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Total System Performance Assessment Sensitivity Analyses for Final Nuclear Regulatory Commission Regulations

Report SACFR160

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CONTENTS

FIGURES

Page

TABLES

1. PURPOSE

This Letter Report presents the results of supplemental evaluations and analyses designed to assess long-term performance of the potential repository at Yucca Mountain. The evaluations were developed in the context of the Nuclear Regulatory Commission (NRC) final public regulation, or rule, 10 CFR Part 63 (66 FR 55732 [DIRS 156671]), which was issued on November 2, 2001. This Letter Report addresses the issues identified in the Department of Energy (DOE) technical direction letter dated October 2, 2001 (Adams 2001 [DIRS 156708]).

The main objective of this Letter Report is to evaluate performance of the potential Yucca Mountain repository using assumptions consistent with performance-assessment-related provisions of 10 CFR Part 63. The incorporation of the final Environmental Protection Agency (EPA) standard, 40 CFR Part 197 (66 FR 32074 [DIRS 155216]), and the analysis of the effect of the 40 CFR Part 197 EPA final rule on long-term repository performance are presented in the *Total System Performance Assessment- Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain – Input to Final Environmental Impact Statement and Site Suitability Evaluation* (BSC 2001 [DIRS 156460]), referred to hereafter as the FEIS/SSE Letter Report.

The Total System Performance Assessment (TSPA) analyses conducted and documented prior to promulgation of the NRC final rule 10 CFR Part 63 (66 FR 55732 [DIRS 156671]), were based on the NRC proposed rule (64 FR 8640 [DIRS 101680]). Slight differences exist between the NRC's proposed and final rules which were not within the scope of the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460]), the Preliminary Site Suitability Evaluation (PSSE) (DOE 2001 [DIRS 155743]), and supporting documents for these reports. These differences include (1) the possible treatment of "unlikely" features, events and processes (FEPs) in evaluation of both the groundwater protection standard and the human-intrusion scenario of the individual protection standard, and (2) the definition of the water demand of the reasonably maximally exposed individual (RMEI). It is these differences, as well as uncertainty associated with the appropriate approach to implement these differences, that have necessitated the additional analyses presented in this document.

This Letter Report will consider the following three performance-assessment-related topics based on the final NRC rule at 10 CFR Part 63 (66 FR 55732 [DIRS 156671]).

- **Groundwater Protection Standard and the Consideration of Unlikely Events (i.e., igneous intrusion).** This Letter Report evaluates the radionuclide concentrations in groundwater assuming an igneous-intrusion scenario. The report considers this scenario under both the higher-temperature operating mode (HTOM), and the lower-temperature operating mode (LTOM), with respect to total radium concentration, gross-alpha concentration, and dose to critical organs. Even though not expressly required by the NRC final rule, this evaluation is being conducted because the phrase "unlikely features events and processes" is not defined in 10 CFR Part 63.342 (66 FR 55732 [DIRS 156671]). The mean annual probability of an igneous intrusion at the location of the potential repository is 1.6 x 10^{-8} (CRWMS M&O 2000 [DIRS 153246] Table 3.10-5, p. 3-203).

- **Individual Protection Standard for Human Intrusion and the Consideration of Unlikely Events (igneous intrusion followed by human intrusion).** This Letter Report discusses the scenario of an igneous intrusion immediately followed by a human intrusion event for both HTOM and LTOM. Even though not expressly required by the NRC final rule, this discussion is being included because the term "unlikely features, events, and processes" is not defined in 10 CFR Part 63. The mean annual probability of an igneous intrusion at the location of the potential repository is 1.6 x 10^{-8} (CRWMS M&O 2000 [DIRS 153246] Table 3.10-5, p. 3-203).

- **Individual Protection Standard and the Effect of 3,000 Acre-Feet Annual Water Demand.** This Letter Report discusses the effect of assuming a 3,000 acre-feet annual water demand for the individual protection standard as the water demand for the simulated calculation of dose to the RMEI in accordance with the NRC final rule. This Letter Report contrasts this water demand with the water demand assumed in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), and implemented in the Supplemental Science and Performance Analysis (SSPA) Volumes 1 and 2 (BSC 2001 [DIRS 154657]; BSC 2001 [DIRS 154659], Section 4.0), and included in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460]). The probabilistic calculations in these documents used a range of water demand from 887 to 3,367 acre-ft per year and averaging approximately 2,000 acre-ft per year. This discussion is being included in this Letter Report because 10 CFR 63.312 specifies 3,000 acre-feet per year as the water demand for the dose calculation to the RMEI (66 FR 55732 [DIRS 156671] p. 55814). The EPA did not specify a volume for water demand for the calculation of dose to the RMEI.

This Letter Report is not intended to reflect the updated and new information included in the Technical Update Impact Letter Report because that report was in preparation and not final during final preparation of this Letter Report.

Background The Nuclear Waste Policy Act of 1982, as amended (NWPA, Public Law 97-425 [DIRS 131951]) directs the DOE to evaluate the suitability of the Yucca Mountain site in southern Nevada as a potential site for development of a geologic repository for the disposal of spent nuclear fuel (SNF) and high-level waste (HLW). 10 CFR 63.342 (66 FR 55732 [DIRS 156671] p. 55815) specifies that "unlikely features, events, and processes or sequences of events and processes shall be excluded from the assessments for the human intrusion and groundwater protection standards upon prior Commission approval for the probability limit used for unlikely features, events, and processes." The NRC provided no specific quantitative value for determining when exclusion of unlikely FEPs is appropriate, the final regulations require DOE to exclude unlikely FEPs from the specified analyses upon prior approval of the Commission for the probability limit used for unlikely FEPs. The Commission recognizes that specification of a probability limit for unlikely FEPs, as is done for "very" unlikely FEPs would be a more direct approach. The Commission considers a frequency for unlikely FEPs would fall somewhere between 10^{-8} to 10^{-4} per year; however, they have not specified a numerical value in the regulations at this time (66 FR 55732 [DIRS 156671] Section II, p. 55734).

Given the absence of precise quantitative frequency that may be applied to the definition of the term "unlikely", but considering that it is expected to be between 10^{-8} and 10^{-4} per year, the performance assessments of the groundwater protection standard and the human-intrusion scenario for the individual protection standard documented herein consider the possibility of FEPs previously classified as "unlikely" potentially affecting the results of the analyses conducted to date and documented in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and the SSPA Volumes 1 and 2 (BSC 2001 [DIRS 154657]; BSC 2001 [DIRS 154659]). If the quantitative definition of "unlikely" were defined at the most conservative end of the range of frequencies greater than or equal to 10^{-8} per year, then such previously "unlikely" FEPs would need to be considered in the human-intrusion and groundwater-protection performance-assessment analyses. Therefore, new analyses have been conducted to assess the potential effects of the one event that was previously excluded from groundwater protection and human intrusion analyses and which has an expected mean annual probability of greater than 10^{-8} per year, i.e., an igneous intrusion. All other potential features, events and processes that may reasonably be considered "unlikely" have been either screened out of the performance assessment on the basis of low consequence or low risk in the FEPs screening process defined in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and associated references or have been included in the nominal performance-assessment-scenario class which was used as the basis for the human-intrusion and groundwater-protection analyses in the TSPA-SR. Although it is anticipated that the expedited rulemaking will ultimately specify whether or not such FEPs need to be considered in any licensing proceeding, DOE is considering them at this point as alternative analyses that provide DOE with a conservative estimate of potential dose and radionuclide concentrations.

The NRC proposed rule (64 FR 8640 [DIRS 101680]) allowed for some flexibility in the treatment of the appropriate water demand of the small farming community considered as the receptors in assessing the individual protection standard. In assessments conducted in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), the farming community was considered to represent from 15 to 25 small farms, consistent with the proposed NRC rule (64 FR 8640 [DIRS 101680]). The NRC final rule 10 CFR Part 63 (66 FR 55732 [DIRS 156671]) states that the RMEI "uses well water with average concentrations of radionuclides based on an annual water demand of 3,000 acre-ft."

The results of assessments assuming an igneous-intrusion event in the groundwater-protection analysis are presented in Section 6.1. The results of assessments assuming an igneous-intrusion event in the evaluation of the individual protection standard for human intrusion are presented in Section 6.2. Section 6.3 presents the results of assessments using the specified value of 3,000 acre-ft as the annual water demand for purposes of assessing the individual protection standard.

Analyses The simulations and evaluations presented in this Letter Report include estimates of the radionuclide concentrations in groundwater, as specified in 10 CFR 63.331 (66 FR 55732 [DIRS 156671] p. 55814), from the simulated release of radioactive materials from the potential Yucca Mountain repository to the accessible environment. The location for these calculations is the same as the RMEI location in the accessible environment where the groundwater path of the highest concentration of the contaminant plume would cross the southernmost boundary of the controlled area of the potential repository at a Latitude of 36° 40' 13.6661" North as specified in 10 CFR 63.332 (66 FR 55732 [DIRS 156671] p. 55814). This location is approximately 18 km from within the potential repository footprint. This Letter Report considers only the igneous-intrusion aspect of the igneous-activity scenario discussed in the FEIS/SSE Letter Report and does not consider the volcanic-eruption scenario, because the groundwater-protection assessments for estimating the radionuclide concentrations in groundwater are unaffected by the volcanic eruption scenario (CRWMS M&O 2000 [DIRS 153246] Section 4). The volcanic-eruption scenario is not considered because the main biosphere pathway due to a volcanic eruption is the air pathway as a result of volcanic ash released into the atmosphere.

The evaluations included in this Letter Report were developed from the calculations completed and documented in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460]). Process models included in the model configuration used in the calculations and sensitivity analyses presented in this Letter Report are the same as the process models referred to in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460]).

This Letter Report is part of the TSPA suite of documentation that entails a number of documents, each with a specific purpose, but utilizing the same information base in assessing the long-term performance of the Yucca Mountain site to support the postclosure suitability evaluation. Table 1-1 identifies the five key documents in the sequence of TSPA modeling, starting with the earliest, and provides a general description of the changes made in each TSPA document relative to succeeding documents.

Table 1-1 TSPA Suite of Documentation

Document	Date	Description
Total System Performance Assessment for the Site Recommendation Technical Document, Rev 00	September 2000	Documents base case TSPA-SR model.
Total System Performance Assessment for the Site Recommendation Technical Document, Rev 00, ICN 01	December 2000	Updates base case model to include long term climate model, and secondary phase effects.
Supplemental Science and Performance Analysis, Volume 2	July 2001	Provided additional supplemental TSPA analyses based on TSPA-SR model, including unquantified uncertainties analysis, updates in scientific information, and analysis of higher- and lower-temperature operating modes.
TSPA – Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain – Input to FEIS and SSE	September 2001	Additional TSPA analyses to respond to final 40 CFR Part 197 EPA rule, including distance to RMEI and calculation of radionuclide concentrations in groundwater at approximately 18 km from the repository and utilizing 3,000 acre-ft as the annual representative volume of water for assessing groundwater protection.
TSPA Sensitivity Analyses for Final Regulation	November 2001	Additional TSPA evaluations to address final 10 CFR Part 63 provisions, including the possible handling of unlikely events (igneous intrusion) in assessing groundwater protection and human intrusion, and the effects of a change to 3,000 acre-feet/year water demand for evaluation against the individual protection standard.

This Letter Report was developed under Technical Work Plan TWP-MGR-PA-000004 REV 00 (BSC 2001 [DIRS 156459]). This Technical Work Plan and the included activity evaluation specified that this Letter Report is not to be developed per the Yucca Mountain Project (YMP) Quality Assurance (QA) program and thus Quality Assurance Requirements Document (QARD) requirements are not applicable. The Technical Work Plan specifies that the document be subject to the same rigorous checking practices as performed for similar documents prepared under the Yucca Mountain QARD.

The performance-assessment calculations included in this Letter Report were performed for the 70,000-MTHM (metric tons of heavy metal) inventory according to the Nuclear Waste Policy

Act of 1982, as amended (NWPA, Public Law 97-425 [DIRS 131951]). The 70,000-MTHM-Inventory Case is comprised of 63,000 MTHM of CSNF (commercial SNF), 2,333 MTHM of DSNF (DOE SNF), and 4,667 MTHM of HLW.

2. METHOD

The analyses in this Letter Report were conducted by the Bechtel SAIC Company (BSC) Total System Performance Assessment Department in support of the DOE Yucca Mountain program. This Letter Report includes evaluations and calculations of various topics pertinent to certain aspects of the NRC final rule 10 CFR Part 63 (66 FR 55732 [DIRS 156671]). The calculations presented in this Letter Report were previously performed using the numerical code GoldSim (BSC 2001, GoldSim V7.17.200 STN:10344-7.17.200-00 [DIRS 155182]). The GoldSim calculations were performed for the evaluation of the EPA final rule 40 CFR Part 197 and documented in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460], Section 2). The model in the FEIS/SSE Letter Report was based on two previous analyses, the TSPA-SR REV 00, ICN 01 (CRWMS M&O 2000 [DIRS 153246]) that was expanded upon in the SSPA (BSC 2001, Volume 1, [DIRS 154657] and BSC 2001, Volume 2, [DIRS 154659]).

As mentioned previously, this Letter Report addresses provisions of the NRC final rule 10 CFR Part 63 that are beyond what was considered in the FEIS/SSE Letter Report. The FEIS/SSE Letter Report considers radiation protection standards addressed in the final EPA rule 40 CFR Part 197 and adopted with added provisions by the NRC in its final rule 10 CFR Part 63. The areas are, as discussed in Section 1: 1) groundwater protection standard and the consideration of unlikely events (i.e., igneous intrusion); 2) individual protection standard for human intrusion and the consideration of unlikely events (i.e., igneous intrusion followed by human intrusion); and 3) the effect on the calculated dose for the individual protection standard due to the 3,000 acre-ft annual water demand specified in the final NRC rule at 10 CFR 63.312(c) (66 FR 55732 [DIRS 156671] p. 55814). The evaluations and comparisons relative to these radiation protection standards in the NRC final rule are presented in Section 6 below.

The revised supplemental TSPA model used in the FEIS/SSE Letter Report was developed from a previous TSPA model to incorporate the requirements of the final EPA Rule. The analyses in this Letter Report are based on that the supplemental TSPA model discussed in the SSPA. The calculations were performed within a probabilistic framework combining the various component models, processes, and corresponding parameters included in the overall conceptual/process model describing the performance of the repository. GoldSim integrates the sub-system models using a Monte-Carlo simulation-based methodology to create multiple random combinations of the uncertain variables, and computes the probabilistic performance of the entire waste-disposal system in terms of mean annual dose to receptors. The GoldSim software calculates radionuclide release and radiological dose as defined in 10 CFR 63.311 (66 FR 55732 [DIRS 156671] p. 55814) from individual radionuclides and the combined annual dose due to all radionuclides released from the repository from failed waste packages. For these analyses, GoldSim calculates the combined annual dose for multiple realizations (300 realizations for the human-intrusion scenarios and 5,000 realizations for the igneous-activity scenario) of the model configuration using randomly selected values of distributed parameters for each realization.

The performance-assessment methodology used for the calculations presented in this Letter Report draws upon the extensive analyses carried out in support of the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and Volumes 1 and 2 of the SSPA (BSC 2001 Volume 1 [DIRS

154657] and BSC 2001 Volume 2 [DIRS 154659]). Those calculations and analyses were based on proposed EPA and NRC rules. The EPA in its final rule (40 CFR 197.31) defined the representative volume for groundwater protection as 3,000 acre-ft/yr of water and did not specify a volume for water demand for the dose calculation to the RMEI for the evaluation against the individual protection standard. Results in FEIS/SSE Letter Report (BSC 2001 [DIRS 156460], Section 6.6) reflect this change for the evaluation of groundwater protection. In its final rule the NRC included 3,000 acre-ft/yr as water demand for the dose calculation to the reasonably maximally exposed individual for the evaluation of individual protection, as well as for the evaluation of groundwater protection. In the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460], Sections 6.2 and 6.3), the annual volume of water used for the evaluation of individual protection used a range from 887 to 3,367 acre-feet consistent with the final EPA rule. Thus, the FEIS/SSE Letter Report considered the effects of the use of a range of groundwater demand volumes as opposed to the use of 3,000 acre-feet annual water demand, as set forth in 10 CFR 63.312(c) (66 FR 55732 [DIRS 156671] p. 55814), for the simulated calculation of dose to the RMEI for evaluation against the individual protection standard. In this Letter Report, the evaluation of groundwater protection considering an unlikely event (i.e. igneous intrusion) uses a representative water volume of 3,000 acre-ft (10 CFR 63.331, 66 FR 55732 [DIRS 156671], Table 1, p. 55814) consistent with both the final EPA rule and the final NRC rule.

This Letter Report utilizes the results of the following scenarios previously calculated for the 70,000-MTHM-inventory case, HTOM and LTOM, and presented in the FEIS/SSE Letter Report or the SSPA, Volume 2. The following description of these scenarios used in the calculations presented in the FEIS/SSE Letter Report is provided for completeness.

- The human-intrusion scenario in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460] Sections 5.2.7 and 6.4; BSC 2001 Volume 1 [DIRS 154657] Appendix A) considers an "intruder" drilling a land-surface borehole using a drilling apparatus (under the common techniques and practices that are currently employed in exploratory drilling for groundwater in the region around Yucca Mountain). The "intruder" drills directly through a degraded waste package, and subsequently into the uppermost aquifer underlying the Yucca Mountain repository. The "intrusion" then causes the subsequent compromise and release to groundwater of the contaminated waste in the penetrated waste package. Two human-intrusion scenarios were simulated for a one-million-year performance period (BSC 2001 [DIRS 156460] Sections 5.2.7 and 6.4): one intrusion at 30,000 years and the other intrusion at 100 years after repository closure in accordance with the proposed NRC rule.
- The igneous-intrusion scenario, which was included as part of the more comprehensive igneous-activity scenario for the evaluation of individual protection, considered a dike (or dikes) intersecting emplacement drifts, causing varying degrees of waste-package damage in the affected drift(s) and subsequent release of radioactive material. The release and transport to the unsaturated zone (UZ) and subsequently to the saturated zone (SZ) was evaluated in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460] Sections 6.3.1 and 6.3.2).

3. ASSUMPTIONS

The TSPA results utilized for the evaluations in this Letter Report have been previously calculated for the FEIS/SSE Letter Report (BSC 2001 [156460]) based on the final EPA rule 40 CFR Part 197 (66 FR 32074 [DIRS 155216]). Some key assumptions used in those calculations and in this Letter Report are listed here for completeness.

3.1 ASSUMPTION 1

The 70,000-MTHM-case model configuration for the calculations in this Letter Report is the same as the model configuration discussed in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460]), which was, in turn, based on the SSPA model configuration (BSC 2001 Volume 1 [DIRS 154657]), and the TSPA-SR model (CRWMS M&O 2000 [DIRS 153246]). The model used for the calculations used in Sections 6.0 of this Letter Report includes the modifications from the SSPA and TSPA-SR models as described in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460], Section 5).

3.2 ASSUMPTION 2

The radionuclide inventories used in the calculations in Section 6.0 are those developed in the *Inventory Abstraction* (BSC 2001 [DIRS 154841], Table 36, p.38). The per-package inventories for the CSNF, and co-disposal waste packages are the same as those used in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Section 3.5.1, p. 3-94 to 3-100). The DSNF inventory includes the U.S. Navy spent nuclear fuel which was modeled using CSNF as a bounding surrogate for naval spent nuclear fuel. Because of the robust design of naval spent nuclear fuel, releases from naval spent nuclear fuel are significantly less than releases from commercial spent fuel (BSC 2001 [DIRS 152059], Section 6.1.1). Therefore, for analysis purposes, releases from naval spent nuclear fuel waste packages are included with releases from CSNF waste packages (DOE 2001 [DIRS 153849], Section 4.2.6.3.9, p. 4-257).

4. USE OF COMPUTER SOFTWARE

The calculations described in this Letter Report were performed using the numerical code GoldSim, Version 7.17.200 (BSC 2001, GoldSim V7.17.200 STN:10344-7.17.200-00 [DIRS 155182]). GoldSim is designed so that probabilistic simulations can be conducted and represented graphically. Although not currently qualified in accordance with AP-SI.1Q, *Software Management*, GoldSim Version 7.17.200 (STN: 10344-7.17.200-00 [DIRS 155182]) is used for this application and used within a specified range that complies with the applicable range for GoldSim Version 7.17.200.

5. CALCULATION

5.1 BACKGROUND

The scope of the calculations presented in this Letter Report includes evaluation of long-term performance after the eventual closure of a potential Yucca Mountain repository as located on Figure 5-1. In particular, these calculations focus on a potential Yucca Mountain repository for the disposal of 70,000 MTHM of nuclear material allowed by the NWPA. The evaluations utilize calculations from the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460]) which were performed in a manner consistent with the specifications of the final EPA standard regarding a repository at Yucca Mountain found at 40 CFR Part 197 (66 FR 32074 [DIRS 155216], pp. 32132 - 32135) and with the final NRC rule at 10 CFR Part 63 (66 FR 55732 [DIRS 156671] p. 55813 - 55816).

5.2 MODEL CONFIGURATION

This Letter Report utilizes the FEIS/SSE (BSC 2001 [DIRS 156460]) modeling of the 70,000-MTHM-case repository configuration. The analysis is provided only for the release of radioactive material from the Primary Block, the area designated for the 70,000 MTHM inventory HTOM of the potential Yucca Mountain repository as shown in Figure 5-2.

The GoldSim numerical code simulates transport of radionuclides from the repository, through the UZ, and through the SZ to the accessible environment. The different process models included in the GoldSim code are fully described and documented in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]).

The GoldSim model configuration used for the FEIS/SSE Letter Report conforms to the recently published EPA final rule 40 CFR Part 197 (66 FR 32074 [DIRS 155216], p. 32132 to 32135). The FEIS/SSE model configuration and changes from previous TSPA model configurations found in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and the Volumes 1 and 2 of the SSPA (BSC 2001 [DIRS 154657] and BSC 2001 [DIRS 154659]) are described in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460] Section 5.2).

5.3 SCENARIOS CONSIDERED IN THIS REPORT

In this Letter Report, the TSPA evaluation considers three cases relative to the impact on protection standards in the final NRC rule 10 CFR Part 63 using the results of calculations presented in the FEIS/SSE Letter Report: (1) the groundwater protection standard considering the unlikely event of an igneous intrusion; (2) the individual protection standard for human intrusion considering the unlikely event of an igneous intrusion followed by a human intrusion; and (3) the effect of the use of a specific water-demand value (i.e., 3,000 acre-ft per year) on the individual protection standard.

5.3.1 Groundwater Protection Standard Evaluation Utilizing an Unlikely Igneous-Intrusion Scenario

The evaluation of the groundwater protection standard utilizing the igneous-intrusion scenario used the results of the same igneous-activity model scenario used for the FEIS/SSE analysis and described in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460] Section 2, p. 5 and Section 5.2.6, p. 16). However, the results of the calculations based on that scenario were post processed to capture the information relevant to this particular case, i.e., the specific groundwater concentrations and critical organ doses attributed to drinking 2 liters per day of water derived from the representative volume.

5.3.2 Individual Protection Standard for Human Intrusion Considering an Unlikely Igneous Intrusion

The evaluation scenario utilized for this topic considered the igneous-intrusion scenario and the human-intrusion scenario, both of which were described in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460] Section 5.2.6, p. 16 and 6.3, p. 24 and Sections 5.2.7, p. 17 and 6.4, p. 25). This scenario assumes that a driller would not be able to detect a waste package that may have been previously damaged by a low-probability igneous-intrusion event. As noted in the FEIS/SSE Letter Report, in the nominal scenario, the driller is expected to be able to detect the presence of waste packages until sufficient time has passed to allow enough damage of the waste package to occur, a minimum of 30,000 years (BSC 2001 [DIRS 156460] Section 5.2.7, p.17).

The scenario was examined by comparing the results of these two scenarios as calculated for the FEIS/SSE Letter Report (BSC 2001, [DIRS 156460] Sections 6.3.1 and 6.4.2). Note that the results used in the evaluations in this Letter Report were those due to the igneous intrusion only, which were extracted from the combined igneous-activity scenario described in the FEIS/SSE Letter Report (BSC 2001, [DIRS 156460] Table 6-1, p. 23).

5.3.3 Use of 3,000 acre-ft Per Year Water Demand on Individual Protection

The evaluation assessed the effect on individual protection of assuming a 3,000 acre-ft annual water demand as the water demand. The assessment was developed by comparing the simulated dose to the RMEI, as presented in the FEIS/SSE Letter report (BSC 2001 [DIRS 156460] Section 6.6), to the possible effect of applying the 3,000 acre-ft water demand, per 10 CFR 63.312 (66 FR 55732 [DIRS 156671] p. 55814).

6. RESULTS

The GoldSim simulations in support of this Letter Report were presented in the FEIS/SSE Letter report and provide estimates of the groundwater radiation concentrations and dose to critical organs assuming an unlikely event (i.e., an igneous intrusion) (See Section 6.1), dose from a human-intrusion event preceded by an unlikely event (i.e., an igneous intrusion) (See Section 6.2), and the effect of consideration of a 3,000 acre-feet water demand on the calculated dose for comparison to the individual-protection standard (See Section 6.3).

The data input and output files containing all the graphical and tabular results for the calculations presented in this report have been submitted to the Records Processing Center along with a list of the files and instructions on retrieving these data (Saulnier 2001 [DIRS 155948]).

6.1 GROUNDWATER PROTECTION STANDARD CONSIDERING AN UNLIKELY EVENT (IGNEOUS INTRUSION)

Figure 6-1 presents the mean activity concentrations of gross alpha activity and total radium (^{226}Ra plus ^{228}Ra) in the representative volume of groundwater for the igneous-intrusion scenario and the 70,000 MTHM inventory, HTOM. These mean activity concentration values are calculated in the same manner that the mean dose is calculated for the individual protection standard; that is, they are the concentrations weighted by the probability of occurrence of the igneous intrusion event. The concentrations are calculated for a representative volume of water of 3,000 acre-ft at the accessible environment at the same location as the RMEI as described in 10 CFR 63.312 and 63.331 (66 FR 55732 [DIRS 156671] p. 55814]). Figure 6-2 presents the same information for the LTOM. Both the radionuclide concentrations and dose are presented to 10,000 years; there are no regulatory requirements for groundwater protection analyses beyond 10,000 years.

The results for the evaluation of groundwater protection considering an unlikely event (igneous intrusion) are obtained by combining the results for the nominal scenario with the results for the igneous intrusion scenario. Results presented in the three tables below show the calculated results for both the nominal scenario (BSC 2001 [DIRS 156460], Tables 6-2, 6-3, and 6-4) and the igneous intrusion scenario. Because the nominal scenario results for groundwater protection calculations are negligible compared to the results calculated for an igneous intrusion, the activity concentrations and dose estimates for groundwater protection considering igneous intrusion are approximated as those calculated for an igneous intrusion.

Naturally occurring background radionuclide concentrations are not included on Figures 6-1 and 6-2 but are presented in Tables 6-1 and 6-2. Table 6-1 shows the maximum mean gross alpha activity for both the nominal scenario and igneous intrusion only (with and without natural background) for the 10,000-year performance period. Table 6-2 shows maximum mean total radium concentration for both the nominal scenario and the igneous intrusion only (with and without natural background) for the 10,000-year performance period. For the first 10,000 years after closure, the gross alpha concentrations are about 10 per cent of natural background. The calculated total radium concentrations are orders of magnitude lower than natural background.

Table 6-1 Maximum Mean Gross Alpha Activity by Scenario for the 10,000-year Performance Period

Mean Alpha Activity (pCi/L)			
Case	**Model File**	**10,000 yr Maximum**	
		w/o bckgrnd	w/ bckgrnd
Nominal, 70,000 MTHM, HTOM	SE01_006nm6	1.8E-08	4.0E-01
Nominal, 70,000 MTHM, LTOM	SE01_007nm6	3.3E-08	4.0E-01
Igneous Intrusive Activity, 70,000 MTHM, HTOM	SE01_003im5	2.9E-02	4.3E-01
Igneous Intrusive Activity, 70,000 MTHM, LTOM	SE01_004im5	5.5E-02	4.6E-01
Background Alpha Activity Concentration is 0.4 ± 0.7 pCi/L (CRWMS M&O 2000 [DIRS 153246] p. 4-16)			
These data are based on a representative water volume equal to 3000 acre-ft/yr.			

Table 6-2 Maximum Total Mean Radium Concentration by Scenario for the 10,000-year Performance Period

Total Radium (226Ra and 228Ra) Concentration (pCi/L)			
Case	**Model File**	**10,000 yr Maximum**	
		w/o bckgrnd	w/ bckgrnd
Nominal, 70,000 MTHM, HTOM	SE01_006nm6	1.1E-11	1.0
Nominal, 70,000 MTHM, LTOM	SE01_007nm6	2.4E-12	1.0
Igneous Intrusive Activity, 70,000 MTHM, HTOM	SE01_003im5	5.0E-06	1.0
Igneous Intrusive Activity, 70,000 MTHM, LTOM	SE01_004im5	5.2E-06	1.0
Background Radium Activity Concentration is 1.04 pCi/L (CRWMS M&O 2000 [DIRS 153246] p. 4-16)			
These data are based on a representative water volume equal to 3000 acre-ft/yr.			

Figure 6-3 presents the mean dose to critical organs for ^{99}Tc, ^{14}C, and ^{129}I, the prominent beta and photon-emitting radionuclides (CRWMS M&O 2000 [DIRS 153246], Section 4.1.5, p. 4-17) considering an igneous-intrusion scenario and the nominal scenario for the 70,000 MTHM inventory, HTOM, for a 10,000-year performance period. Figure 6-4 presents the same information for the LTOM. Table 6-3 shows the maximum mean dose to critical organs in 10,000 years for ^{99}Tc, ^{14}C, and ^{129}I for the nominal scenario and for the igneous-intrusion scenario only.

Table 6-3 Maximum Mean Dose to Critical Organs in 10,000 years for ^{99}Tc, ^{14}C, and ^{129}I by Scenario

Maximum Mean Dose to Critical Organs In 10,000 years (mrem/yr)					
Case	**Model File**	**Tc-99**	**C-14**	**I-129**	**Total[1]**
Nominal, 70,000 MTHM, HTOM	SE01_006nm6	1.2E-05	2.4E-07	9.1E-06	2.1E-05
Nominal, 70,000 MTHM, LTOM	SE01_007nm6	7.0E-06	1.8E-07	7.5E-06	1.5E-05
Igneous Intrusive Activity, 70,000 MTHM, HTOM	SE01_003im5	6.9E-02	1.9E-03	2.0E-01	2.7E-01
Igneous Intrusive Activity, 70,000 MTHM, LTOM	SE01_004im5	6.3E-02	2.0E-03	1.9E-01	2.6E-01

These data are based on a representative water volume equal to 3000 acre-ft/yr.
[1]Total values represent a bounding (overestimate) of the maximum dose to any organ because the different radionuclides would affect different organs preferentially.

6.2 INDIVIDUAL PROTECTION STANDARD FOR HUMAN INTRUSION CONSIDERING A PRIOR UNLIKELY EVENT (IGNEOUS INTRUSION)

The FEIS/SSE Letter Report presents analyses of a 100-year human intrusion scenario (per proposed NRC regulations (64 FR 8640 [DIRS 101680]) and a 30,000 year human-intrusion scenario, HTOM (BSC 2001 [DIRS 156460] Section 6.4, p.25-26)). The calculated dose for a human intrusion at 30,000 years is consistent with the final EPA and NRC rules and represents the DOE determination that the earliest time after disposal that an individual waste package would degrade sufficiently that a human intrusion could occur without recognition by a driller is 30,000 years, assuming no unlikely event (such as an igneous intrusion) affected the waste package.

An analysis of a possible human intrusion of the potential Yucca Mountain repository, according to the requirements of 10 CFR 63.321, resulted in the determination that an undetected human intrusion would not occur until at least 30,000 years post closure. That determination was based on the following summary analysis excerpted from the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Section 3.4) and also described in Volume 1 of the SSPA (BSC 2001 [DIRS 154657], Appendix A). The results of the TSPA-SR drip shield and waste package studies indicate long lifetimes for these components (CRWMS M&O 2000 [DIRS 153246], Section 3.4), with the first drip shield failures occurring after about 20,000 years. The first failures of the waste package outer material, Alloy 22, by general corrosion occur after approximately 30,000 years. The duration of general corrosion for this analysis does not consider the 5 cm of stainless steel beneath the Alloy 22 in the standard waste-package configuration. Although, general corrosion occurs gradually over time up to the time of failure, the oxidation process is a surface phenomenon, and the underlying metal retains its integrity and resistance to drilling. Although results show failures at early time, these failures are the result of localized corrosion and are not associated with degradation of the overall structural integrity of the waste package, and the resistance to drilling is maintained. Considering the nature of the waste-package materials in the current design, the earliest time after disposal at which a driller would not recognize they had penetrated a waste-package and drip-shield would be about 30,000 years.

As discussed in Section 1, the NRC final rule does not define "unlikely," and does not expressly require consideration of a human intrusion preceded by an igneous intrusion. Nonetheless, this event is considered here as an alternative analysis even though the mean annual probability of an igneous intrusion at the location of the potential repository is 1.6×10^{-8} (CRWMS M&O 2000 [DIRS 153246] Table 3.10-5, p. 3-203). If an igneous-intrusion event were to occur, it could compromise some waste packages such that a driller would not recognize a waste-package penetration. If such an unlikely event were to precede a human intrusion, the consequences of the human intrusion should reasonably be weighted by the probability of the initiating igneous intrusion in order to calculate the mean value results of a human intrusion that could occur before 30,000 years. As discussed above, the results of a human intrusion at 100 years without a prior igneous intrusion were presented in the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460] Table 6-1a, Figures 6-10b and 6-15). However, the calculated dose for the time period of that scenario before 30,000 years would have to be reduced because of the probabilistic weighting due to the two unlikely events occurring in succession (i.e., the igneous-intrusion event followed by a human intrusion). A waste package damaged by an igneous event and then drilled through during a human intrusion would release the inventory of only one waste package versus the results of the waste packages compromised in the repository drift or drifts affected by the igneous intrusion. Thus, because the human intrusion post-dates the igneous intrusion, the dose due to the igneous intrusion bounds the possible dose due to the human intrusion.

To provide a quantitative understanding of the potential dose attributed to a human-intrusion event that follows an unlikely igneous-intrusion event, the following estimate of dose was prepared. The mean annual individual dose due to a human intrusion following an unlikely igneous intrusion can be approximated by multiplying (1) the conditional dose assuming a human-intrusion event occurs times (2) the probability of the initiating igneous-intrusion event times (3) the probability of the driller not detecting the waste package (assumed to be equal to one if the drilling is preceded by an igneous-intrusion event). The conditional human-intrusion dose would be a function of when the initiating igneous intrusion occurs as well as when the succeeding human-intrusion event occurs. However, a worse case would be assuming the human-intrusion event occurs immediately following the loss of institutional controls. Such a calculation has been presented in the FEIS/SSE Letter Report for a human intrusion at 100 years, and the resultant maximum mean dose was 4.8×10^{-3} mrem/yr (BSC 2001 [DIRS 156460] Table 6-1, p. 23). The probability of the igneous initiating event occurring is a function of time. Considering that we are interested in the possibility of an event occurring prior to the 30,000 years (the time at which the driller would not be expected to detect a waste package due to likely features, events and processes), the probability of an igneous event occurring sometime in 30,000 years is 4.8×10^{-4} (30,000 years times a mean annual probability of 1.6×10^{-8} per year (CRWMS M&O 2000 [DIRS 153246] Table 3.10-5, p. 3-203). Therefore the approximate maximum mean dose due to a human intrusion following an igneous intrusion would be the probability times the maximum mean dose or 2.3×10^{-6} mrem/year. In the FEIS/SSE Letter Report, the maximum mean dose in the first 10,000 years postclosure due to an igneous intrusion is 4.3×10^{-4} mrem/year (BSC 2001 [DIRS 156460] Table 6-1, p. 23). Therefore, the potential maximum mean dose due to a human intrusion preceded by an igneous intrusion is concluded to be much lower than the maximum mean dose due to the igneous intrusion alone.

6.3 INDIVIDUAL PROTECTION STANDARD AND THE EFFECT OF 3,000 ACRE-FEET WATER DEMAND

The TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), Volume 2 of the SSPA (BSC 2001 [DIRS 154659], and the FEIS/SSE Letter Report BSC 2001 [DIRS 156460], Section 4.0) calculated individual-protection-standard dose in a probabilistic manner using a volume of water necessary to operate 15 to 25 farms, representing a range of groundwater volumes from 887 to 3,367 acre-ft, with an average water demand of approximately 2,000 acre-ft/year. The calculations assume that the water volume contains all of the annual radionuclide releases. This range and approximate average demand is consistent with the proposed NRC rule and the final EPA rule. The final NRC rule states that the individual protection standard should be calculated using an average water demand of 3,000 acre-ft (10 CFR 63.312(c)). The use of 3,000 acre-ft /year as the water demand would result in a subsequent decrease in the calculated mean annual dose relative to the individual protection standard. Dose calculated to the RMEI for the assessment of individual protection in the FEIS/SSE Letter Report represents a more conservative (i.e., higher) estimate of dose because the average water demand for the calculations was approximately two thirds of the water demand specified by the NRC in 10 CFR 63.312(c). Thus, increasing the water demand to the water volume specified by NRC at 10 CFR Part 63.312(c) (66 FR 55732 [DIRS 156671] p. 55814) would result in a calculated values of dose that would be approximately two thirds of the calculated values of dose for each scenario shown on Table 6-1 of the FEIS/SSE Letter Report (BSC 2001 [DIRS 156460] p. 23). For example, the peak mean annual dose for a human-intrusion scenario would be reduced from $4.8x10^{-3}$ mrem/year to $3.2x10^{-3}$ mrem/year using the increased water demand. Other values in this table would be similarly reduced.

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156459 BSC 2001. Technical Work Plan for TSPA Sensitivity Analyses for Final Regulations. TWP-MGR-PA-000004 REV 00. Las Vegas, NV: Bechtel SAIC Company LLC. ACC: MOL.20011105.0324..

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156708 Adams, J.J. 2001. Direction to Assess Postclosure Impacts of Draft 10 Code of Federal Regulations (CFR) Part 63 Final Rule; Contract Number DE-AC08-01RW12101, DOE Letter From JJ Adams (DOE/YMSCO) to K. Hess (BSC) 10/2/01. ACC: MOL.20011030.0394.

7.2 CODES, STANDARDS, AND REGULATIONS

131951 Nuclear Waste Policy Act of 1982, as amended (NWPA, Public Law 97-425) Readily available.

101680 64 FR 8640. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada. Proposed rule 10 CFR Part 63. Readily available.

155216 66 FR 32074. 40 CFR Part 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV; Final Rule. Readily available.

156671 66 FR 55732. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, NV. Final Rule 10 CFR Part 63. Readily available.

7.3 PROCEDURES

AP-SI.1Q, Rev. 3, ICN 02, ECN 01. *Software Management*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20011030.0598.

8. ATTACHMENTS

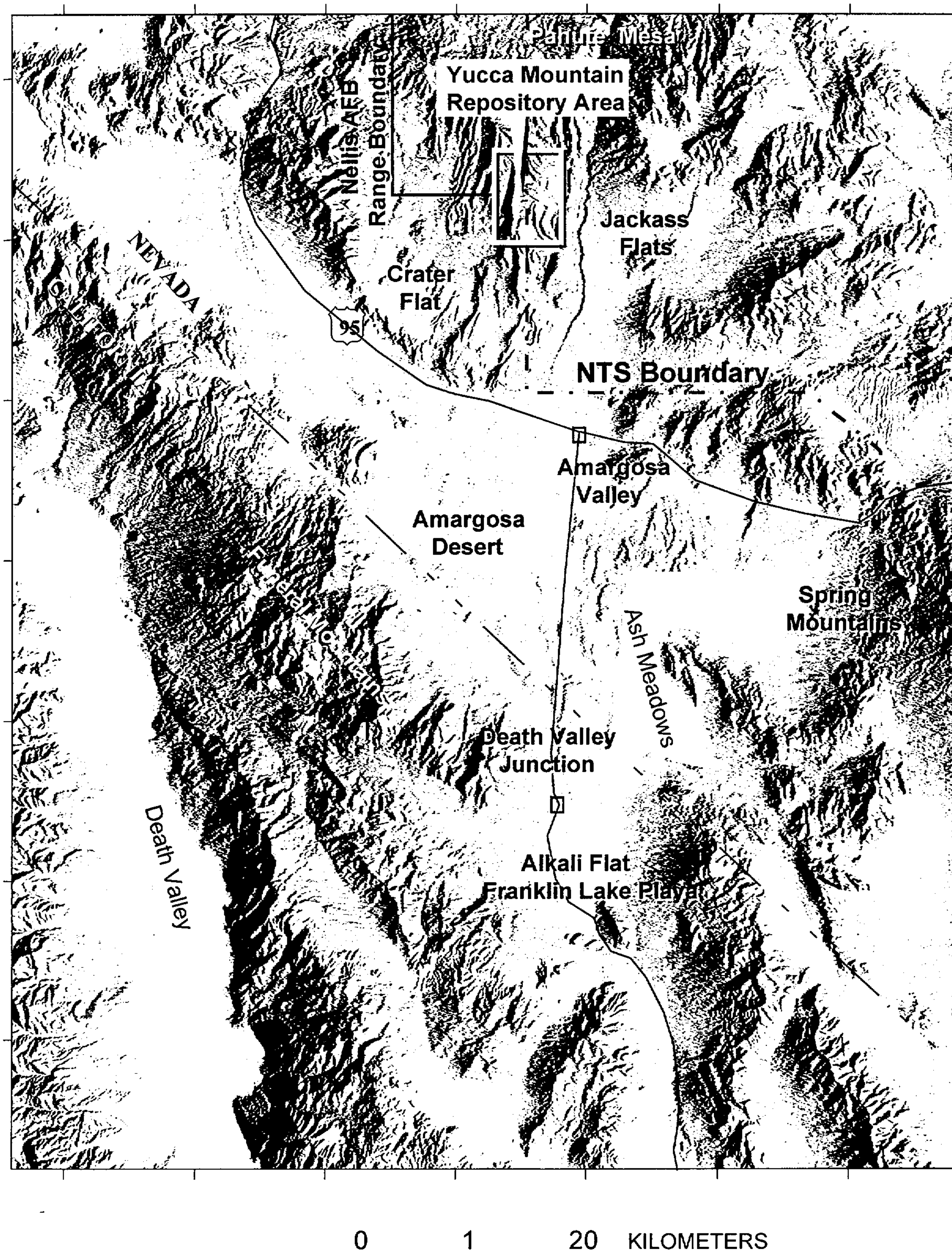

Figure 5-1 Location of a Potential Yucca Mountain Repository

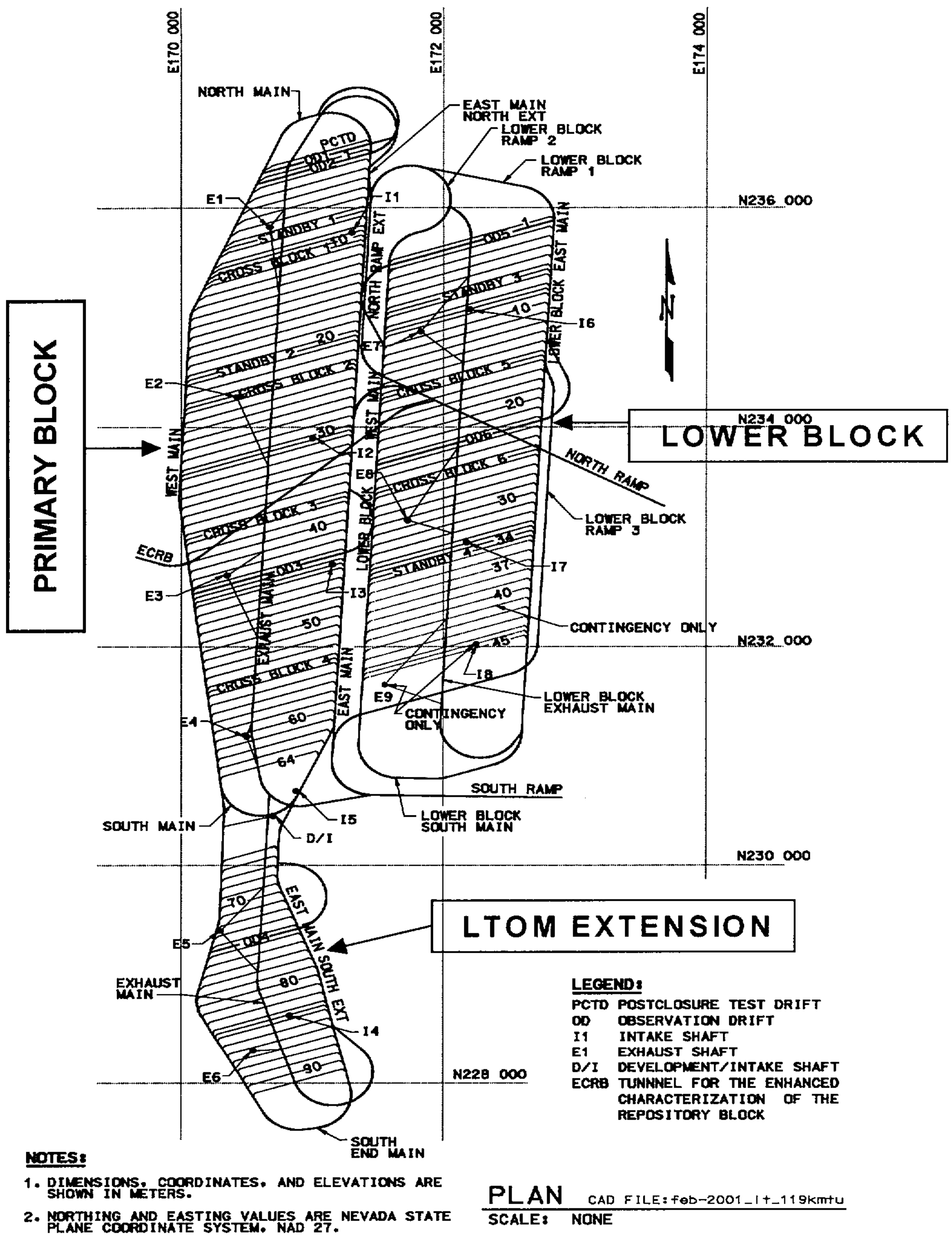

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Figure 5-2 Approximate Configuration of a Potential Yucca Mountain Repository

Note:Disposal for the 70,000 MTHM case under the HTOM would utilize the Primary Block. Disposal for the Expanded Inventory Case, approximately 119,000 MTHM, would utilize the Primay Block and the Lower Block. (Source BSC 2001 [DIRS 154554], Section 6.1.2.1, Figure 3, p. 43 of 126)

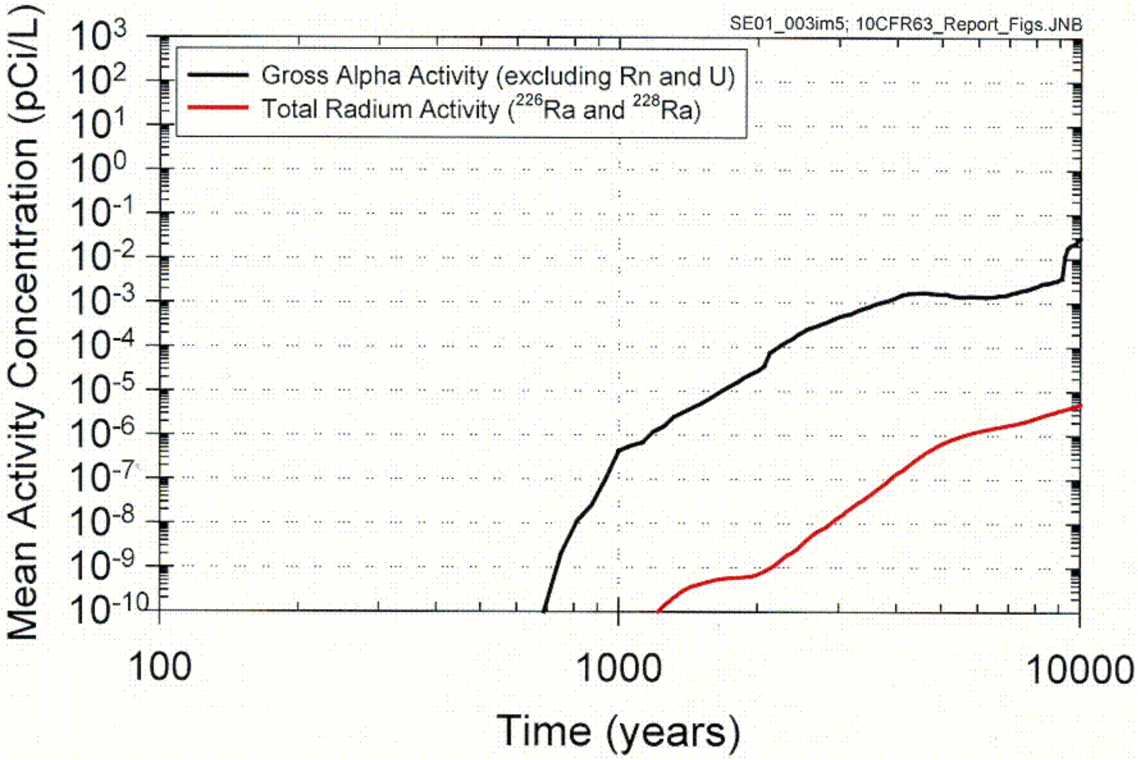

Figure 6-1 Mean Activity Concentrations of Gross Alpha Activity and Total Radium (^{226}Ra plus ^{228}Ra) for the Igneous-Intrusion Scenario, HTOM. The Concentrations are Calculated for a Representative Volume of Groundwater of 3,000 acre-feet at the Accessible Environment, Which is the Same as the RMEI Location

C01

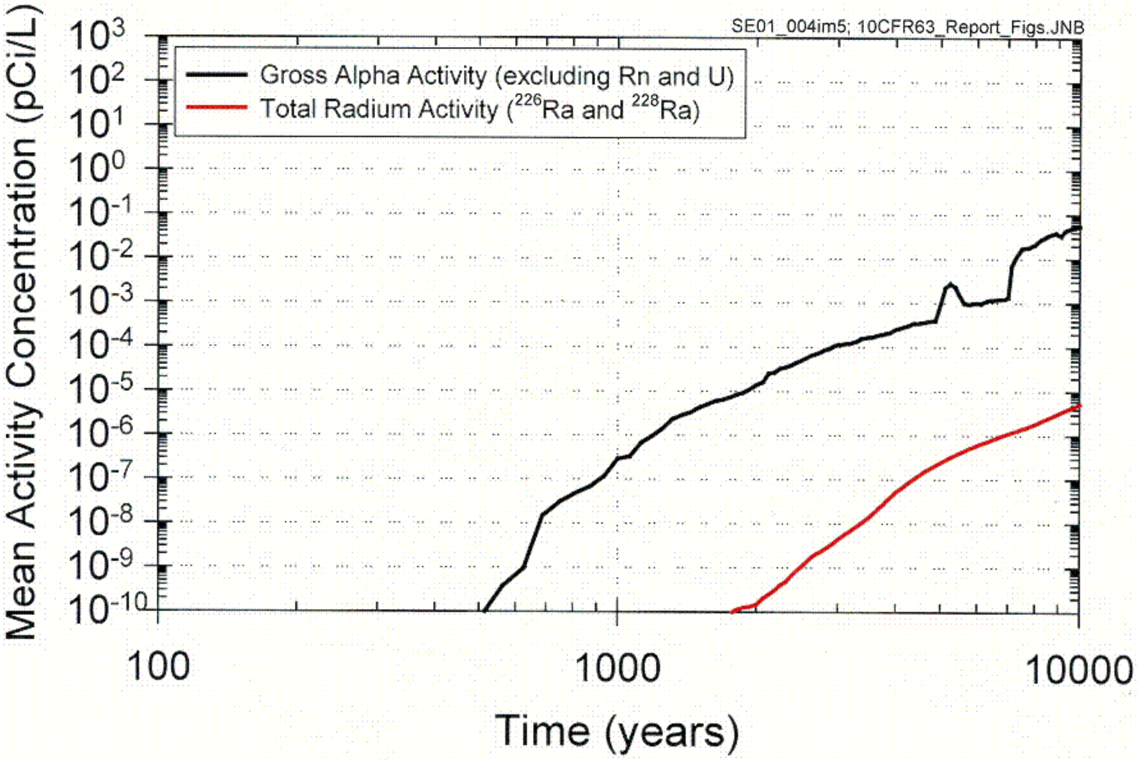

Figure 6-2 Mean Activity Concentrations of Gross Alpha Activity and Total Radium (^{226}Ra plus ^{228}Ra) for the Igneous-Intrusion Scenario, LTOM. The Concentrations are Calculated for a Representative Volume of Groundwater of 3,000 acre-feet at the Accessible Environment, Which is the Same as the RMEI Location

C02

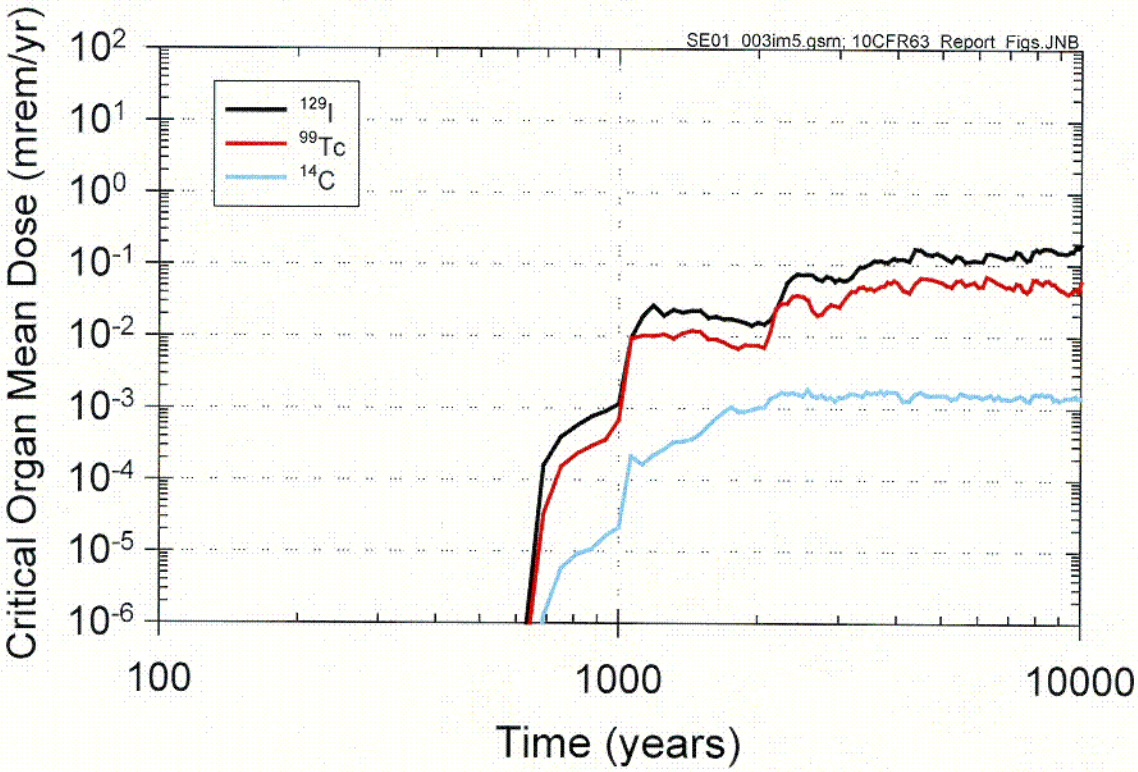

Figure 6-3 Mean Dose to Critical Organs for ^{99}Tc, ^{14}C, and ^{129}I for the Igneous-Intrusion Scenario, HTOM. The Concentrations are Calculated for a Representative Volume of Groundwater of 3,000 acre-feet at the Accessible Environment, Which is the Same as the RMEI Location

C03

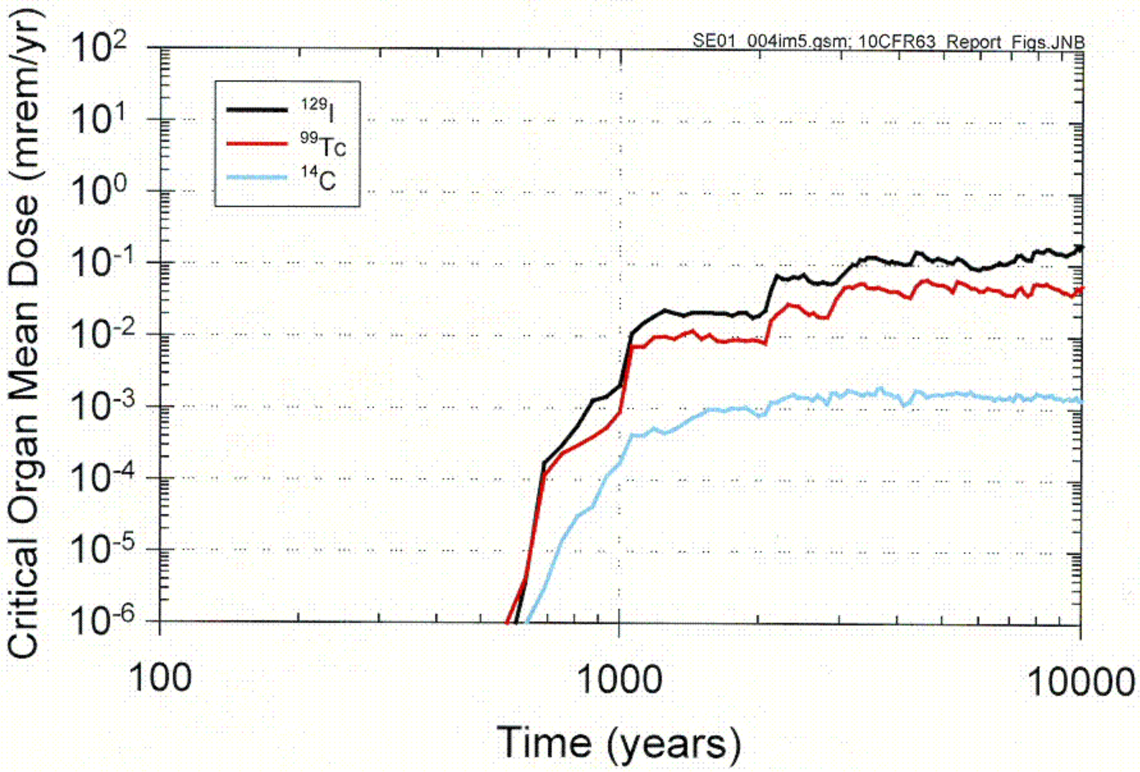

Figure 6-4 Mean Dose to Critical Organs for ^{99}Tc, ^{14}C, and ^{129}I for the Igneous-Intrusion Scenario, LTOM. The Concentrations are Calculated for a Representative Volume of Groundwater of 3,000 acre-feet at the Accessible Environment, Which is the Same as the RMEI Location

C04

ATTACHMENT I

ACRONYMS AND ABBREVIATIONS

ACRONYMS AND ABBREVIATIONS

BSC	Bechtel SAIC Company, LLC
CFR	Code of Federal Regulations
CRWMS	Civilian Radioactive Waste Management System
CSNF	Commercial Spent Nuclear Fuel
DIRS	Document Input Reference System
DOE	U.S. Department of Energy
DSNF	DOE Spent Nuclear Fuel
EPA	U.S. Environmental Protection Agency
EIS	Environmental Impact Statement
FEIS	Final Environmental Impact Statement
FEPs	features, events, and processes
FR	Federal Register
HLW	High-Level Waste
HTOM	high-temperature operating mode
LTOM	low-temperature operating mode
MTHM	Metric Tons Heavy Metal
M&O	Management and Operating Contractor
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
REV	Revision
RMEI	reasonably maximally exposed individual
SSE	Site Suitability Evaluation
SNF	Spent Nuclear Fuel
SR	Site Recommendation
SSPA	Supplemental Science and Performance Analysis
STN	Software Tracking Number
SZ	Saturated Zone
TSPA	Total System Performance Assessment
UZ	Unsaturated Zone

WBS: 1.2.21
QA:N/A

Total System Performance Assessment - Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain – Input to Final Environmental Impact Statement and Site Suitability Evaluation

REV 00 ICN 01

September 2001

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UNDER CONTRACT NUMBER
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CONTENTS

Page

CONTENTS

FIGURES

FIGURES

Page

FIGURES

Page

TABLES

Page

1. PURPOSE

This Letter Report presents the results of calculations to assess long-term performance of commercial spent nuclear fuel (CSNF), U. S. Department of Energy (DOE) spent nuclear fuel (DSNF), high-level radioactive waste (HLW), and Greater Than Class C (GTCC) radioactive waste and DOE Special Performance Assessment Required (SPAR) radioactive waste at the potential Yucca Mountain repository in Nye County Nevada with respect to the 10,000-year performance period specified in 40 CFR Part 197.30 (66 FR 32074 [DIRS 155216], p. 32134) with regard to radiation-protection standards. The EPA Final Rule 40 CFR Part 197 has three separate standards, individual-protection, human-intrusion, and groundwater-protection standards, all with a compliance timeframe of 10,000 years. These calculations evaluate the dose to receptors for each of these standards. Further, this Letter Report includes the results of simulations to the 1,000,000-year performance period described in 40 CFR Part 197.35 (66 FR 32074 [DIRS 155216], p. 32135) which calls for the calculation of the peak dose to the Reasonably Maximally Exposed Individual (RMEI) that would occur after 10,000 years and within the period of geological stability. In accordance with TSPA-SR the "period of geologic stability" is from zero to 1,000,000 years after repository closure. The calculations also present the 5th and 95th percentiles, and the mean and median of the set of probabilistic simulations used to evaluate various disposal scenarios.

These calculations have been conducted by the BSC Total System Performance Assessment Department in support of the *Final Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, and the *Yucca Mountain Site Suitability Evaluation (SSE)*. The Nuclear Waste Policy Act of 1982, as amended (NWPA, Public Law 97-425 [DIRS 131951]) directs the DOE to evaluate the suitability of the Yucca Mountain site in southern Nevada as a potential site for development of a geologic repository for the disposal of spent nuclear fuel (SNF) and HLW. If the Secretary of Energy determines that the Yucca Mountain site is suitable, the Secretary may then recommend that the President approve the site for the development of a mined geologic repository.

The simulations conducted for this Letter Report calculate dose to the RMEI (as defined by 40 CFR Part 197.20 [DIRS 155216]) from the simulated release of radioactive materials from the potential Yucca Mountain repository to the accessible environment as specified in 40 CFR Part 197.21 (66 FR 32074 [DIRS 155216], p.32133). The RMEI is located in the accessible environment where the groundwater path of the highest concentration of the contaminant plume would cross the southernmost boundary of the controlled area of the potential repository (at a Latitude of 36° 40' 13.6661" North). This location is approximately 18 km from within the potential repository footprint. The objective of this Letter Report is to update the results of the TSPA-SR and SSPA analyses and incorporate the requirements of 40 CFR Part 197 (66 FR 32074 [DIRS 155216]).

40 CFR Part 197.20 (66 FR 32074 [DIRS 155216], p. 32135) directed DOE to calculate the dose to the RMEI from releases from the undisturbed Yucca Mountain disposal system, and to include in the analysis, all potential pathways of radionuclide transport and exposure. Therefore, calculations in this Letter Report incorporate an igneous-activity scenario that includes a volcanic eruption. Under this scenario, the RMEI could receive part of the simulated total dose

from an air pathway contaminated during an eruptive event, as well as from the groundwater pathway.

The calculations included in this Letter Report were conducted following the *Total System Performance Assessment for the Site Recommendation* (TSPA-SR) (CRWMS M&O 2000 [DIRS 153246], all) and the *Supplemental Science and Performance Analyses* (SSPA) (BSC 2001 [DIRS 154657], all). Process models included in the model configuration used in the calculations are generally consistent with the process models described in the TSPA-SR and implemented in the SSPA (CRWMS M&O 2000 [DIRS 153246], all; BSC 2001 [DIRS 154657], all; BSC 2001 [DIRS 154659], Section 4.0, all); exceptions are described in Section 5 below.

The calculations include evaluation of annual dose histories for the 70,000-MTHM-inventory case used in TSPA-SR REV 00 ICN 01 and the SSPA, and two expanded-inventory cases, Module 1 and Module 2 (See Section 1.1 RADIONUCLIDE INVENTORIES immediately below) that ultimately include the total amount of commercial and DOE nuclear waste that could become available for disposal. The cases in these calculations utilized waste-package distributions consistent with the 70,000-MTHM-case thermal loading of approximately 56 MTHM per acre for the high-temperature operating mode (HTOM). In addition, the 70,000-MTHM-case was evaluated under a thermal loading of approximately 45 MTHM/acre, which is described as the low-temperature operating mode (LTOM).

This Letter Report was developed under Technical Work Plan TWP-MGR-MD-000016 REV 00 (BSC 2001 [DIRS 155906], all). This Technical Work Plan and the activity evaluation specified that this Letter Report was not to be developed per the YMP QA program and thus QARD requirements are not applicable.

1.1 RADIONUCLIDE-INVENTORIES

The performance-assessment calculations included in this Letter Report were performed for three separate radionuclide inventories that could be disposed at the potential Yucca Mountain repository. The 70,000-MTHM inventory is the limit for Yucca Mountain until a second repository becomes operational according to *)*. the Nuclear Waste Policy Act of 1982, as amended (NWPA, Public Law 97-425 [DIRS 131951]). The other two cases consider two radionuclide inventories that would require the expansion of the repository to include the complete inventory of commercial and DOE radioactive waste. The cases, as directed by DOE in the Technical Work Plan TWP-MGR-MD-000016 for this activity (BSC 2001 [DIRS 155906], all) are described as follows:

- <u>70,000-MTHM-Inventory Case</u>: The 70,000-MTHM-Inventory Case is comprised of 63,000 MTHM of CSNF, 2,333 MTHM of DSNF, and 4,667 MTHM of HLW.

- <u>Expanded-Inventory Case - Module 1</u>: Module 1 includes the CSNF and DSNF waste included in the 70,000-MTHM case plus all remaining CSNF, DSNF, and HLW. The Module 1 inventory consists of approximately 105,000 MTHM of CSNF, 2,500 MTHM of DSNF, and 11,500 MTHM of HLW.

- <u>Expanded-Inventory Case - Module 2</u>: Module 2 includes all the CSNF, DSNF, and HLW in Module 1 plus approximately 2,100 m^3 of GTCC waste and 4,000 m^3 DOE SPAR waste.

1.2 PERFORMANCE-ASSESSMENT CALCULATIONS

The set of calculations included in this Letter Report cover both the 10,000-and 1,000,000-year performance periods specified in 40 CFR Part 197.30 and 197.35 (66 32074 [DIRS 155216] p. 32134 and 32135) and the Technical Work Plan TWP-MGR-MD-000016 for this activity (BSC 2001 [DIRS 155906], all). The calculations comprise the following scenarios:

- 70,000-MTHM Inventory, HTOM
- 70,000-MTHM Inventory, LTOM
- Expanded-inventory Case, Module 1, HTOM
- Expanded-inventory Case, Module 2, HTOM
- Igneous-Activity Scenario including both the igneous-intrusion and volcanic-eruption scenarios, 70,000-MTHM Inventory, HTOM
- Igneous-Activity Scenario including both the igneous-intrusion and volcanic-eruption scenarios, 70,000-MTHM Inventory, LTOM
- Human-Intrusion Scenario, 70,000-MTHM Inventory, 30,000 years postclosure, HTOM
- Human-Intrusion Scenario, 70,000-MTHM Inventory, 100 years postclosure, HTOM

These performance-assessment calculations primarily address only the long-term impacts from radionuclides released from the potential repository. All these scenarios calculate dose due to the groundwater pathway to the location of the RMEI. The igneous-activity scenarios also include an atmospheric-transport pathway due to a volcanic-eruption.

2. METHOD

The calculations presented in this Letter Report were performed using the numerical code GoldSim, Version 7.17.200 (BSC 2001, GoldSim V7.17.200 10344-7.17.200-00. URN 0901 [DIRS 155182]). The GoldSim calculations were performed for the conceptual/process modeling of the potential Yucca Mountain repository described in TSPA-SR Rev 00, ICN 01 (CRWMS M&O 2000 [DIRS 153246]) and expanded upon in the SSPA (BSC 2001, Volume 1, [DIRS 154657]; BSC 2001, Volume 2, [DIRS 154659]). The Technical Work Plan TWP-MGR-MD-000016 REV 00 (BSC 2001 [DIRS 155906], all) indicates that a primary task of this Letter Report is to incorporate technical requirements of 40 CFR Part 197 (66 FR 32074 [DIRS 155216]) into the model configuration used to simulate repository performance and to present results that document any difference in dose as compared to TSPA-SR and SSPA. The results of these calculations are presented in Section 6.

The TSPA calculations for both the TSPA-SR, the SSPA, and the calculations described in this Letter Report were performed within a probabilistic framework combining the most likely ranges of behavior for the various component models, processes, and corresponding parameters included in the overall conceptual/process model describing the performance of the repository. GoldSim integrates the sub-system models using a Monte-Carlo simulation-based methodology to create multiple random combinations of the uncertain variables, and computes the probabilistic performance of the entire waste-disposal system in terms of mean annual dose to receptors. The GoldSim software calculates radionuclide release and radiological dose (the annual committed effective dose equivalent (CEDE) as defined in 40 CFR Part 197.2 [DIRS 155216], p. 32132) from individual radionuclides and the total annual dose due to all radionuclides released from the repository from failed waste packages. In this Letter Report the CEDE will be referred to as the annual dose. GoldSim calculates the total annual dose for 300 realizations of the model configuration using randomly selected values of distributed parameters for each realization. The calculation results are available in two main forms: (1) probability distributions for peak dose to the RMEI, and (2) time histories of annual dose to the RMEI.

The recently promulgated U.S. Environmental Protection Agency Final Rule 40 CFR Part 197 (66 FR 32074 [DIRS 155216]) stipulates that the performance assessment of the potential Yucca Mountain repository include an estimate of dose to the RMEI. The Rule further states that this assessment provide, for 10,000 years, the RMEI CEDE (40 CFR Parts 197.20 and 25 [DIRS 155216], p 32134). For the purposes of an EIS, the performance assessment must calculate the peak dose that would occur within the period of geologic stability (40 CFR Part 197 35 (66 FR 32074 [DIRS 155216], p. 32135)). The peak dose is projected to be within 1,000,000 years.

The performance-assessment methodology used for the calculations presented in this Letter Report draws upon the extensive analyses carried out in support of the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], all) and in the SSPA Volume 1 and Volume 2 (BSC 2001 [DIRS 154657], all, and BSC 2001 [DIRS 154659], all). Only those model components and related parameters that were modified to account for the scenarios considered in addition to those used in the TSPA-SR or the SSPA are described in this Letter Report. In addition, the model configuration used for the calculations presented in this Letter Report was modified to conform to the recently promulgated U.S. Environmental Protection Agency Final Rule. The Final Rule provides the criteria to be used in determining the RMEI location (40 CFR Part 197.12 and Part 197.21 [DIRS 155216], p. 32133 and 32134), the other criteria of the RMEI (which were applied in the calculation of biosphere dose-conversion factors (BDCFs)), and the groundwater protection standard, including the representative volume to be used for the calculation of gross alpha activity, total radium activity, and whole-body dose (40 CFR Part 197.30 [DIRS 155216], Table 1, p. 32134). These model modifications are described below in Section 5.2.

This Letter Report considers inventories in addition to those described in the TSPA-SR and the SSPA for the 70,000 MTHM inventory. The calculations in this Letter Report include the 70,000 MTHM-inventory case under both the HTOM and LTOM, the expanded-inventory cases under the HTOM, and the following scenarios:

- The human-intrusion scenario (CRWMS M&O 2000 [DIRS 153246], Section 4.4, p. 4-25 to 4-32) which considers an "intruder" drilling a land-surface borehole using a drilling apparatus (under the common techniques and practices that are currently employed in exploratory drilling for groundwater in the region around Yucca Mountain), drills directly through an intact or a degraded waste package, and subsequently into the uppermost aquifer underlying Yucca Mountain. The "intrusion" then causes the subsequent compromise and release of the contaminated waste in the penetrated waste package. Two human-intrusion scenarios were simulated for a one-million-year performance period: one intrusion at 30,000 years and the other intrusion at 100 years after repository closure.

- The igneous-activity scenario, contains a volcanic-eruption, which includes exposure as a result of atmospheric-transport and deposition on the ground, and an igneous-intrusion groundwater-transport scenario (BSC 2001 [DIRS 154657], Section 14.2.1, p. 14-5). In the volcanic-eruption scenario (CRWMS M&O 2000 [DIRS 153246], Section 3.10, p3-187 to 3-216), a dike (or dikes) intersects one or more repository drifts and compromises all waste packages in the affected drifts. Then, an eruptive conduit of an associated volcano intersects waste packages in its path. Waste packages in the path of the conduit are sufficiently damaged that they provide no further protection, and the waste in the packages is entrained in the eruption and subject to atmospheric transport. In the igneous-intrusion groundwater-transport scenario, the analysis calculated releases caused by a dike (or dikes) intersecting emplacement drifts, causing varying degrees of waste-package damage.

3. ASSUMPTIONS

3.1 ASSUMPTION 1

The 70,000-MTHM-case model configuration for the calculations in this Letter Report is based on the SSPA model configuration (BSC 2001 [DIRS 154657], all), which differs from the TSPA-SR model (CRWMS M&O 2000 [DIRS 153246], all). The model used for the calculations in Sections 6.0 below includes the modifications from the SSPA and TSPA-SR models as described below in Section 5. Other assumptions incorporated into the SSPA model are documented in the SSPA Volume 2 (BSC 2001 [DIRS 154659], Section 2, all). The key differences between the SSPA and the model configuration used in the calculations presented in this Letter Report are described in Section 5.2.

3.2 ASSUMPTION 2

The radionuclide inventories used in the calculations in Section 6.0 are those developed in the *Inventory Abstraction* (BSC 2001 [DIRS 154841], Table 36, p.38). The per-package inventories for the CSNF, and co-disposal waste packages are the same as those used in the TSPA-SR (CRWMS M&O 2000 [153246], Section 3.5.1, p. 3-94 to 3-100) but the DSNF inventory does not include the U.S. Navy spent nuclear fuel. The Navy spent nuclear fuel is conservatively represented by commercial spent nuclear fuel (BSC 2001 [DIRS 152059], all; DOE 2001 [DIRS 153849], Section 4.2.6.3.9, p. 4-257). The per-package inventories used for the GTCC and SPAR calculations use the inventory presented in Attachment III of this Letter Report.

3.3 ASSUMPTION 3

This Letter Report provides calculations which incorporate information and requirements in the recently promulgated EPA Final Rule 40 CFR Part 197, into the existing modeling runs to document any difference in dose. This Letter Report will not produce either qualified or baseline outputs. If needed for future baseline, the outputs will be developed in a technical product using qualified software and submitted to the Technical Data Management System

4. USE OF COMPUTER SOFTWARE

The calculations described in this Letter Report were performed using the numerical code GoldSim, Version 7.17.200. (BSC, 2001, GoldSim V7.17.200 10344-7.17.200-00. URN 0901 [DIRS 155182]). GoldSim was developed by Golder Associates as an update to the baseline software, RIP v.5.19.01 (Golder Associates 1999 [DIRS 151395], Computer Software Configuration Item (CSCI) 30055 V5.19.01). GoldSim is a Windows-based program that is computationally similar to RIP v.5.19.01 which was used for TSPA calculations for the Viability Assessment (DOE 1998, Volume 3 [DIRS 100550], p. 2-29). GoldSim is designed so that probabilistic simulations can be conducted and represented graphically. Although not currently qualified in accordance with AP-SI.1Q, *Software Management*, GoldSim Version 7.17.200 (STN: 10344-7.17.200-00 [DIRS 155182]) is used for this application and used within an acceptable specified range (See Assumption 3).

5. CALCULATION

5.1 BACKGROUND

The scope of the calculations presented in this Letter Report includes evaluation of long-term performance after the eventual closure of a Yucca Mountain Repository (Figure 5-1). In particular, these calculations focus on a Yucca Mountain repository for the disposal of 70,000 MTHM of nuclear material allowed by the amended NWPA. The calculations were performed in a manner consistent with the specifications of the EPA standard regarding a repository at Yucca Mountain found in 40 CFR Part 197 (66 FR 32074 [DIRS 155216], pp. 32132 - 32135) with respect to potential public-health impacts. The calculations also address the potential expansion of a repository to include additional mined areas needed for the expanded-inventory cases. The Module 2 inventory includes all of the Module 1 inventory plus the total projected inventory of GTCC commercial low-level radioactive waste and DOE SPAR low-level radioactive waste.

5.2 MODIFICATIONS TO THE TSPA-SR AND SSPA MODELS

This Letter Report builds on the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and SSPA (BSC 2001 [DIRS 154657]) modeling of the 70,000-MTHM-case repository configuration. Because the EIS will also evaluate the possible consequences of ultimately including the entire CSNF, DSNF, and HLW waste inventories, an expanded repository area was also considered.

The change from the TSPA-SR waste inventory and repository area to a calculation of the performance of an expanded repository includes addition of the Lower Block, shown on Figure 5-2, in the calculations. The TSPA-SR and SSPA reports relied on a detailed analysis of only the Primary Block shown on Figure 5-2.

The GoldSim numerical code simulates transport of radionuclides from the repository, through the unsaturated zone (UZ), and through the saturated zone (SZ) to the accessible environment. The different process models included in the GoldSim code are fully described and documented in the TSPA-SR (CRWMS M&O 2001 [DIRS 153246], all). The UZ-transport release nodes and SZ-transport capture areas for the 70,000 MTHM inventory in the TSPA-SR and SSPA models were modified for the expanded-inventory cases to include the Lower Block emplacement area for the Module 1 and Module 2 inventories. (See Section 5.2.1 and Attachment II of this Letter Report.)

The GoldSim model configuration used for the SSPA was modified to conform to the recently published EPA Final Rule 40 CFR Part 197 (66 FR 32074 [DIRS 155216], p. 32132 to 32135). The model also assesses the performance of additional radionuclide inventories and performance scenarios. The following Sections 5.2.1 through 5.2.7 describe the modifications to the TSPA-

SR and SSPA models. The model configuration for the calculations presented in the Letter Report differs from these earlier TSPA models in the following areas:

- The model used for the calculations in this Letter Report used BDCFs based on the RMEI defined in 40 CFR Part 197.21 (66 FR 32074 [DIRS 155216], p. 32134). The models used in the TSPA-SR and SSPA used different BDCFs based on the Average Member of the Critical Group (AMCG) in the proposed 10 CFR PART 63.115 9([DIRS 107770], p. 8645 to 8646).

- The length of the SZ simulated in the model configuration for the calculations in this Letter Report extends from within the repository footprint to the boundary between the controlled area and the accessible environment specified in 40 CFR Part 197.12 (66 FR 32074 [DIRS 155216], p. 32132 to 32133), namely, Latitude 36° 40' 13.6661" North, above the highest concentration of radionuclides in the plume of contamination. The RMEI is assumed to reside at this location in the accessible environment. The latitude at this location is the latitude at the southwestern corner of the Nevada Test Site.

- Groundwater protection was assessed using an annual representative volume of 3,000 acre-ft/yr, of groundwater as specified at 40 CFR Part 197, to calculate the total alpha activity, the total radium concentration, and the whole-body dose. To calculate all other concentrations not included in the groundwater-protection standard, the water usage was assigned in the same probabilistic manner as used in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246] Section 3.9.2.4, p. 3-184) and the SSPA (BSC 2001 [DIRS 154657], Section 13.3.5, p. 13-41 to 13-44).

- The waste inventories used for the calculations in this Letter Report are presented in the *Inventory Abstraction Analysis Model Report* (AMR) (BSC 2001 [DIRS 154841], Table 36, p. 38). The difference between this inventory and that used in the TSPA-SR and SSPA reports is that, for the calculations in this Letter Report, the DSNF inventory does not include the U.S. Navy spent nuclear fuel. The Navy spent nuclear fuel is conservatively represented by commercial spent nuclear fuel (BSC 2001 [DIRS 152059], all; DOE 2001 [DIRS 153849], Section 4.2.6.3.9, p. 4-257).

- Waste-package corrosion for the calculations in this Letter Report is due to general corrosion independent of temperature as was true for TSPA-SR. The SSPA calculations included temperature-dependent waste-package corrosion.

- The process-level LTOM thermal-hydrologic results for this Letter Report were corrected from those presented in the SSPA to include radiation connections in the Nonisothermal Unsaturated-saturated Flow and Transport (NUFT) model (Nitao 1998 [DIRS 100474], all).

5.2.1 Modifications to FEHM Particle Tracker Input and Output

The UZ flow-and-transport modeling in the TSPA-SR, SSPA, and this Letter Report is conducted with the Finite Element Heat and Mass (FEHM) model (Zyvoloski et al. 1999 [DIRS 107889], all). The movement of fluid and radionuclides released from the waste packages is followed through the UZ by means of a particle-tracking algorithm in the TSPA-SR and SSPA process models (CRWMS M&O 2000 [DIRS 153246], p.2-27) and (BSC 2001 [DIRS 154657], Section 11, all). The particle-tracking files used in the TSPA-SR were modified for the expanded-inventory case to allow the FEHM UZ input regions to correspond to the Lower Block area used for the simulations. The interface file in GoldSim was modified for this case by changing the FEHM nodes used for transport from the Primary Block as considered in the TSPA-SR, the SSPA, and the 70,000 MTHM inventory. The calculations presented in this Letter Report also include the Lower Block of a potential repository, which would also be used for input of mass from an expanded-repository area. The FEHM nodes were chosen to correspond to the Lower Block repository coordinates because of the changes to the regions from which mass is captured coming out of the FEHM model (CRWMS M&O 2000 [DIRS 155393], Attachments II and III, all). Capture regions at the surface of the saturated zone accumulate water and mass released from the repository that has been transported through the UZ. The capture regions for the Primary Block are shown in Figure 5-3. These capture regions were modified to ensure all the mass was captured and to distribute the mass to the SZ capture regions including release from the Lower Block. Figure 5-4 shows the capture regions used for the expanded-inventory cases.

The repository nodes were extracted based on the information and representation of the repository configuration provided by the following documents and data as described in *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (CRWMS M&O 2000 [DIRS 155393], Attachment II, all): (1) CRWMS M&O (2000 [DIRS 150941]), Figure 4-14), and (2) Emplacement Drift Coordinates - Expanded Waste Inventory Layout. The drifts in the Lower Block were first grouped into larger groups based on similar elevations. Then, the boundary coordinates of the larger groups were used to define rectangular regions. The Software Routine *repocoord1.f* (Version 1.0) (CRWMS M&O 2000, [DIRS 155393], Attachment II, all) was used to extract FEHM nodes within the rectangular region. The extracted nodes were then plotted using SigmaPlot (Version 4.01, a commercial, graphics software) and nodes that fall beyond the defined drift region were removed from the repository node list. Use of Software Routine *repocoord1.f* (Version 1.0) in the calculations in this Letter Report is documented in (CRWMS M&O 2000 [DIRS 155393], Attachment II, all).

5.2.2 Estimation of the Thermal Profiles and Infiltration for the Lower Block

The TSPA-SR and SSPA models used to assess repository performance utilized thermohydrologic modeling to estimate infiltration from land surface to the repository horizon. Infiltration water is the principal cause of waste-package corrosion and the main agent for waste transport. The TSPA-SR and SSPA model conceptualizations for the Yucca Mountain repository consider waste forms in discrete areal regions of the repository as source terms for flow and transport from the repository to the SZ. The GoldSim conceptualization for TSPA-SR considers the repository block, referred to as the "Primary Block", to be comprised of four source regions (Figure 5-3). The four regions are covered by the Yucca Mountain multiscale thermohydrologic model and its abstraction which was used to develop the thermodynamic-environment time histories at different potential waste-package locations distributed throughout the Primary Block (CRWMS M&O 2000 [DIRS 139610], Section 6.6, all and CRWMS M&O 2001 [DIRS 154594], Section 6.3, all). These time-histories for the HTOM were used in both the TSPA-SR and the SSPA.

The expanded-inventory calculations for this Letter Report use two additional areas for disposal; up to an additional ~218 acres of the Primary Block (The design of the Primary Block includes area not used in the 70,000 MTHM-inventory scenario, HTOM, {CRWMS M&O 2000 [DIRS

150941], Figure 4-14}); and up to a ~408-acre "Lower Block", which lies to the east of the Primary Block (Figure 5-2). For the expanded inventory, source-region 2 was expanded to the east so that its areal extent would cover the Lower Block (Figure 5.4) (CRWMS M&O 2000 [DIRS 155393], Section 5.2.2, p. 11-12).

The following methodology was used to develop thermal histories for waste packages emplaced in the Lower Block. The thermal response from the multi-scale thermohydrologic model (CRWMS M&O 2000 [DIRS 149862] all) is correlated to the distance from the edge of the repository. Further, seepage into the drift is a function of the local infiltration flux. Therefore, the location and estimated infiltration flux were used to select analogous Primary-Block thermohydrologic responses for application to comparable locations in the Lower Block. Thus, the Primary Block thermohydrologic data was extended to the 51 Lower-Block elements shown on Figure 5-5. Details of the extension of this method to the 51 nodes is provided in CRWMS M&O (2000 [DIRS 155393] Attachment II, p. II-2 to II-5) and the estimation of Lower-Block infiltration seepage is provided in CRWMS M&O (2000 [DIRS 155393] Attachment III, p. III-2 to III-19). The glacial-transition climate infiltration rate for the 51 elements was estimated from the site-scale hydrologic model (Bodvarsson et. al. 1997 [DIRS 100103]). For each of the 51 Lower-Block elements, the GoldSim software code was configured with thermal-history data sets from the site multi-scale thermohydrologic model (CRWMS M&O 2000 [DIRS 139610], Section 6.6, all, and its abstractions CRWMS M&O 2001 [DIRS 154594], Section 6.3, all) based on similar infiltration and proximity to the edge of the repository as the analogous Primary-Block locations. Using these data, the infiltration categories, or bins, for the waste packages associated with the Expanded-Inventory case were established as described in *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (CRWMS M&O 2000 [DIRS 155393], p. IV-2 to IV-4). The use of thermal profiles in estimating infiltration to the repository blocks is described in detail in *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (CRWMS M&O 2000 [DIRS 155393], p. III-2 to III-19). Attachment II of this Letter Report describes the calculation of the fractional Lower-Block repository areas corresponding to the infiltration bins.

5.2.3 The Saturated-Zone Breakthrough Curves

Transport in the SZ beneath the repository is the main route for groundwater transport of contaminants leached from the repository. The radioactive contaminants move through the SZ to the accessible environment. The accessible environment is defined as any area outside of the controlled area (40 CFR Part 197.12; 66 FR 32074 [DIRS 155216], p. 32132). The EPA Final Rule, 40 CFR Part 197.12 (66 FR 32074 [DIRS 155216], p. 32133), specifies the following elements of the controlled area:

(1) The surface area, identified by passive institutional controls, that encompasses no more than 300 square kilometers. It must not extend farther:

  (a) south than 36° 40' 13.6661" North Latitude, in the predominant direction of ground water flow; and

  (b) than five kilometers from the repository footprint in any other direction; and

(2) The subsurface underlying the surface area.

The location where the RMEI resides, which is also where groundwater protection will be analyzed, is the point above the highest concentration of radionuclides in the simulated plume of SZ contamination where the plume crosses the southernmost boundary of the controlled area (at a Latitude of 36° 40' 13.6661" North) and reaches the accessible environment. For this analysis, DOE has selected the southern boundary of the controlled area and the location of the RMEI to be at the limit discussed above, which is approximately 18 km (11 miles) from within the potential repository, compared to the corresponding distance of approximately 20 km (12 miles) used in the SZ transport modeling for TSPA-SR and the SSPA, as shown in Figure 5-6. To evaluate long-term performance with respect to the standard set in the EPA Final Rule 40 CFR Part 197.12 (66FR32074 [DIRS 155216]), additional SZ breakthrough curves, which describe the time-related arrivals of radionuclides at the RMEI location, were calculated for all radionuclides used in the calculations in this Letter Report. The SZ breakthrough curves were used in the analyses to simulate radionuclide transport from the water table beneath the potential repository to the RMEI location. It should be noted that, depending on the subsurface layout of a repository, the distance to the RMEI location from any point in the subsurface layout could be more or less than 18 km. For convenience and consistency with other documents, the RMEI location will be consistently discussed as being approximately 18 km from the potential repository.

To generate the SZ breakthrough curves used in the calculations in this Letter Report, 100 realizations of the SZ site-scale flow-and-transport model were performed as described in the SZ process model (CRWMS M&O 2000 [DIRS 139440], Sections 6.2 and 6.3, all) to generate SZ breakthrough curves at the RMEI location. Other stochastic parameters for the SZ simulations use the same values as were used in the SZ breakthrough curves for the SSPA analysis (BSC 2001 [DIRS 154659], Section 3.2.10, all). The simulated radionuclide breakthrough curves at the RMEI location (approximately 18 km) exhibited shorter transport times than those at 20 km as presented in SSPA analysis (BSC 2001 [DIRS 154657], Section 13.2.1.3, all) on a realization-by-realization basis. In particular, those radionuclides that may have significantly greater sorption in the alluvium than in the volcanic units (e.g., Np-237) exhibit shorter transport times to the RMEI location in this analysis relative to the 20-km location used in TSPA-SR, SSPA, and the draft EIS. This result is related to the fact that the RMEI location in this analysis results in a decrease in the length of transport through the alluvium relative to the transport path to the 20-km location.

The approach used for simulations of groundwater flow and radionuclide transport in the SZ used in this Letter Report is the same as the approach used in TSPA-SR. The SZ site-scale flow-and-transport model has been used to simulate the unit radionuclide mass-breakthrough curves for radionuclides of concern to the site recommendation (SR) at the RMEI location, approximately 18 km downgradient from the repository. In the model configuration for the calculations for this Letter Report, these SZ breakthrough curves are coupled with the other components of the system (mass flux and representative volume or water usage) using the convolution-integral method in the same manner as described and implemented in the GoldSim program for TSPA-SR and the SSPA (CRWMS M&O 2000 [DIRS 153246], Section 2.2.2, all) and (BSC 2001 [DIRS 154657], Section 3.2.10, all). In addition, the simulation of radionuclide decay chains and the transport of daughter products in the SZ system is performed using a one-dimensional model directly in the GoldSim numerical code.

In the SZ model, the capture regions that accumulate flow and mass at the base of the UZ become the source regions for the SZ model. The four radionuclide source regions (Figures 5-3 and 5-4) in the SZ that were defined for the 70,000-MTHM case of the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Section 3.8.2.2, all and Figure 3.8-14, p. F3-117) are used in the calculations in this Letter Report. For the expanded-repository case, radionuclide mass originating from the Lower Block of the repository is applied to source region number 2 in the SZ transport module. The Lower Block of the expanded repository extends farther to the east than the SZ source region number 2 for the TSPA-SR base case. However, applying the radionuclide mass from the Lower Block to this source region constitutes a conservative approximation of transport in the SZ. Lower permeability rocks of the upper volcanic confining unit exist at the water table in the area immediately to the east of SZ source region number 2, which would result in slower initial advective groundwater velocity for radionuclide transport in this area. Preliminary results of radionuclide-transport simulations with the SZ site-scale flow-and-transport model confirm that radionuclide transport times in the SZ from the area below the expanded-repository Lower Block are longer than the transport times from SZ source region number 2 in the 70,000-MTHM case considered in this Letter Report.

5.2.4 Modifications to the TSPA-SR Model and Early-Waste Package Failures

5.2.4.1 Modifications to the Waste Package Degradation Model

The WAste Package DEGradation (WAPDEG) model (CRWMS M&O 2000 [DIRS 151566]) is used to calculate drip-shield and waste-package degradation profiles with time in the GoldSim TSPA model configurations used for TSPA-SR, SSPA, and this Letter Report. Several input parameters to the WAPDEG model developed for TSPA-SR REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151566]) were re-evaluated in SSPA Volume 1 (BSC 2001 [DIRS 154657], Section 7, all). The re-evaluation led to the following changes to the TSPA-SR WAPDEG model and parameters used in the SSPA and the calculations in this Letter Report. These changes are described in detail in SSPA Volume 1 (BSC 2001 [DIRS 154657], Section 7, all) and are summarized here:

- All surface-breaking weld flaws and all weld flaws embedded in the outer ¼ of the closure weld thickness were considered capable of propagation in the radial direction in the WAPDEG Model developed for TSPA-SR REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151566], Section 5.5, p. 39). In the SSPA and this analysis, the fraction of these weld flaws capable of propagation in the radial direction is given by a ±3 standard deviation truncated lognormal distribution with a mean of 0.01 and bounded between 0.5 (+3 standard deviations) and 0.0002 (-3 standard deviations) (BSC 2001 [DIRS 154657], Section 7.3.3.3.4, p. 7-41).

- The stress threshold for the initiation of stress-corrosion cracking was given by a uniform distribution between 20 and 30 percent of the Alloy 22 yield strength in the WAPDEG Model developed for TSPA-SR REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151566], Section 4.1.9, p. 29). In the SSPA and this analysis, the stress threshold for the initiation of stress-corrosion cracking is given by a uniform distribution between 80 and 90 percent of the Alloy 22 yield strength (BSC 2001 [DIRS 154657], Section 7.3.3.3.3, p. 7-39).

- The uncertainty bounds of the residual-stress profile in the Alloy 22 waste package outer closure lid weld regions (induction annealed) were set to ±30 percent of the yield strength of Alloy 22 in the WAPDEG Model developed for TSPA-SR REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151566], Section 6.5.1, p.79). In SSPA and this analysis, the uncertainty bounds of the residual stress profile in the Alloy 22 waste package outer closure lid weld regions were set to ±21.4 percent of the yield strength (BSC 2001 [DIRS 154657], Section 7.3.3.3.1, p. 7-74).

- The uncertainty bounds of the residual-stress profile in the Alloy 22 waste package inner closure lid weld regions (laser peened) were set to ±30 percent of the yield strength of Alloy 22 in the WAPDEG Model developed for TSPA-SR REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151566], Section 6.5.1, p. 79). In SSPA and this analysis, the uncertainty bounds of the residual-stress profile in the Alloy 22 waste package inner closure lid weld regions are sampled from a cumulative distribution function (BSC 2001 [DIRS 154657], Section 7.3.3.3.2, p. 7-37 and Table 7.3.3-2, p. 7T-4).

- The variances of the general-corrosion-rate distributions for Alloy 22 and Titanium Grade 7 were considered to result from contributions of both uncertainty and variability in the WAPDEG Model developed for TSPA-SR REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151566], Section 6.3.1, p. 55). In SSPA and this analysis, the total variance of the general-corrosion-rate distributions is considered to be entirely due to uncertainty (BSC 2001 [DIRS 154657], Section 7.3.5.2, p. 7-54). Note that to ensure conservatism in the analysis, the temperature-dependent Alloy 22 general-corrosion model developed for the SSPA (BSC 2001 [DIRS 154657], Section 7.3.5.3.2, p. 7-56) was not used in the this analysis. The same Alloy 22 and Titanium Grade 7 general-corrosion-rate distributions used in the WAPDEG model developed for TSPA-SR REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 153246] Section 3.4.1, p. 3-80 to 3-87) and the SSPA (BSC 2001 [DIRS 154657], Section 7.3.5, p. 7-52 to 7.61) are also used in the calculations presented in this Letter Report. The calculated means of the general-corrosion-rate distribution used for the calculations in this Letter Report are 1.94×10^{-4} mm/yr for Titanium Grade 7 and 6.80×10^{-5} mm/yr for Alloy 22. The data used to calculate the means are from complementary distribution functions presented in *Analysis of Waste Package and Drip Shield Degradation* (CRWMS M&O 2000 [DIRS 151566], Section 4, p. 19 to 20.

5.2.4.2 Early Waste-Package Failure

The potential waste-package early-failure mechanisms were re-evaluated in the SSPA, particularly improper heat treatment of waste packages (BSC 2001 [DIRS 154657], Section 7.3.6, p.7-62). These results are incorporated in the calculations in this Letter Report. The results of the analysis show that the probability of having one waste package in the potential repository improperly heat-treated is about 20.2 percent, and the probability of having two waste packages affected is about 2.6 percent. The probability of having three waste packages with improper heat treatment is about 0.2 percent.

In evaluating the potential consequences of early failures by improper heat treatment for the SSPA and this analysis, early waste-package failure occurs upon initiation of corrosive processes and is due to failure of the outer and inner closure lids of the waste-package outer barrier and the failure of the closure lid of the stainless-steel structural waste-package inner shell. Details of the use of this model in performance-assessment analyses are discussed in SSPA Volume 2 (BSC 2001 [DIRS 154659], Section 3.2.5.4, p. 3-21). The following elements were employed in that evaluation:

- Those waste packages affected by early waste-package failure fail immediately by general corrosion as patches (BSC 2001 [DIRS 154659], Section 3.2.5.4, p. 3-21).
- The area on the waste package affected by improper heat treatment is equal to the area of closure-weld patches because improper heat treatment is most likely to occur during the induction annealing of the outer-closure-lid welds of the waste-package outer barrier.
- The materials of the entire affected area are lost upon failure of the waste packages because the affected area will be subject to stress-corrosion cracking and highly enhanced localized and general corrosion.
- The weld region of the inner closure lid of the outer barrier and the closure lid of the stainless-steel structural inner shell fail at the same time when the outer closure-lid weld region fails.

The above assumptions are conservative because only the weld region of the outer lid of the outer barrier would be affected by potential improper heat treatment during the stress-mitigation heat treatment (i.e. induction annealing), and the inner lid of the outer barrier is not likely to be affected. In a more realistic scenario, the breached weld patches of the affected waste package would remain with the waste package until the weakened areas are affected by a major mechanical impact or corroded away by general corrosion.

5.2.5 BDCFs for the 40 CFR Part 197 RMEI

BDCFs are used to estimate the radiation dose incurred by a receptor when a unit activity concentration of a radionuclide reaches the accessible environment. The BDCFs for the RMEI were developed using the environmental and agricultural parameters characteristic of the Amargosa Valley region, and the dietary and lifestyle characteristics of the receptor consistent with those specified in 40 CFR Part 197.21 (66 FR 32074 [DIRS 155216], p. 32134). The lifestyle characteristics of the RMEI were representative of a rural residential population. The dietary characteristics of the RMEI were based on a food-consumption survey (DOE 1997 [DIRS 100332]) for the population of the town of Amargosa Valley. Consistent with the Final Rule at 40 CFR Part 197.21 ([DIRS 155216, p. 32134), the dietary characteristics of the RMEI were represented by the mean values of locally produced food for the Amargosa Valley residents. The dietary and lifestyle attributes of the RMEI are listed in Table 5-1. The dietary attributes of the RMEI shown in Table 5-1 were developed using the set of recently re-evaluated and updated values of consumption rates of locally produced food as found in *Calculation: Consumption Rates of Locally Produced Food in Nye and Lincoln Counties* (BSC 2001, [DIRS 156016], all). This set of consumption rates is different from the set used in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Section 3.9, all) and the SSPA (BSC 2001 [DIRS 154657], Section 13, all) analyses. The changes include the update of the contingent average daily intake of food, the adjustments in the grouping of the food categories, and the adjustments in the selection of the individuals whose consumption rates were used to develop the receptors. If the same food-consumption data set, the same food grouping, and the individual selection criteria were used to construct the dietary characteristics of the AMCG under proposed NRC regulations (proposed 10

CFR PART 63.115(b), 64 FR 8640 [DIRS 107770], p 8645 to 8646), the consumption rates would be different from the values used in TSPA-SR. These modified attributes for the AMCG are also listed, for comparison, in Table 5-1.

Table 5-1 Comparison of the Average Values of the Dietary and Lifestyle Attributes for the Receptors

Parameter	Mean Value of an Attribute for Annual Exposure	
	Reasonably Maximally Exposed Individual	Average Member of the Critical Group
Leafy vegetables consumption rate, kg/yr	3.9	7.0
Other vegetables consumption rate, kg/yr	4.8	8.5
Fruit consumption rate, kg/yr	12.4	23.1
Grain consumption rate, kg/yr	0.3	0.6
Meat consumption rate, kg/yr	2.6	3.3
Poultry consumption rate, kg/yr	0.4	0.6
Milk consumption rate, L/yr	4.8	4.2
Eggs consumption rate, kg/yr	5.6	8.9
Fish consumption rate, kg/yr	0.3	0.5
Water consumption rate, L/yr	730	791.2
Inadvertent soil ingestion, mg/d	50	50
Inhalation exposure time, hr	5073.5	6073.5
Soil exposure time, hr	2387	3387

The BDCFs for the two receptors, the RMEI, and the AMCG, characterized by the set of attributes listed in Table 5-1, are compared in Table 5-2. The comparison includes the BDCF values for the groundwater-release and the volcanic-eruption-exposure scenarios. Both the BDCFs for the RMEI and the BDCFs for the AMCG were developed using the same set of environmental and agricultural parameters. Lifestyle characteristics of the AMCG were consistent with those of a farmer who works a considerable number of hours per year (full time or more) outdoors in the contaminated area and recreates a considerable number of hours per year outdoors in the contaminated area. The members of the critical group were assumed to consume domestically produced food and water and have gardens.

Table 5-2 Comparison of the BDCFs for the Receptors for the Groundwater Release and the Volcanic-Eruption Scenarios

Radionuclide	Groundwater release BDCFs, rem per pCi/L			Volcanic-exposure-release BDCFs [a] rem per pCi/m^2		
	RMEI	AMCG [b]	RMEI/AMCG Ratio	RMEI	AMCG	RMEI/AMCG Ratio
C-14	2.9E-05	5.8E-05	0.50	NA	NA	NA
Se-79	1.2E-05	1.5E-05	0.77	3.8E-11	5.5E-11	0.69
Sr-90	2.0E-04	2.6E-04	0.75	4.2E-09	7.1E-09	0.60
Tc-99	2.8E-06	3.2E-06	0.85	NA	NA	NA
I-129	2.5E-04	3.0E-04	0.85	NA	NA	NA
Cs-137	3.4E-04	4.8E-04	0.71	1.2E-09	1.8E-09	0.68
Pb-210	5.1E-03	6.4E-03	0.79	1.4E-08	1.7E-08	0.80
Ra-226	5.0E-03	7.0E-03	0.72	4.2E-09	5.2E-09	0.81
Ac-227	1.3E-02	1.5E-02	0.85	1.9E-06	2.3E-06	0.84
Th-229	6.1E-03	7.4E-03	0.82	6.0E-07	7.2E-07	0.84
Th-230	1.2E-03	1.6E-03	0.78	9.1E-08	1.1E-07	0.84
Pa-231	1.6E-02	1.9E-02	0.84	3.8E-07	4.5E-07	0.84
U-232	1.8E-03	2.3E-03	0.80	1.9E-07	2.3E-07	0.84
U-233	2.8E-04	3.4E-04	0.84	3.8E-08	4.6E-08	0.84
U-234	2.7E-04	3.3E-04	0.84	3.8E-08	4.5E-08	0.84
U-236	2.6E-04	3.1E-04	0.84	NA	NA	NA
U-238	2.6E-04	3.1E-04	0.83	NA	NA	NA
Np-237	4.5E-03	5.4E-03	0.84	1.9E-07	2.3E-07	0.83
Pu-238	2.9E-03	3.4E-03	0.85	1.1E-07	1.4E-07	0.84
Pu239	3.5E-03	4.1E-03	0.85	1.3E-07	1.5E-07	0.84
Pu-240	3.5E-03	4.1E-03	0.85	1.3E-07	1.5E-07	0.84
Pu-242	3.2E-03	3.8E-03	0.85	1.2E-07	1.4E-07	0.84
Am-241	3.5E-03	4.8E-03	0.72	1.3E-07	1.5E-07	0.84
Am-243	4.0E-03	4.8E-03	0.83	1.3E-07	1.5E-07	0.84

NOTES:
[a] BDCFs for the transition phase, 1-cm layer of ash and annual average mass loading
[b] AMCG – Note that the dietary characteristics of the AMCG used in this comparison are different from those of the receptor used in the TSPA-SR analyses.

The comparison presented in Table 5-2 indicates that the BDCFs for the AMCG, calculated using the updated consumption rates of locally produced food and water, are up to a factor of 2 more conservative than the BDCFs for the RMEI for both exposure scenarios. In most cases the BDCFs for the AMCG are greater than the BDCFs for the RMEI by only a factor of 1.2 to 1.3. Similar conclusions remain valid for the BDCFs used in the TSPA-SR because both the BDCFs for the AMCG developed using the preliminary and the modified food-consumption data sets are comparable.

The dietary and lifestyle characteristics of the AMCG are more conservative than those of the RMEI because the critical group represents the fraction of the Amargosa Valley population expected to experience higher-than-average potential exposures. Considering the ratios of the BDCFs for the RMEI and the AMCG presented in Table 5-2, a performance analysis using either of these receptors yields very similar results.