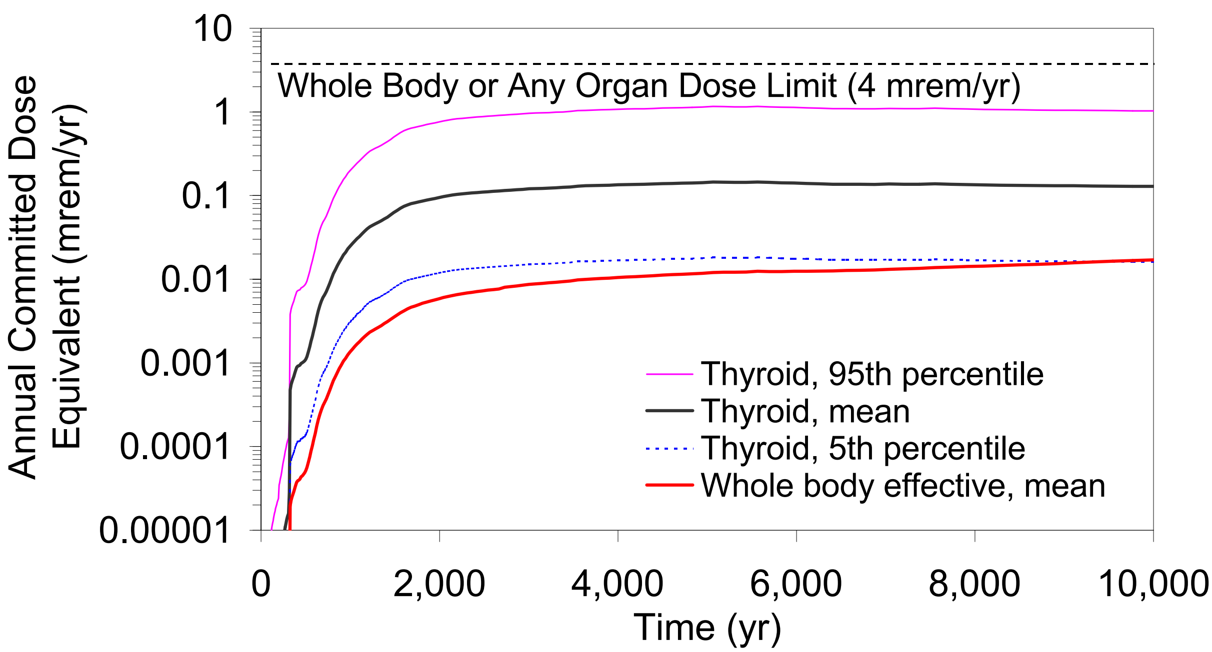


Figure 2-19. Illustration Displaying Estimated Mean Whole Body and the Limiting Organ Dose for Groundwater Protection (Selected Percentiles Shown for Limiting Value) (This Figure Does Not Show Actual Results from the TPA Version 4.1 Code but Shows Hypothetical Results.)

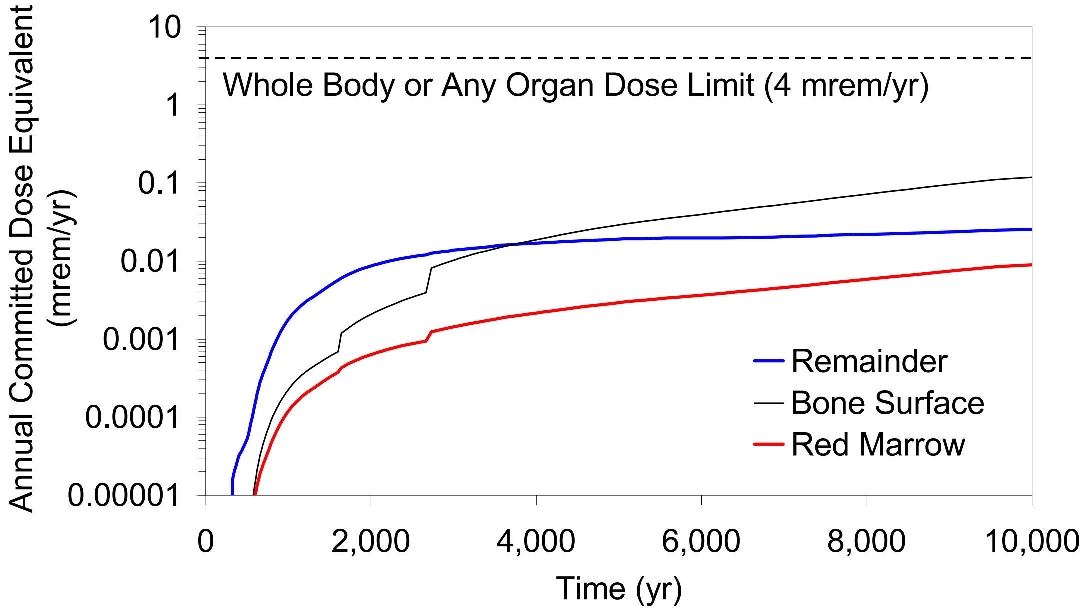


Figure 2-20. Illustration Displaying Selected Estimated Mean Organ Doses for Groundwater Protection (This Figure Does Not Show Actual Results from the TPA Version 4.1 Code but Shows Hypothetical Results.)

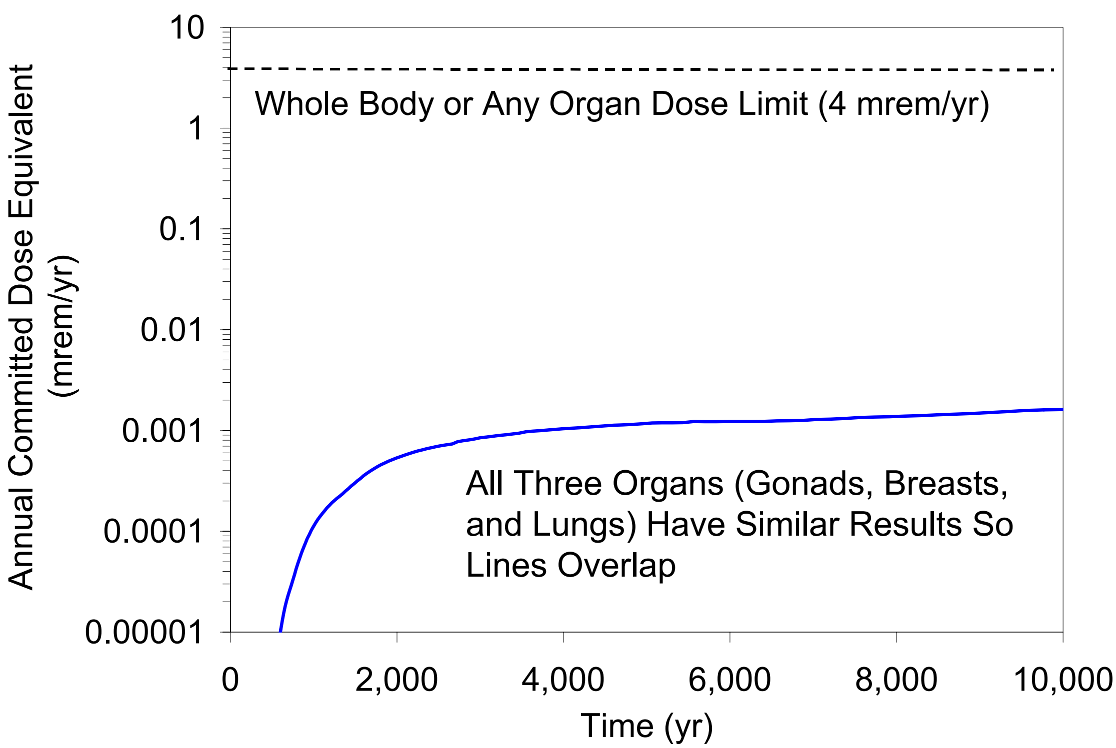


Figure 2-21. Illustration Displaying Selected Estimated Mean Organ Doses for Groundwater Protection with Similar Results (This Figure Does Not Show Actual Results from the TPA Version 4.1 Code but Shows Hypothetical Results.)

needed to estimate radionuclide releases from the proposed repository to the accessible environment should already be included in the total system performance assessment for any potential license application for demonstrating compliance with the individual protection standard. If the same modeling is used to determine the annual rate of radionuclides entering into the accessible environment, the adequate documentation of the model should already be provided in the materials supporting total system performance assessment model abstractions (e.g., abstraction and model reports). Any deviations in the methodology or parameters for applying the total system performance assessment model to groundwater protection calculations should be discussed in documentation related to the groundwater protection calculations.

2.3.3 Physical Dimensions of the Representative Volume of Groundwater

This subsection relates to Acceptance Criterion 3 for the Groundwater Protection Standards (NRC, 2002a, Section 4.2.1.4.3.3).

The requirements in 10 CFR 63.332(b) provide two approaches DOE can use for determining the dimensions of the representative volume (one method must be chosen). The dimensions of the representative volume are important to the calculation of groundwater radionuclide concentrations because the activity concentration used in further calculations is inversely proportional to the water volume. Because the representative volume is the denominator in the concentration calculation, and this value is fixed at approximately 3,714,450,000 liters [3,000 acre-ft] of water, the activity concentration of radionuclides in groundwater (Bq/L) made available to the biosphere is only affected by the radionuclide activity.

The estimated concentrations are thus effectively bounded when the dimensions of the representative volume are larger than the annual extent of the plume in the accessible environment (i.e., all radionuclides in the accessible environment in any given year are included in the concentration calculation). Needs regarding the dimensions of the representative volume are minimal, and the review should focus on the basis for the estimated annual rate of radionuclides entering into the accessible environment. Documentation should allow staff to understand how the rate of radionuclides entering into the accessible environment is determined and that the total rate is included in annual concentration calculations.

If the dimensions of the representative volume do not encompass the entire annual extent of the plume in the accessible environment, the concentration is no longer bounded, and greater documentation is necessary. Such documentation would include selection of method (plume capture versus slice of plume) for estimating the size of the representative volume, details of key parameters and assumptions used, the resulting location and dimensions of the representative volume, and consistency with the requirements, for example 10 CFR 63.332(b), that apply to the selected method.

Prior DOE groundwater protection calculations used a representative volume of approximately 1,591,023,000 liters [1,285 acre-ft], and all radionuclides reaching the accessible environment were captured by the assumed well pumping (CRWMS M&O, 2000a). Subsequent analyses with a larger representative volume produced similar results (Bechtel SAIC Company, LLC, 2001). Graphical display of the locations of the representative volume, annual extent of the plume, and highest concentration of the plume would become beneficial if the dimension of the representative volume is exceeded by the annual extent of the plume. Unless the DOE approach changes significantly, the dimension of the representative volume for the license application analyses

would be greater than the annual extent of the plume. Therefore, specific information needs have not been presented for the situation where the dimensions of the representative volume do not exceed the annual extent of the plume.

3 SUMMARY REMARKS

This report provides recommendations on the type of information and its display for reviewing part of any licensing application that demonstrates compliance with the postclosure public health and environmental standards. This report applies to a specific section of NRC (2002a, Section 4.2.1.4). It is expected that the likelihood of requests for additional information in this part of any license application would be reduced if the presented recommendations are followed.

The recommendations presented in this report neither replace nor augment the requirements of the regulation in 10 CFR Part 63 (NRC, 2001) or the review guidance provided by NRC (2002a). The recommendations are focused on the display of certain types of information in graphs and tables and, as such, are incomplete with respect to all of the information requested by NRC (2002a, Section 4.2.1.4). Graphical and tabular examples illustrate the recommendations presented in this report and are for information only. This report makes no conclusions about what would be sufficient for satisfying the regulatory requirements and makes no determinations for regulatory compliance.

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