13. BIOSPHERE

13.1 INTRODUCTION AND CONCEPTUAL BASIS

The biosphere is comprised of those parts of the crust of the earth, the waters, and the atmosphere that support life. As opposed to this understanding of the biosphere as a global feature, the Yucca Mountain reference biosphere is limited in spatial extent, that at a minimum should include all biosphere-related features, events, and processes (FEPs) applicable to the Yucca Mountain region. The biosphere conceptual model applies to the Yucca Mountain reference biosphere. If radionuclides from the potential repository find their way to the reference biosphere, there is a possibility that humans, as well as other living entities, will be exposed to radiation in addition to the natural radiation background. The biosphere analyses provide the means of evaluating radiation exposure to humans from radioactive material that might be released to the limited Yucca Mountain biosphere. The biosphere model includes both the characteristics of the receptor of interest (such as lifestyles, including dietary and activity habits) and the characteristics of the environment around these potentially exposed people that are important to assessing their radiation exposure.

The reference biosphere is a component of the repository system. Because of the location of the receptor (proposed 10 CFR 63.115(b) [64 FR 8640 [DIRS 101680]]), the reference biosphere is sufficiently distant from the engineered barriers component of the potential repository that there are no direct interactions between these two system components. Thus, the thermal operating conditions within the repository have no effect on the biosphere model or the dose prediction capability. This section, therefore, addresses new data and previously unquantified uncertainties that apply irrespective of the thermal design of the potential repository.

The starting point for developing a biosphere model was to define the reference biosphere. Once the reference biosphere was defined, the subsequent step in developing a biosphere model was to identify the appropriate routes for introducing the radionuclides into the biosphere. Two potential mechanisms for radionuclide release into the biosphere were identified (CRWMS M&O 2000 [DIRS 153246], pp. xiv to xv and Figures ES-8 and ES-9). The first arises from pumping of contaminated groundwater to support the needs of a hypothetical farming community at a specified location (proposed 10 CFR 63.115 [64 FR 8640 [DIRS 101680]]). This release is characteristic of the nominal, human intrusion, and igneous intrusion groundwater transport scenarios. The second release mechanism is through the action of a volcanic eruption that entrains and disperses the radionuclides in the waste with the ensuing ash fall. The biosphere modeling is thus performed for two types of human exposure scenarios, one associated with groundwater release (usage of contaminated groundwater), the other associated with ash fall (deposition of contaminated volcanic ash on the ground surface).

During the development of the biosphere model, biosphere-related FEPs were identified. The intent was to capture all aspects of the biosphere model that can affect human exposure using the primary FEPs. The subsequent screening process evaluated the significance of each FEP and identified those that could be associated with nontrivial exposures. These FEPs were then modeled in more detail and included in the biosphere model.

The implementing computer code for the biosphere model was GENII-S V.1.4.8.5, which was developed for the Waste Isolation Pilot Plant in New Mexico. The approach adopted to support the *Total System Performance Assessment for the Site Recommendation* (TSPA-SR) (CRWMS M&O 2000 [DIRS 153246]) was to use GENII-S V.1.4.8.5 for each radionuclide of interest (CRWMS M&O 2000 [DIRS 136383], Section 3.9) to develop an annual dose prediction for unit concentration of that radionuclide in groundwater and ash. These values of annual dose for unit concentrations are known as biosphere dose conversion factors (BDCFs). This approach allowed the TSPA-SR to generate doses once radionuclide concentrations at the source of contamination had been calculated. A number of input parameters to the code were represented by distributions of values to reflect inherent uncertainty. The GENII-S V.1.4.8.5 code can accept such input distributions for many (but not all) parameters, and in turn generates the associated BDCF distribution for use in a total system performance assessment (TSPA). Once generated and abstracted, these BDCF distributions are provided to analysts for use in stochastic dose determinations.

The approach outlined above was used to support both the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and the TSPA presented in Volume 2 (McNeish 2001 [DIRS 155023]). To supplement the TSPA-SR, some additional uncertainties associated with the biosphere model have been identified and quantified. Estimates of the impacts of uncertainties not previously considered on BDCFs and dose predictions have been generated. Additional analyses have been conducted to provide a demonstration of the robustness of the approach.

Since the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) was conducted, some analysis model reports (AMRs) supporting the biosphere effort have been updated. In addition, some new analyses have been conducted (Wu 2001 [DIRS 154892]; Wu 2001 [DIRS 154893]; Wu 2001 [DIRS 154894]; Tappen 2001 [DIRS 154890]) to provide more information on previously unquantified uncertainties. The first part of Section 13.2 provides a review of the AMRs developed to support the TSPA-SR evaluation. The section also identifies new work in the updated AMRs that supports the TSPA presented in Volume 2 (McNeish 2001 [DIRS 155023]). Unquantified uncertainties in the biosphere model are presented and discussed in Section 13.2.2. Section 13.2.3 presents a comparison of biosphere modeling efforts adopted by this and other programs. The similarity of constituent models and data is used to describe multiple lines of evidence in the biosphere model and provide confidence in the approach described in this report.

The main intent of the new biosphere analyses was to assess model uncertainties and sensitivities that had not been previously addressed. Section 13.3 presents the results of these efforts. Several areas of uncertainty are discussed and summarized in Table 13.1-1. The table also shows updates in scientific information.

The first of the analyses presented in Section 13.3 looks at the sensitivity of the dose calculation to the definition of the receptor of interest. The second provides some insight into the ramifications of performing a dose calculation using International Commission on Radiological Protection (ICRP) 72 (ICRP 1996 [DIRS 152446]) methodology rather than that specified in ICRP 30 (ICRP 1979 [DIRS 110386]; ICRP 1980 [DIRS 110351]; ICRP 1981 [DIRS 110352]). Both analyses were intended to provide confidence in the approaches used in TSPA-SR calculations and demonstrate robustness in that approach. They are followed by two uncertainty assessments of the inability of GENII-S V.1.4.8.5 to represent some processes stochastically.

Table 13-1. Summary of Supplemental Models and Analyses

Key Attributes of System	Process Model (Section of S&ER)	Topic of Supplemental Scientific Model or Analysis	Reason For Supplemental Scientific Model or Analysis			Section of Volume 1	Performance Assessment Treatment of Supplemental Scientific Model or Analysis[a]	
			Unquantified Uncertainty Analysis	Update in Scientific Information	Lower-Temperature Operating Mode Analysis		TSPA Sensitivity Analysis	Included in Supplemental TSPA Model
Delay and Dilution of Radionuclide Concentrations by the Natural Barriers	Biosphere (4.2.10)	Receptor of interest	X			13.3.1		
		Comparison of dose assessment methods	X			13.3.2		
		Radionuclide removal from soil by leaching	X			13.3.3		
		Uncertainties not captured by GENII-S	X			13.3.4		
		Influence of climate change on groundwater usage and BDCFs	X			13.3.5 13.3.7		
		BDCFs for groundwater and igneous releases		X		13.3.6 13.3.8 13.4	X	X

NOTE: S&ER = Yucca Mountain Science and Engineering Report (DOE 2001 [DIRS 153849]).

[a] Performance assessment treatment of supplemental scientific model or analysis discussed in SSPA Volume 2 (McNeish 2001 [DIRS 155023]).

The first evaluates the effect on BDCFs arising from the uncertainty in the partition coefficient through its impact on the leaching coefficient. The second investigation builds on the previous one and considers additional BDCF uncertainty from some parameters defining the leafy vegetable pathway. In Section 13.3.5, possible changes in annual water usage estimates for the proposed farming community are assessed for the present and future climate using the predicted irrigation requirements of alfalfa. The next section presents a reevaluation of the inhalation exposure pathway that reduces some uncertainty in the BDCF values. Section 13.3.7 evaluates the effect of the predicted climate change on the BDCF values. The final section presents BDCF data for two radionuclides (selenium-79 in both release cases and neptunium-237 in the disruptive scenario) that have not been previously considered as important dose contributors in TSPA-SR calculations (CRWMS M&O 2000 [DIRS 153246]).

Section 13 ends with a summary discussion of the work performed and the data provided on BDCFs for exposure scenarios and annual groundwater usage to support the TSPA analysis documented in Volume 2 (McNeish 2001 [DIRS 155023]).

The International Atomic Energy Agency (IAEA) recently completed an international peer review of the DOE's biosphere modeling work (IAEA 2001 [DIRS 155188]). The final report was not available in time to consider it in this update of work supporting the SR, but will be taken under consideration for subsequent phases of repository performance evaluations, if the site is recommended and designated. The IAEA review resulted in 37 specific suggestions for further work on improving the bases, and extending the application, of the modeling of the biosphere. The review will be followed up with a response and with a work plan to implement the suggestions that are most appropriate given the specific regulatory and national context of the Yucca Mountain project.

13.2 REVIEW OF TOTAL SYSTEM PERFORMANCE ASSESSMENT-SITE RECOMMENDATION TREATMENT AND UPDATES

Section 13.2.1 reviews the approach described in biosphere documents supporting the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and changes that are incorporated into the TSPA described in Volume 2 (McNeish 2001 [DIRS 155023]). Section 13.2.2 discusses unquantified uncertainties in the biosphere model, and Section 13.2.3 describes multiple lines of evidence supporting the results of that model.

13.2.1 Relationship of Biosphere Model Tasks

Development of the biosphere model and BDCF outputs included several categories of tasks. One of them was to develop the data necessary to define the reference biosphere and the receptor of interest. The selection of radionuclides for which BDCFs were required is provided in *Inventory Abstraction* (CRWMS M&O 2000 [DIRS 150561], Section 7.1). Another function involved performing BDCF calculations using GENII-S V.1.4.8.5 for the two exposure scenarios under consideration. In addition, pathway and sensitivity analyses were performed. Finally, data generated by GENII-S V.1.4.8.5 were further processed to provide abstractions for using the BDCFs in a TSPA. These tasks were conducted initially during the 1999 to 2000 year to support the TSPA analysis summarized in the *Yucca Mountain Science and Engineering Report* (DOE 2001 [DIRS 153849]), as described in a series of biosphere AMRs and in the *Biosphere*

Process Model Report (CRWMS M&O 2000 [DIRS 151615]). Many of those AMRs have since been updated to include contributions to the resolutions of key technical issues (NRC 2000 [DIRS 149372]), incorporation of recent data, more comprehensive documentation of biosphere tasks, and corrections to the initial versions of the documents. The following sections briefly describe how those tasks were conducted in the biosphere AMRs and changes that have been made to support the TSPA analysis presented in Volume 2 (McNeish 2001 [DIRS 155023]).

13.2.1.1 Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes

Total System Performance Assessment-Site Recommendation Treatment–In the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (CRWMS M&O 2000 [DIRS 142844]), which supported the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), a screening analysis of FEPs that were potentially biosphere-related was performed. This analysis was based on U.S. Department of Energy (DOE) guidance (Dyer 1999 [DIRS 105655]) and limited to those FEPs considered relevant given current conditions. The analysis indicated that 22 of the primary FEPs in the Yucca Mountain Site Characterization Project (YMP) database (CRWMS M&O 1999 [DIRS 142970]) were applicable to Yucca Mountain. However, because of the specificity of the guidance, climatic evolution and surficial processes were not considered to be relevant.

Updated Treatment–The update of the FEPs evaluation (BSC 2001 [DIRS 153921]) applied the DOE guidance (Dyer 1999 [DIRS 105655]) and proposed 10 CFR Part 63 (64 FR 8640 [DIRS 101680]) to a reevaluation of the biosphere-related FEPs in an updated YMP database (CRWMS M&O 2000 [DIRS 150806]). Consideration of proposed 10 CFR Part 63 resulted in an increase in the number of relevant primary FEPs, which now include climatic evolution and surface processes. Twenty-five primary FEPs were determined as applicable, in part or total, to the biosphere analyses. The effects of the added FEPs and their associated uncertainty were addressed in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]) and *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [DIRS 152517]).

13.2.1.2 Identification of the Receptor of Interest

Total System Performance Assessment-Site Recommendation Treatment–The *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000 [DIRS 143940]) documented one of the analyses that developed input parameters for GENII-S V.1.4.8.5. This report identified a receptor of interest for the TSPA-SR analyses (CRWMS M&O 2000 [DIRS 153246]) as the average member of the critical group (proposed 10 CFR 63.115(b) [64 FR 8640 [DIRS 101680]]). The receptor was defined using attributes of the potential behaviors and characteristics of the population surrounding Yucca Mountain. Characteristics examined included the consumption of locally produced food and tap water, as identified in a food consumption survey (DOE 1997 [DIRS 100332]); lifestyle characteristics, including employment and recreation; type of housing; and land uses that would lead to the highest potential exposures. Employment behaviors were based on data from the U.S. Census Bureau (1999 [DIRS 135344]), and an assumption of outdoor recreation was based on data from a national U.S. Environmental Protection Agency (EPA) survey (EPA 1997 [DIRS 116135]).

The report identified a receptor that would be expected to exhibit the attributes of a residential farming group who raise and consume some of their own food and obtain all their drinking and irrigation water from a contaminated groundwater supply. This group would be expected to spend a considerable amount of time outdoors on contaminated land, including agricultural or construction employment and outdoor recreational activities, such as gardening. Members of this group would be expected to live in mobile or manufactured housing and have a land use characteristic associated with irrigated land.

Updated Treatment–An update (CRWMS M&O 2001 [DIRS 153342]) further examined the potential behaviors and characteristics of the population surrounding Yucca Mountain. Relative behavioral factors for unit concentrations were developed for four key radionuclides: technetium-99, iodine-129, neptunium-237, and plutonium-239 (CRWMS M&O 2001 [DIRS 153342], Section 6.2). These factors represent annual dose per unit activity concentration of a radionuclide in groundwater as the result of a predefined behavior. The relative behavioral factors provide a tool for evaluating relative exposures to the receptor groups. These factors were summed across combinations of behaviors to identify a receptor group that exhibits those behaviors and characteristics that will result in the highest expected annual doses. The analysis showed that for the groundwater release exposure scenario, diet was the most significant contributor to potential exposure, contributing over 99 percent of the total for technetium-99, iodine-129, and neptunium-237 and approximately 90 percent of the total for plutonium-239. Consideration of alternative receptors and analysis of changes in predicted annual dose caused by varying the characteristics of the receptor are discussed in Section 13.3.1.

13.2.1.3 Groundwater Usage by the Proposed Farming Community

Total System Performance Assessment-Site Recommendation Treatment–Consistent with proposed 10 CFR Part 63 (64 FR 8640 [DIRS 101680]), the approach used in the TSPA-SR analysis (CRWMS M&O 2000 [DIRS 153246], Section 3.9) conservatively assumed that all radionuclides reaching the location of the receptor, approximately 20 km south of the potential repository, were captured by the water used by a hypothetical farming community of approximately 100 people living on 15 to 25 farms.

Annual water usage in the Amargosa Valley area (State of Nevada 1997 [DIRS 110951]) was examined to derive water usage and statistical uncertainty for an average farm. Once this information was known, it was a straightforward step to generate a sampling algorithm for the TSPA to provide a statistically meaningful annual consumption for the hypothetical farming community.

Updated Treatment–This analysis was not updated. However, the effect of climate change on the predicted distribution of water usage by the hypothetical farming community was evaluated, as described in Section 13.3.5.

13.2.1.4 Input Parameter Values for External and Inhalation Radiation Exposure Analysis

Total System Performance Assessment-Site Recommendation Treatment–Estimates of inhalation exposure time, mass loading, and chronic breathing rate were developed to provide

GENII-S V.1.4.8.5 input for the inhalation pathway. In the initial version of *Input Parameter Values for External and Inhalation Radiation Exposure Analysis* (CRWMS M&O 1999 [DIRS 110602]), a distribution of inhalation exposure time was developed based on time spent indoors and outdoors in the contaminated area by Amargosa Valley residents who commute to distant areas to work (minimum exposure) and farmers and others who work outdoors in the area (maximum exposure). Mass loading (i.e., mass of suspended particles per volume of air) was calculated based on measurements of suspended air particles less than 10 μm (PM_{10}) taken at Yucca Mountain between 1992 and 1997. A typical volume of air breathed per day by an average adult male was selected as the chronic breathing rate.

To provide GENII-S V.1.4.8.5 input for the external exposure pathway, estimates of soil exposure time, home irrigation rate, and home irrigation duration were developed. The distribution of soil exposure time was based on the time commuters and outdoor workers spend outdoors in the contaminated area. A distribution of home irrigation rate was calculated based on the irrigation requirements of bermuda grass (minimum) and tall fescue (maximum) in Amargosa Valley. A value for year-round home irrigation duration was selected based on the watering requirements of those turf grasses. A change to the initial report (CRWMS M&O 2000 [DIRS 149880], Section 6.5) introduced minor modifications that included changed irrigation rates for residential lawns.

Updated Treatment–In the updated report (CRWMS M&O 2000 [DIRS 152438], Section 6), the following changes were made:

- Distributions for the duration of external exposure and soil exposure were developed to better match employment scenarios for potential receptor groups in a farming community.
- New distributions of mass loading were selected based on measurements of total suspended particles in farming communities and, separately, for the conditions following volcanic eruptions.
- Additional distributions of home irrigation rate and duration were calculated based on a change from the present-day climate to a glacial-transition climate.

See Section 13.3.6 for a description of changes in the inhalation exposure parameters.

13.2.1.5 Identification of Ingestion Exposure Parameters

Total System Performance Assessment-Site Recommendation Treatment–*Identification of Ingestion Exposure Parameters* (CRWMS M&O 2000 [DIRS 133719]) describes the selection and justification of the values for the ingestion exposure pathway parameters used by GENII-S V.1.4.8.5. In this report, 13 ingestion exposure parameters (some of them divided into multiple food type categories) were developed. The estimates were based on the current climate in the Yucca Mountain region.

Updated Treatment–*Identification of Ingestion Exposure Parameters* (CRWMS M&O 2000 [DIRS 133719]) was not revised. However, selected ingestion exposure parameters applicable to the cooler and wetter glacial-transition climate were developed to support BDCF calculations for the evolved climate. Additionally, the values of some parameters for the current climate were revised. These calculations are documented in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539], Section 6.5.2 and Attachment III).

13.2.1.6 Environmental Transport Parameter Analysis

Total System Performance Assessment-Site Recommendation Treatment–The purpose of the *Environmental Transport Parameters Analysis* (CRWMS M&O 1999 [DIRS 110520]) was to develop or select values for environmental transport parameters, which include over 50 values required by GENII-S V.1.4.8.5. The code's default parameters were evaluated for adequacy by comparing them with the values in the scientific literature. The parameter value selections were justified and documented.

Updated Treatment–One change was made (CRWMS M&O 2001 [DIRS 152434]) to include additional input parameters for biosphere dose modeling. A set of new crop resuspension factors was developed based on a high mass loading after a volcanic eruption. A new value for the crop resuspension factor for the arid agricultural area was developed for the groundwater release exposure scenario. This was done because the previously developed resuspension factor was derived from Yucca Mountain site data, and it was found to be lower than the typical value in arid agricultural areas.

13.2.1.7 Transfer Coefficient Analysis

Total System Performance Assessment-Site Recommendation Treatment–*Transfer Coefficient Analysis* (CRWMS M&O 1999 [DIRS 110523]) describes the selection of values for transfer coefficients, including soil-to-plant transfer factors for four crop categories, animal feed transfer coefficients for four animal products, and bioaccumulation factors for freshwater fish. Because these parameters are element-specific, seventeen elements were included in the initial report. Distributions for two scaling factors were also considered. These distributions attempted to quantify the uncertainties in deterministic values used for each of the soil-to-plant and animal uptake coefficients. To perform the analysis, parameter values were collected from a search of the scientific literature. Typically, about ten references were considered for each parameter.

Updated Treatment–After the initial report was issued, two changes were made. The first (CRWMS M&O 2000 [DIRS 149879]) was made to clarify selection criteria, correct a few previously selected values, and make editorial modifications. The second (CRWMS M&O 2000 [DIRS 152435]) added lead, bismuth, and polonium to the analysis. This change was made to accommodate the modified list of radionuclides of interest based on the source term inventory.

13.2.1.8 Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods

Total System Performance Assessment-Site Recommendation Treatment–The dose assessment component of GENII-S V.1.4.8.5, the code used to implement the biosphere model, was evaluated (CRWMS M&O 1999 [DIRS 110635]) to ensure that the calculated doses were consistent with doses calculated using other radiation dose assessment methods currently accepted by the scientific and engineering community. For internal exposure, doses calculated by GENII-S V.1.4.8.5 were compared with doses calculated using published values of dose conversion factors. It was recommended that GENII-S V.1.4.8.5 internal dose assessment be conducted with no modifications to the code's auxiliary files containing dose conversion factors for internal exposure. For external exposure, GENII-S V.1.4.8.5 dose coefficients were replaced with more recently published dose coefficient values from Federal Guidance Report No. 12 (Eckerman and Ryman 1993 [DIRS 107684]).

Updated Treatment–This report has not been updated. However, an additional evaluation of dose assessment methods was conducted, as described in Section 13.3.2.

13.2.1.9 Evaluation of Soil and Radionuclide Removal by Erosion and Leaching

Total System Performance Assessment-Site Recommendation Treatment–The effort described in *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000 [DIRS 136281]) focused on the removal of radionuclides from soil by leaching and erosion, including wind and water removal. An appropriate leaching coefficient was derived for each elemental contaminant by using the overwatering term (estimated in a separate analysis), the partition coefficient, and the soil model employed in GENII-S V.1.4.8.5. Assuming accepted agricultural methods, the analysis also derived estimates of annual soil removal rates for the soil types present in the Amargosa Valley region.

Updated Treatment–The updated report (CRWMS M&O 2001 [DIRS 152517]) addressed the impact of possible climate change on the parameters derived from the initial analysis. The findings were that a cooler and wetter climate would not change the annual rate of soil removal as long as current cultivation practices continue. The analysis of climate effects on leaching rate showed that the leaching rate of radionuclides from the top 15-cm surface layer could vary as a function of changes in the annual overwatering rate. Such a change could result from modifications in irrigation practices under different climatic regimes. Climate change had no effect on leaching rate because an overwatering rate of 15 cm/yr was assumed in all analyses to account for the removal of salts.

13.2.1.10 Biosphere Dose Conversion Factors for the Groundwater Release Exposure Scenario

Total System Performance Assessment-Site Recommendation Treatment–The objective of *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000 [DIRS 136285]) was to develop the BDCFs for the nominal postclosure performance assessment. The analysis used input data from the reports listed in Section 13.2.1.2 and Sections 13.2.1.4 through 13.2.1.9. Radionuclide-specific BDCFs were calculated for sixteen radionuclides: carbon-14, technetium-99, iodine-129, actinium-227, thorium-229, uranium-232, uranium-233, uranium-234, uranium-236, uranium-238, neptunium-237, plutonium-238, plutonium-239, plutonium-240, americium-241, and americium-243. The selection of these radionuclides is discussed in CRWMS M&O (2000 [DIRS 136285], Section 4.2.2). The analysis included stochastic runs, which were performed to propagate the defined uncertainties of input parameters to the output BDCFs. The BDCFs were subsequently used in the TSPA-SR

(CRWMS M&O 2000 [DIRS 153246]) to determine the expected annual dose from the potential repository.

Biosphere Dose Conversion Factors for Reasonably Maximally Exposed Individual and Average Member of Critical Group (CRWMS M&O 2000 [DIRS 144700]) documented the development of BDCFs for seven additional radionuclides identified in Section 5 as: strontium-90, cesium-137, lead-210, radium-226, protactinium-231, thorium-230, and plutonium-242. This brought the total number of radionuclides investigated to 23. After the initial BDCFs were developed (CRWMS M&O 2000 [DIRS 136285]), these radionuclides were identified as being potentially significant for evaluating the radiological impact of the potential repository for up to 1 million years after permanent closure. BDCFs were also calculated for the reasonably maximally exposed individual prescribed in EPA regulations.

Updated Treatment–The updated analysis (CRWMS M&O 2001 [DIRS 152539]) developed BDCFs for all TSPA scenarios resulting in groundwater release. The analysis:

- Used revised input parameters
- Incorporated an analysis of climate change effects on the BDCFs for the groundwater release scenario
- Added pathway and limited uncertainty analyses
- Appended the list of radionuclides to include those that may be important for up to 1 million years after permanent closure of the potential repository
- Changed the document title to better describe the document purpose and contents
- Added the biosphere model validation.

The title of the report was changed to *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]). The updated analysis used revised input data where available (see list of input reports above).

13.2.1.11 Sensitivity Analysis for the Groundwater Release Biosphere Dose Conversion Factors

Total System Performance Assessment-Site Recommendation Treatment–The *Non-Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis* (CRWMS M&O 2000 [DIRS 144692]) determined the sensitivity of the nominal performance BDCFs, which were developed in *Non-disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000 [DIRS 136285]), to variations in the input parameters and documented the results of an exposure pathway analysis. These analyses provided insights regarding the parameters and exposure pathways that have the greatest impact on the BDCFs.

Updated Treatment–The report has not been updated. However, an updated pathway analysis for the groundwater release BDCFs was conducted in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]; see also Section 13.2.1.10).

13.2.1.12 Distribution Fitting to the Stochastic Biosphere Dose Conversion Factors for the Groundwater Release Exposure Scenario

Total System Performance Assessment-Site Recommendation Treatment–The activity documented in *Distribution Fitting to the Stochastic BDCF Data* (CRWMS M&O 2000 [DIRS 144055]) was conducted to derive statistical distributions of the BDCFs. The individual realizations (130 for this approach) for each GENII-S V.1.4.8.5 run were analyzed to ascertain which of several distributions were acceptable for representing the data. The distributions included normal, lognormal, shifted lognormal, and others. The chi-square test was used to determine acceptability of fitting.

Radionuclides that exhibited a change in mean BDCF value of less than 15 percent over the periods of continuing irrigation considered were represented by the distribution derived from the longest period of irrigation. In cases where the change in BDCF mean value was larger than 15 percent over the period of irrigation, the data were further analyzed to incorporate the effect of soil erosion.

Updated Treatment–The updated report (CRWMS M&O 2001 [DIRS 153207]) documented distribution fitting to the updated BDCFs for the groundwater release exposure scenario. The approach to distribution fitting was identical to that presented above. For this iteration, 150 individual model realizations were generated per each GENII-S V.1.4.8.5 run. This increase in sample size improved the treatment of statistical uncertainty inherent in the process.

In the case of carbon-14, none of the distributions considered were deemed to be acceptable; therefore, an empirical distribution was used in the TSPA. The empirical distribution was specified in terms of percentiles at five-percent intervals.

13.2.1.13 Abstraction of Biosphere Dose Conversion Factor Distributions for Irrigation Periods

Total System Performance Assessment-Site Recommendation Treatment–In cases where radionuclide buildup in soils was found to be potentially significant (see Section 13.2.1.12), the BDCF data (see Section 13.2.1.10) were subjected to additional analysis, as documented in *Abstraction of BDCF Distributions for Irrigation Periods* (CRWMS M&O 2000 [DIRS 144054], Section 6). The mean value of the fitted data for each radionuclide was shown to be in the form of an asymptotic exponential function, as expected from the model used by the GENII-S V.1.4.8.5 code for radionuclide loss from decay, leaching, and harvesting. The exponential factor was then modified to include the additional loss mechanism of soil removal, with a characteristic time of 250 years. The overall effect was to reduce the asymptotic (long-term) BDCF value by some degree. For radionuclides with a short buildup time compared to 250 years, the change in BDCF was insignificant. However, in cases where the predicted radionuclide buildup was long compared to 250 years, the effect was significant. In all cases, the long-term, and therefore conservative, values of BDCFs were used in the TSPA. This conservative approach eliminated the need to define and justify a representative distribution for the number of years that various plots of land associated with the hypothetical community had been subject to continuing (or sporadic) irrigation and production.

Updated Treatment–In the updated report (CRWMS M&O 2001 [DIRS 153206]), the revised BDCF data were used (see Section 13.2.1.10). Otherwise, the methods were the same as those used for the TSPA-SR treatment.

13.2.1.14 Volcanic Eruption Biosphere Dose Conversion Factor Analysis

Total System Performance Assessment-Site Recommendation Treatment–The second exposure scenario considered in biosphere modeling concerned the conditions of human exposure following a volcanic eruption through the repository. BDCFs for a volcanic eruption were documented in the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000 [DIRS 143378]). The initial exposure scenario considered only a thin layer of contaminated ash deposition, although the scenario was subsequently modified to include an event that resulted in thicker deposits of ash. The analysis used input data from the reports listed in Section 13.2.1.2 and Sections 13.2.1.4 through 13.2.1.9. Radionuclide-specific BDCFs for volcanic eruptions were calculated for twelve radionuclides: strontium-90, cesium-137, actinium-227, thorium-229, protactinium-231, uranium-232, uranium-233, plutonium-238, plutonium-239, plutonium-240, americium-241, and americium-243. The analysis included stochastic runs, which were performed to propagate the defined uncertainties of input parameters to the output BDCFs. As the result of the exposure scenario change, these BDCFs were not used in the TSPA-SR to calculate the annual doses for a volcanic eruption. Instead, a new set of BDCFs was developed (see below) that corresponded to the eruption conditions predicted by the TSPA-SR analyses.

Scoping Calculation for Volcanic Eruption Biosphere Dose Conversion Factors (CRWMS M&O 2000 [DIRS 152632]) documents the development of updated sets of volcanic eruption BDCFs, which were subsequently used in the TSPA-SR. Compared to the previous approach (CRWMS M&O 2000 [DIRS 143378]), the following changes were made:

- The list of radionuclides was expanded to include those important in assessing repository performance during the 10,000-year compliance period and those that may be important to repository performance for up to 1 million years.
- Three exposure scenarios based on three phases during and after volcanic eruption were considered.
- BDCFs were calculated for two thicknesses of contaminated ash: 1 cm and 15 cm.

Updated Treatment–The update to the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]):

- Incorporated the revised exposure scenarios
- Used revised input parameters
- Added pathway and limited uncertainty analyses

- Appended the list of radionuclides to include those that may be important for up to 1 million years after permanent closure of the potential repository

- Added a biosphere model validation.

13.2.1.15 Sensitivity Analysis for the Volcanic Eruption Biosphere Dose Conversion Factors

Total System Performance Assessment-Site Recommendation Treatment–The *Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis* (CRWMS M&O 2000 [DIRS 149736]) determined the sensitivity of the volcanic eruption BDCFs, which were developed in *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000 [DIRS 143378]), to variations in input parameters. The report also documented the results of the exposure pathway analysis. These analyses provided insights regarding the parameters and exposure pathways that have the greatest impact on the BDCFs.

Updated Treatment–This report has not been updated. However, an updated pathway analysis was conducted for the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]; see also Section 13.2.1.12).

13.2.2 Identification of Unquantified Uncertainties in the Biosphere Model

In any numerical modeling activity, such as TSPA or its constituent models, there are numerous sources of uncertainty. In a deterministic model, where all parameters are defined by fixed values, the uncertainties (or errors) are of a systematic nature: uncertainties in the input parameter(s) or modeling approach produce a result that is biased. In the case of a stochastic model (such as GENII-S V.1.4.8.5), where some input parameters are sampled from justifiable distributions, the effects of parameter uncertainties can be propagated through to the desired result. After many evaluations have been made using randomly selected input values, the collection of individual results is a distribution. This section discusses uncertainties in the conceptual model, the mathematical model, and input parameters, as well as the uncertainties between BDCFs for various radionuclides. GENII-S V.1.4.8.5 is used in the stochastic mode to evaluate the effect of parameter uncertainties. The numerical modeling uncertainties are assumed to be insignificant when compared to other uncertainties, since the GENII-S code (including V.1.4.8.5) has gained acceptance within the radiation community (CRWMS M&O 2000 [DIRS 151615], Sections 3.2.1.1 and 3.2.1.3).

BDCF data generated for the TSPA have included parametric uncertainty. To put this assessed uncertainty of the BDCFs into perspective, the results of GENII-S V1.4.8.5 using data presented later in this section can be used. For instance, the groundwater release BDCF distributions for selenium-79 are presented in Table 13.3-22. The median BDCF value for the 6^{th} irrigation period is 1.28×10^{-5} rem per pCi/L. The 5 percent and 95 percent points are approximately a factor of 2.8 below and above the median. Thus, the uncertainty in BDCFs from currently estimated parametric uncertainty covers a range of about a factor of eight. If any other uncertainty produces a much smaller additional variation, the effect can safely be ignored.

13.2.2.1 Conceptual Model Uncertainty

FEPs Screening–The biosphere conceptual model describes the human exposure pathways associated with the FEPs that were screened and found to be applicable to the biosphere model. Although uncertainty associated with the screening decisions (i.e., decisions to include or exclude selected FEPs and associated exposure pathways in the model) was not mathematically evaluated, there should be little additional uncertainty because potentially significant FEPs were included in the conceptual model.

Conceptual Models of Radionuclide Transport–The conceptual model of radionuclide transport in the biosphere (i.e., between the environmental media) is based on the selection of participating media (e.g., groundwater, soil, air, fauna, flora) and the FEPs that cause the transport of radionuclides between them. The behavior of radionuclides in the biosphere may, in principle, be complex because of the variety of participating media and transport processes; however, it is neither possible nor necessary to engage such complexity to construct a conceptual model of radionuclide transport. Simplified compartment models are used by modelers in codes such as GENII-S V.1.4.8.5. Such models are inevitably a simplified representation of actual radionuclide migration in the biosphere, and uncertainty is an inherent part of such representation. Uncertainties associated with the model representation of environmental radionuclide transport have not been quantified. However, the model used by GENII-S V.1.4.8.5 compares favorably with alternative models (see Section 13.2.3). Additional uncertainties are likely to be minor relative to the overall range of uncertainty in the BDCFs.

Conceptual Models of the Receptor of Interest–Human exposure was evaluated for the hypothetical receptor. To quantify radiation exposure from interactions with contaminated environmental media, the attributes and behavioral characteristics of the receptor that may influence the degree of radiation exposure have to be determined. An example of a behavioral characteristic is employment outdoors, and a corresponding attribute is the amount of time spent at outdoor locations. Another behavioral characteristic potentially leading to radiation exposure is consumption of locally produced food. Attributes of this behavior include consumption rates of various locally produced food types. Although the receptor is defined in proposed 10 CFR 63 (64 FR 8640 [DIRS 101680]) and 40 CFR 197 (64 FR 46976 [DIRS 105065]), there is no unequivocal way of defining the appropriate characteristics and attributes. Therefore, selection of characteristics and attributes of the receptor involves uncertainty. This is a concern for both of the human exposure scenarios under consideration and their corresponding parameters (e.g., consumption rates for locally produced food and water). The sensitivity of BDCF results to variations in the definition of the receptor is discussed in Section 13.3.1.

13.2.2.2 Mathematical Model Uncertainty

Overall Uncertainty of the Mathematical Model–The mathematical model of radionuclide transport and human exposure in the biosphere is based on the model used by GENII-S V.1.4.8.5. This code was selected as the implementing software for the biosphere assessment, except for the treatment of radionuclide removal by soil erosion and the groundwater usage analysis. The overall uncertainty associated with this mathematical model has not been quantified. Many individual model components contribute to the overall uncertainty, as described in this section. The multiple lines of evidence presented in Section 13.2.3 indicate that mathematical uncertainties contribute little additional uncertainty.

Exposure Pathways Not Included in GENII-S V.1.4.8.5–The mathematical model is based on a specific choice of the environmental media and radionuclide transport processes—which, together, make up the human exposure pathways—that are believed to be the most important for total radiation exposure. However, there is always a possibility that all pathways will not be included in a given mathematical model. For example, among the GENII-S V.1.4.8.5 ingestion pathways, only one kind of meat (beef) is included; organs, such as beef or chicken livers, are not. Other pathways that are not modeled in GENII-S V.1.4.8.5 include soil ingestion by grazing animals and inhalation by animals. The impact of these omissions on model uncertainty was not mathematically evaluated. Since potentially significant FEPs were included in the conceptual model, little additional uncertainty should be introduced.

Treatment of Environmental Transport within the Mathematical Model–Radionuclide transport between the environmental media via transport processes contributing to the human exposure pathways is represented in the mathematical model as a series of pathway submodels. Each of these submodels represents a simplified way to describe and quantify complex radionuclide behavior in the environment. This particular approach to radionuclide pathway transport modeling is subject to uncertainty because of the simplification of the process when represented by a mathematical model and the representation of the interfaces between the modeled processes. These uncertainties were not evaluated. Given the acceptance of GENII-S V.1.4.8.5, additional uncertainties are assumed to be inconsequential and, therefore, are likely to be minor relative to the overall range of uncertainty in the BDCFs.

General Categorization of Input Parameters–Many of the input parameters used in GENII-S V.1.4.8.5 are composed of several contributing data points: their values are selected by grouping available data for a given parameter. For example, transfer factors for leafy vegetables were derived using transfer coefficients for individual crops, such as lettuce, cabbage, and spinach. The available data for the same crops would also be used to calculate other parameters for leafy vegetables, such as irrigation rate, growing time, and irrigation time. Some uncertainties are associated with this method of grouping data points to arrive at the values of composite parameters. The parameters associated with these pathways were represented by distributions to approximate these uncertainties.

Limitations on Correlations Between Sampled Parameters–The mathematical model (and implementing computer code) does not allow the user to specify the correlation between pairs of parameters belonging to different groups of inputs defined by distributions. For example, the correlation between mass loading (inhalation and external exposure) and the resuspension factor (ingestion) cannot be defined in GENII-S V.1.4.8.5.

Each food transfer coefficient group (crops and animal products) uses the same transfer coefficient scaling factor for all coefficients in the group. Although such treatment provides a way of correlating transfer coefficients between members of the group, it introduces additional uncertainty, which was not quantified.

Fixed Parameter Values–GENII-S V.1.4.8.5 has the capability to represent some model parameters by probability distribution functions or fixed values. However, many parameters can only be represented by fixed values (e.g., leaching rate, time duration of previous irrigation, weathering rate for the removal of contamination from foliage). In this case, software limitations prevent the user from factoring uncertainty associated with some parameters into the model. Uncertainty resulting from an inability to select a range of parameter values for certain parameters was not quantified. Limited studies presented in Sections 13.3.3 and 13.3.4 evaluated the additional uncertainty introduced by this limitation. They concluded that the uncertainty in the three parameters under consideration was estimated to impact BDCFs by ±50 percent in the cases of iodine-129, neptunium-237, and plutonium-239 and by up to 400 percent in the case of technetium-99.

13.2.2.3 Model Parameter Uncertainty

Use of Literature Data Instead of Site-Specific Data–The development of a fully site-specific biosphere model at Yucca Mountain is not possible because of the limited availability of site-specific data. Wherever possible, the modeling effort used site-specific and regional information. Information from scientific literature was selected with care when site-specific or regional information was not available. The magnitude of uncertainty resulting from the use of information from literature in lieu of site-specific or regional data was not evaluated. However, the range over which the parameters were distributed was considered sufficient to capture these uncertainties.

Selection of Fixed Parameter Values–Many parameters are used in performing BDCF calculations. GENII-S V.1.4.8.5 can represent some of the model parameters by their probability density function. However, not every input parameter that could be represented this way was. In general, distributions were used for parameters with a large amount of uncertainty or a major influence on the final BDCFs; otherwise, fixed values were used. Representing less important parameters as fixed values reduced the computational burden on the software and allowed an increase in the maximum possible number of model realizations, improving the statistical representation of the outcome. Since fixed values were used in place of distributions for pathways making relatively minor contributions, this omission likely added little additional uncertainty to the calculation of the BDCFs.

Parameter Ranges for Probability Distributions–In many instances, probability distributions were based on temporal and spatial variations in the data rather than on uncertainty. This was the case for the consumption rates of locally produced food, for many of the ingestion exposure parameters (e.g., rates and durations), and for the growing times of various crops. The range of variations examined in selecting these parameters was intended to be large enough to account for uncertainty in site-specific conditions. However, the contribution of uncertainty to these distributions was not evaluated.

User-Defined Correlations Between Parameters–Parameters represented by their probability density functions were assumed to vary independently, except for transfer factors representing plant-to-soil and animal food to animal product transfers. Therefore, the covariance among parameters for BDCF calculations was not included in the biosphere model. In general, the effect of neglecting covariances is to imprecisely estimate confidence intervals on the BDCFs.

In other words, if the correlation among input parameters is positive, the uncertainty in the BDCFs will be underestimated, while if the correlation is negative, the uncertainty will be overestimated. This uncertainty was not quantified.

Statistical Error in Data–Statistical errors in the data were not quantified, yet they may constitute an additional source of uncertainty. For example, uncertainties in the consumption rates of locally produced food due to the sampling procedure were not determined. In addition, the selection of a smaller population subgroup from the larger sample, which was done to identify the receptor, leads to an increase in standard error. This uncertainty was not evaluated. Because variability in the consumption habits of the receptor was large, additional sampling uncertainty likely was of little consequence.

13.2.2.4 Uncertainty in the Model Results

Correlations Between the Results–The impact of possible correlations between the BDCFs for individual radionuclides (e.g., the BDCFs for various isotopes may be correlated) is a concern for their use in the TSPA. The uncertainty depends on the predicted radionuclide concentration and could not be evaluated in this report. Such correlations may have an impact on the uncertainty in the expected annual dose calculated in the TSPA model.

Uncertainty Associated with Model Abstraction–Using statistical distributions to abstract the BDCFs generated by the biosphere model was shown to provide a reasonable and statistically acceptable representation (CRWMS M&O 2001 [DIRS 153207]; CRWMS M&O 2001 [DIRS 153206]). However, because a limited number of model realizations could be generated (130 realizations in the initial analysis and 150 in the update), there is an intrinsic sampling uncertainty in the overall modeling result. The uncertainty in the mean value of a given set of BDCF data is small compared to the distribution width, so it was ignored. This is achieved by calculating the uncertainty in the mean value from the standard deviation, as reported in *Distribution Fitting to the Stochastic BDCF Data* (CRWMS M&O 2000 [DIRS 144055]).

13.2.3 Multiple Lines of Evidence in the Biosphere Model

This section summarizes the evidence that supports the validity of the approach adopted in modeling the biosphere. The approach taken was to compare the YMP biosphere modeling details with work performed and published by peers.

13.2.3.1 Biosphere Conceptual and Mathematical Model

The YMP biosphere model is based on the GENII-S V.1.4.8.5 code, which was developed and used for the Waste Isolation Pilot Plant performance assessment as part of the application for a certificate of compliance from the EPA (Leigh et al. 1993 [DIRS 100464], Abstract). The code was also used by the Center for Nuclear Waste Regulatory Analyses in support of a performance assessment for the potential repository at Yucca Mountain (LaPlante and Poor 1997 [DIRS 101079]).

A preliminary comparison was conducted between the model used for the groundwater release exposure scenario for the potential repository at Yucca Mountain and the International Atomic Energy Agency (IAEA) biosphere model developed by the BIOMASS program

(BIOMASS 2000 [DIRS 154522], Example Reference Biosphere 2A). The assessment context for the biosphere model gives background information and the requirements of the performance assessment. Several aspects of the assessment context were compared for the YMP model for groundwater release and the BIOMASS Example Reference Biosphere 2A model (Table 13.2-1). The comparison indicated that the two models are very similar. Many aspects are identical, while others are equivalent. Using the same or equivalent aspects of the assessment context, an overall comparison of the pathways and methodologies used in the two biosphere models was conducted, as shown in Table 13.2-2. Each pathway included in the models was compared. Most pathways are considered in both models using the same or similar methods, although some pathways are considered in only one of the models. However, the model comparisons indicated that the pathways not included in the YMP model were of lesser significance when compared with other pathways for the groundwater release model. Documentation for the BIOMASS program (BIOMASS 2000 [DIRS 154522], Section 8), indicates that some pathways, such as water immersion and aerosol inhalation, are much less important than other pathways, such as drinking water and crop consumption.

13.2.3.2 Biosphere Input Parameters

Several methods were used to develop input parameters for the YMP biosphere model (CRWMS M&O 2000 [DIRS 151615]). Using site-specific information was the first priority for developing input parameters. Site-specific information included Yucca Mountain site field measurements (such as meteorological data), a regional food consumption survey of such items as food consumption rates, and firsthand observations in Amargosa Valley of behaviors such as well water usage. The quality of site-specific information depends on data collection methods. Furthermore, site-specific information may be subject to temporal variations and, therefore, reflect the conditions at the time of measurement. Other regional and national demographic data, such as mass loading for agricultural area, were also used in the development of some environmental parameters and human behavior attributes.

If site-specific data were not available, parameter values were obtained from the literature. Literature information includes scientific articles in reviewed journals, published technical reports, and internationally accepted generic databases. The reliability of the derived values depends on many factors, including the uncertainties in the source data, decisions regarding the applicability of the data for conditions other than the original ones, and the ability to define distributions and ranges of parameters. When literature information was used for the YMP biosphere model, input data were chosen to best reflect the local conditions (such as environmental transport parameters). This method of selecting parameter values (CRWMS M&O 2000 [DIRS 152435]; CRWMS M&O 2000 [DIRS 152438]; CRWMS M&O 2001 [DIRS 152517]; CRWMS M&O 2001 [DIRS 152434]) incorporated an aspect of multiple lines of evidence because it considered a significant portion of current scientific knowledge reported by others.

13.3 UNCERTAINTY, SENSITIVITY, AND NEW ANALYSES

The previous two sections identified multiple areas in the biosphere that are potentially subject to uncertainty. Each of these uncertainties propagates through the biosphere calculation, where their combined effects are incorporated into a distribution for each radionuclide identified as important to dose and for defined release/exposure scenarios. This section describes only those analyses conducted since the development of the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]). These additional analyses were conducted to help the DOE better understand the uncertainties and sensitivities inherent in the biosphere model or to provide new or updated analyses of the biosphere. The following paragraphs briefly introduce each analysis and identify the rationale for the work performed.

The first analysis provides information on the sensitivity of predicted annual doses to the modeling of the receptor of interest. In draft regulations, both regulatory agencies—the U.S. Nuclear Regulatory Commission (NRC) in proposed 10 CFR 63.115(b)(2) (64 FR 8640 [DIRS 101680]) and the EPA in proposed 40 CFR 197.21(b) (64 FR 46976 [DIRS 105065])—identify their receptor of interest for evaluation of annual doses from potential repository releases. The detailed implementation of the receptor of interest within the computer code is subject to uncertainty, so the sensitivity of annual dose to the details of the receptor definition is evaluated and discussed.

Annual dose limits evaluated by the biosphere effort to support the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) are based on the definition of the total effective dose equivalent (TEDE) in 10 CFR 20.1003. A sensitivity study investigated the changes in the BDCFs for four important radionuclides that would be expected if the more recent International Commission on Radiological Protection recommendations (ICRP 1991 [DIRS 101836]) were used.

Three uncertainty analyses follow the sensitivity study. The first investigates the previously unquantified uncertainty of partition coefficients on BDCFs. The uncertainty in a given partition coefficient for an element affects its leaching coefficient. Uncertainty in this parameter causes variation in the degree of radionuclide buildup in soil from prolonged irrigation and has a direct effect on BDCFs. The second analysis focuses on the four dominant radionuclides, and investigates the effect of uncertainty on several ingestion pathway parameters that GENII-S V.1.4.8.5 can only accept as fixed inputs. The remaining uncertainty analysis develops a sampling algorithm to predict the annual rate of water usage by the proposed farming community in a future cooler and wetter climate.

Section 13.3 closes with the details of three new analyses, each generating new data. The first of these investigated the parameters associated with inhalation. In particular, the estimates of the mass loading of particulate matter in the atmosphere were revised, along with inhalation exposure time and breathing rate. The revised mass loading values were used in both the groundwater release scenario and the volcanic eruption scenario. These new data were used to generate revised BDCFs.

The second new analysis involved the generation of BDCFs for the predicted cooler and wetter climate over the 10,000-year compliance period. This new data was generated to evaluate the sensitivity of the BDCFs to expected climate change.

The final analysis supported dose calculations for two radionuclides that had not been previously identified as of concern to dose calculations, selenium-79 and neptunium-237. BDCFs were generated for both release scenarios for selenium and for the extrusive scenario for neptunium.

13.3.1 Receptor of Interest

Inherent in the reference biosphere for the potential repository at Yucca Mountain is the representation of the population expected to be at risk. The model represents the potentially exposed population as a hypothetical individual, referred to as the receptor of interest or simply the receptor. Biosphere pathway analyses were performed for a receptor called the average member of the critical group, as defined in proposed 10 CFR Part 63 (64 FR 8640 [DIRS 101680]). An alternative receptor is the reasonably maximally exposed individual, defined in 40 CFR Part 197 (66 FR 32074 [DIRS 155216]). The parameters to define both receptors are based on the behaviors and characteristics of the Amargosa Valley population.

The task of identifying a receptor of interest for the performance assessment had three objectives. The first was to define the population at risk, consisting of the hypothetical groups of exposed individuals and the corresponding characteristics of their expected behavior. The second was to develop estimates of the parameters or attributes for the expected behaviors that are required to evaluate the magnitude of radiation exposure of the group members. The final objective was to choose a receptor or a critical receptor group that is representative of the individuals in the population at risk expected to receive the highest annual doses.

Although the representation of the receptor is based on proposed regulations (see Section 13.3.1.1), the actual realization of the requirements pertaining to the receptor includes many sources of uncertainty. The effect of some of these uncertainties on the outcome of biosphere modeling is evaluated in this section. One question posed was: How sensitive is the modeling outcome to the selection of the attributes of behaviors and characteristics for the receptor? To address this subject, five different farming receptor groups were analyzed, each represented by different values of behavioral attributes.

13.3.1.1 Existing Guidance and Requirements

The representation of the expected population at risk was based on proposed NRC (64 FR 8640 [DIRS 101680]) and EPA (64 FR 46976 [DIRS 105065]) regulations. In the proposed NRC regulations, the exposed population is represented by the average member of the critical group (proposed 10 CFR 63.113(c), 64 FR 8640 [DIRS 101680]). The critical group selected based on the proposed regulations and guidance should be a group of people whose location and habits are characteristic of those individuals that are expected to receive the highest annual doses from the potential release of radionuclides. Specific requirements for assessment of the critical group are as follows (proposed 10 CFR 63.115(b), 64 FR 8640 [DIRS 101680]):

1) The critical group shall reside within a farming community located approximately 20 km south from the underground facility (in the general location of U.S. Route 95 and Nevada Route 373, near Lathrop Wells, Nevada).

2) The behaviors and characteristics of the farming community shall be consistent with current conditions of the region surrounding the Yucca Mountain site. Changes over time in the behaviors and characteristics of the critical group including, but not necessarily limited to, land use, lifestyle, diet, human physiology, or metabolics; shall not be considered.

3) The critical group resides within a farming community consisting of approximately 100 individuals, and exhibits behaviors or characteristics that will result in the highest expected annual doses.

4) The behaviors and characteristics of the average member of the critical group shall be based on the mean value of the critical group's variability range. The mean value shall not be unduly biased based on the extreme habits of a few individuals.

5) The average member of the critical group shall be an adult. Metabolic and physiological considerations shall be consistent with present knowledge of adults.

To select a critical group, individuals likely to be at the highest risk from among the potentially exposed population must be specified. In the process, assumptions are made about diet, nature of human activities, lifestyles, and exposure pathways that affect the level of radiation exposure. The proposed EPA regulations used the reasonably maximally exposed individual (RMEI) to represent the exposed population (proposed 40 CFR 197.20, 64 FR 46976 [DIRS 105065]).

On June 13, 2001, the Environmental Protection Agency (EPA) issued the final rule 40 CFR Part 197 (66 FR 32074 [DIRS 155216]) to establish "public health and safety standards for radioactive material stored or disposed of in the potential repository at Yucca Mountain." The EPA final rule requires the DOE to calculate the annual dose to a reasonably maximally exposed individual (RMEI) as a result of nominal, disruptive, and stylized human intrusion scenarios projected to occur during the 10,000-year compliance period. The calculated annual dose to the RMEI is to demonstrate whether there is reasonable expectation that the individual protection standard is satisfied.

To demonstrate compliance with the EPA individual protection standard, a hypothetical receptor must be defined. 40 CFR 197.21 [DIRS 155216] sets the following criteria for defining the hypothetical receptor, called the reasonably maximally exposed individual:

> The reasonably maximally exposed individual is a hypothetical person who meets the following criteria:
>
> a) Lives in the accessible environment above the highest concentration of radionuclides in the plume of contamination;
>
> b) Has a diet and living style representative of the people who now reside in the Town of Amargosa Valley, Nevada. The DOE must use projections based upon surveys of the people residing in the Town of Amargosa Valley, Nevada, to determine their current diets and living styles and use the mean values of these factors in the assessments conducted for 40 CFR 197.20 and 197.25; and
>
> c) Drinks 2 liters of water per day from wells drilled into the groundwater at the location specified in (a).

By specifying a series of requirements and assumptions about the reasonably maximally exposed individual and the average member of the critical group, the EPA (66 FR 32074 [DIRS 155216], p. 32090) and the NRC (64 FR 8640 [DIRS 101680], p. 8645) establish a reasonably conservative basis for protection of the individuals expected to be at risk from a potential repository at Yucca Mountain. The concepts used are consistent with the proposed NRC rule and the EPA rule.

The location of the point of compliance is a basic part of the total system performance assessment scenarios. However, location is not included for calculating the biosphere dose conversion factors for the receptor. The exact location of the receptor, whether in the accessible environment (just beyond controlled area southern boundary at approximately 18 km) as specified by EPA (40 CFR 197.21(a) (66 FR 32074 [DIRS 155216]), or in the general location of U.S. Route 95 and Nevada Route 373, near Lathrop Wells, Nevada (at approximately 20 km) as specified by NRC (proposed 10 CFR 63.115(b)(1) 64 FR 8640, [DIRS 101680]), is not a factor in defining the characteristics of the receptor for biosphere modeling because the characteristics of the receptor, as specified by both NRC and EPA, are based on the population residing in the region surrounding the Yucca Mountain site.

The RMEI is similar in many aspects to the average member of the critical group. Both receptors are composite individuals. Also, the use of site-specific dietary and lifestyle characteristics are analogous for the proposed NRC (proposed 10 CFR 63.115(b)(2) (64 FR 8640 [DIRS 101680]) and EPA (40 CFR 197.21(b) (66 FR 32074 [DIRS 155216]) regulations.

Drinking water consumption for the average member of the critical group and for the RMEI is also consistent. The average member of the critical group is estimated to drink an average of 2.1 L (0.54 gal) of water per day from wells drilled into the groundwater, which is comparable with the RMEI's defined water consumption of 2 L (0.53 gal) per day.

Further discussion of these two receptors in the context of the sensitivity analysis is provided in Sections 13.3.1.3 and 13.3.1.8. Given these sensitivity and uncertainty considerations for receptor concepts, the current receptor (average member of the critical group) is similar to the reasonably maximally exposed individual defined by the EPA (40 CFR 197.21, 66 FR 32074 [DIRS 155216]).

13.3.1.2 Development of the Receptor of Interest

As noted previously, the average member of the critical group was chosen as the receptor of interest for the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) analyses. Identification of the receptor was an iterative process. The first step was to identify screening groups based on the framework of criteria identified in the proposed NRC and EPA regulations. Data regarding behaviors and characteristics of the population in the vicinity of Yucca Mountain were used to characterize screening groups and identify a preliminary receptor. This group exhibited behaviors and characteristics that would result in expected annual doses among the highest in the potentially exposed population. Finally, the analysis examined additional lifestyle and land use data to refine the characterization of the receptor. The results of this analysis are documented in *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2001 [DIRS 153342]).

The critical group was selected as the one with the highest exposure of all the potentially exposed groups identified using attributes of the potential behaviors and characteristics of the population in Amargosa Valley (CRWMS M&O 2000 [DIRS 143940]; CRWMS M&O 2001 [DIRS 153342]). The behaviors and characteristics identified were based upon U.S. Census Bureau data (U.S. Census Bureau 1999 [DIRS 135344]), the *Exposure Factors Handbook* (EPA 1997 [DIRS 103038]; EPA 1997 [DIRS 152549]; EPA 1997 [DIRS 116135]), and a 1997 food consumption survey conducted in the Yucca Mountain region (DOE 1997 [DIRS 100332]). The selected receptor was represented by a farmer who worked 40-60 hours per week outdoors in the contaminated area, recreated a considerable number of hours (over two hours per day) outdoors in the contaminated area, lived in a mobile home or trailer, had a food garden, and consumed locally produced food and well water.

The average member of the critical group, as used in the TSPA analyses, is defined as a composite individual, similar to the definition of the RMEI. The characteristics of both the RMEI and the average member of the critical group are defined from consideration of a range of conditions, typical of the local environment and the local population, that affect exposures. The development of the specifications for the critical group in the context of the potential repository at Yucca Mountain is based on the principles of ICRP, as discussed in the supplementary information to the proposed 10 CFR Part 63 (64 FR 8640 [DIRS 101680], p. 8645). The critical group used in the TSPA analyses, similar to the RMEI, is located directly above the path of the contamination plume, where the exposures are expected to be the highest.

As noted previously, the receptor selection is not unequivocal. The outcome of the process of modeling the receptor of interest depends on many factors, assumptions, and circumstances that contribute to the overall uncertainty associated with the final selection. This section describes how sensitive the resulting annual dose is to the uncertainties in the definition of the receptor. The effects of several factors were evaluated, including:

- Attributes of behaviors and characteristics of the critical group
- Critical group size
- Temporal changes of exposure conditions
- Selection of exposure scenario
- Critical group composition.

13.3.1.3 Effect of Behavioral Attributes

The selected receptor can be described by the set of attributes for behaviors and characteristics used as input parameters in GENII-S V.1.4.8.5 to calculate the BDCFs. These attributes allow quantification of the expected level of exposure of the receptor to radionuclides in the environment. The following characteristics and their corresponding attributes were considered:

- Employment and recreation, which are characterized by the attributes of inhalation exposure time; soil (external) exposure time; and inadvertent soil ingestion rate

- Diet, which is characterized by consumption rates of water and the following locally produced food types: leafy vegetables, other (root) vegetables, fruit, grain, meat (beef and pork), poultry, milk, eggs, and fish.

The attributes of inhalation and soil exposure times are indices of human exposure to airborne and soil contamination, respectively. Both quantities reflect time activity budgets and the associated exposure levels, outdoors and indoors, for the population at risk. Dietary attributes (consumption rates) apply to only that portion of the diet that is derived from local sources.

To explore the effect of choosing a specific set of attributes to characterize a receptor, several alternative receptors characterized by different sets of attributes were analyzed. The analysis focused on the dietary attributes and developed several possible sets of consumption rate values. The alternative receptors included, a receptor based on average food consumption rates for the U.S. population, a receptor based on the food consumption rates recommended for the license termination dose assessment (Kennedy and Strenge 1992 [DIRS 103776]), and three receptors based on the consumption rates of locally produced food for the Amargosa Valley population, as explained in Section 13.3.1.3.3. The first two of the alternative receptors were based on the assumption that 100 percent of the receptor's diet is locally produced, although the food consumption survey (DOE 1997 [DIRS 100332]) did not identify such a dietary pattern among the population in the vicinity of Yucca Mountain. Because it was determined that the receptor of interest was represented by a farmer, the behavioral characteristics of employment, with their associated attributes of inhalation and soil exposure times, were not modified. The analysis employed pathway factors calculated using GENII-S V.1.4.8.5 as described in Section 13.3.1.3.1.

The current receptor in the biosphere model was based on characteristics of the population of the Yucca Mountain region, such as employment, recreation, land use, and diet. Although the employment attributes, including the amount of time spent outdoors, were characteristic of farmers, the dietary attributes were not specific to farmers. They were derived from the results of the food consumption survey, irrespective of the actual employment of the respondents. It was then assumed that the dietary attributes of the receptor coincided with the consumption rates of those members of the Amargosa Valley population who consumed locally produced food and water and had a garden.

13.3.1.3.1 Calculation of Pathway Factors

Radionuclide-specific pathway factors were calculated using a method similar to the one used to calculate BDCFs for the groundwater release exposure scenario (CRWMS M&O 2001 [DIRS 152539], Section 6.7). Pathway factors were calculated for the condition of assumed radionuclide equilibrium concentrations in soil. Radionuclide concentration in soil is important because the magnitude of exposure from a number of exposure pathways depends on this value.

Pathway factors represent annual dose per unit pathway exposure per unit radionuclide concentration in groundwater. The significance of pathway factors is that they represent radionuclide transport in the biosphere for a specific pathway and can be used, as multipliers, to calculate the annual dose for any level of pathway exposure. For example, pathway factors for ingestion of leafy vegetables represent the annual dose resulting from an annual consumption of 1 kg of leafy vegetables grown using contaminated irrigation water with a radionuclide concentration of 1 pCi/L. The summary of pathway factors can be found in Table 13.3-1 (Wu 2001 [DIRS 154894], Table 2).

The annual dose to an individual from a specific radionuclide can be calculated using pathway factors, radionuclide concentration in groundwater, and the actual level of pathway exposure with the following formula:

$$Annual\ Dose\ [rem] = PF\left[\frac{\frac{rem}{kg,\ L,\ or\ hr}}{\frac{pCi}{L}}\right] \times PE\ [kg,\ L,\ or\ hr] \times C_w \left[\frac{pCi}{L}\right]$$

(Eq. 13-1)

where:

PF = pathway factor
PE = annual pathway exposure
C_w = radionuclide concentration in groundwater.

13.3.1.3.2 Individual Annual Doses for the Farming Group Based on the Amargosa Valley Population

Several assumptions were made in selecting the receptor for Yucca Mountain. Since there was not enough information to accurately integrate attributes of behavioral characteristics for the critical group comprised of farmers, the values of the attributes were developed such that the result would be a conservative value at the high end of the range of annual doses for the exposed population. For example, inhalation and external exposure times were calculated assuming that the person spent a substantial part of the day outdoors. The dietary characteristics were typical of a subset of the Amargosa Valley population, specifically those individuals who consumed locally produced food and had a garden. Individuals who had a garden were determined to consume higher quantities of locally produced crops.

To assess the expected range of individual annual doses to a hypothetical group composed of farmers based on the dietary attributes of the Amargosa Valley population, and to evaluate the sensitivity of the group selection to the values of dietary attributes, the annual doses to individuals in a group composed of farmers were evaluated. The individual annual doses were based on the whole set of the consumption survey responses for the Amargosa Valley population. Annual doses presented in this section are estimates generated only for comparisons (sensitivity studies) and were not directly used in the performance assessment process.

The individual annual doses were determined by combining pathway factors with estimates of the consumption rates of locally produced food and water for individual members of the Amargosa Valley population (DOE 1997 [DIRS 100332]). The food consumption survey was conducted in 1997 to collect socioeconomic information for biosphere modeling. For this purpose, dietary and lifestyle data were collected on adults residing within a 50-mile grid centered on Yucca Mountain. It was estimated that nearly 13,000 adults resided in the total study area at the time of the survey, with about 900 of them in Amargosa Valley, comprising approximately 450 households (DOE 1997 [DIRS 100332], p. vi). The total survey sample consisted of 1,079 responses, with an Amargosa Valley sample of 195. Not all responses from

Amargosa Valley were used in this sensitivity analysis; incomplete responses were deleted from the set. Overall, 37 responses were excluded from consideration.

The food consumption survey determined the consumption frequencies of locally produced food and the consumption rates of water. To estimate individual consumption rates, consumption frequencies were multiplied by the contingent average daily intakes (CADI) for these food groups (DOE 1997 [DIRS 100332], Section 3.6). Since the CADIs represent average values, the individual consumption rates calculated using the survey results do not correspond to the actual consumption rates of the surveyed individuals. Instead, they represent the annual consumption of locally produced food for a hypothetical individual characterized by an average contingency diet and the consumption frequency characteristic of the individuals participating in the survey. (Average contingent intakes, unlike per capita intakes, are calculated for consumers only.) The consequence of this approach is that, although the mean values of consumption rates are represented correctly using the survey results (provided the sample is large enough), the variability of individual consumption rates in the population is not captured. In other words, there is more uncertainty in the distribution of individual consumption rates than indicated by the survey results. Water consumption rates were based on the actual amount of water consumed by individuals surveyed.

Individual annual doses to a hypothetical group of farmers characterized by the estimated values of the individual consumption rates for the Amargosa Valley population were calculated using the mean values of radionuclide concentrations in groundwater at 25,000 years after repository closure predicted in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), the pathway factors described in the previous section, and the individual exposure pathway levels for the hypothetical group of farmers (Wu 2001 [DIRS 154894], Section 3.6). The distribution of the annual doses is shown in Figure 13.3-1. The histogram shows that the annual doses for the majority of the individuals are in the low and moderate range of the distribution. Only a few individuals would receive the annual doses in the upper range of the distribution.

The reason for selecting 25,000 years, as opposed to the compliance period of 10,000 years, to evaluate annual doses for the groundwater release scenario results from the expected repository performance predicted by the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Section 4.3.2). When the performance of the potential repository is evaluated, the probability-weighted consequences for the nominal scenario and the two igneous disruption scenarios are added together. Because there are no predicted nominal waste package failures during the 10,000-year compliance period, the nominal scenario contributes nothing to the combined annual dose from the repository; the combined annual dose comes from igneous disruption alone. The combined annual dose is dominated by the nominal annual dose only at later times because of the larger number of nominal waste package failures (CRWMS M&O 2000 [DIRS 153246], Section 4.3.2). The 25,000-year point in time was also selected for the TSPA-SR calculation (CRWMS M&O 2000 [DIRS 153246], Figure 4.1-6).

13.3.1.3.3 Comparison of the Current Receptor with Alternative Receptors

To evaluate the sensitivity of the biosphere model to the selection of the receptor, annual doses to the receptor as used in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) were compared with annual doses to alternative receptors. The receptors were assumed to be characterized by a specific set of dietary attributes (food consumption rates), but otherwise have the characteristics of the current receptor. The analysis was focused on the dietary attributes because ingestion of locally produced food and tap water was by far a dominant exposure pathway (CRWMS M&O 2001 [DIRS 152539]) in the groundwater release exposure scenario.

The consumption rates for the current receptor were based on the group of 77 individuals who eat locally produced food and have a garden. These individuals were selected from the 195 survey responses for the Amargosa Valley residents. The consumption rates for the alternative receptors were based on the responses of 158 individuals because 37 incomplete responses were excluded from the set, as described in the previous section. In addition, consumption of leafy vegetables was adjusted to reflect the re-classification of consumption of tomatoes from the leafy vegetables group to the fruit group. This resulted in the decreased consumption of leafy vegetables and increased consumption of fruit.

Table 13.3-2 summarizes annual exposure levels for the current receptor and the alternative receptors (Wu 2001 [DIRS 154894], Table 3; Wu 2001 [DIRS 155203], Table 1). The annual consumption rates for the current receptor listed in Table 13.3-2 correspond to those used for both the TSPA-SR analyses (CRWMS M&O 2000 [DIRS 153246]) and the analyses presented in Volume 2 (McNeish 2001 [DIRS 155023]). Other potential receptors were developed based on published consumption rates and the food consumption survey results. For the alternative receptors, labeled U.S. Average Receptor and NUREG/CR-5512 Receptor (Kennedy and Strenge 1992 [DIRS 103776]), 100 percent of the food and water are assumed to be locally produced. This assumption is inconsistent with the findings of the food consumption survey (DOE 1997 [DIRS 100332]), which did not identify any individuals whose entire diet would come from local sources. Nevertheless, these alternative receptors were included to provide bounding values for the analysis.

The consumption rates for the U.S. Average Receptor were derived from the *Exposure Factors Handbook* (EPA 1997 [DIRS 103038]; EPA 1997 [DIRS 152549]) and correspond to the recommended average values for the U.S. population. NUREG/CR-5512 (Kennedy and Strenge 1992 [DIRS 103776]) provides guidance for the dose assessment from exposures to residual radioactive contamination after decommissioning of nuclear facilities. The report identifies the limiting exposure scenarios and provides methods of exposure pathway analysis for critical groups at decommissioned facilities. The report provides numerical values for a wide spectrum of model parameters that may be used in generic screening scenarios. The recommended consumption parameters from NUREG/CR-5512 (Kennedy and Strange 1992 [DIRS 103776], Table 6.23) are listed in Table 13.3-2. Note that the fraction of diet from gardens, recommended for license termination dose assessment, is 0.25 (Kennedy and Strange 1992 [DIRS 103776], Table 6.23), which would decrease the consumption rates of locally produced food by a factor of 4 compared with the values listed in Table 13.3-2.

Table 13.3-2 includes three alternative receptors whose consumption rates were based on the dietary attributes of the Amargosa Valley population: these receptors are labeled in Table 13.3-2 as the Alternative Amargosa Valley Receptors 1, 2, and 3. The annual consumption rates for the Alternative Amargosa Valley Receptor 1 were constructed using the 95th percentile of the estimated locally produced food consumption rates for the Amargosa Valley population (based on 158 individual survey responses) and a daily water consumption of 2 L. The Alternative

Amargosa Valley Receptor 2 is an average member of a group selected using the top 5 percent of annual doses at 25,000 years and 100,000 years.

The decision for selecting the group that receives the top 5 percent of annual doses was influenced by recommendations from the BIOMASS program sponsored by the International Atomic Energy Agency (BIOMASS 1999 [DIRS 154523]). These recommendations concern the determination of critical and other hypothetical exposed groups for analyses of solid radioactive waste disposal. The report states that, as far as the consumption of specific dietary items is concerned, it is often assumed that, provided the sampled population is sufficiently large, the top 5 percent of a distribution may be taken as representative of a high consumer group (BIOMASS 1999 [DIRS 154523], Executive Summary).

The results of the food consumption survey conducted in the Yucca Mountain region indicated that the consumption rates of the local population were highly inhomogeneous. In other words, people who consumed high fractions of a specific food type from local sources usually did not consume much locally grown food of other types. To select a subset of the Amargosa Valley population that would potentially be exposed to the highest annual doses, individuals who received the top 5 percent of the annual dose at 25,000 years were selected (9 individuals). Because the annual doses are time-dependent, this group was combined with individuals whose potential annual doses at 100,000 years were the in the top 5 percent. This group also consisted of 9 different individuals, only one of whom also belonged to the first group; therefore, the final group consisted of 17 individuals. Consideration of the upper 5 percent of annual doses at 250,000 years did not produce any individuals other than those already included in the 25,000-and 100,000-year set. By composing an alternative group of the individuals whose exposures would be among the highest at different times, the group selection becomes independent of the time after repository closure. In other words, the average member of the group receives relatively high exposures regardless of the time after closure when the exposure took place. The consumption rates (consumption exposure levels) for the average member of this alternative farming group (Alternative Amargosa Valley Receptor 2) are listed in Table 13.3-2.

The Alternative Amargosa Valley Receptor 3 was based on the estimated average locally produced food consumption rates for the Amargosa Valley population and a daily water consumption of 2 L. Dietary attributes of this receptor meet the definition of the RMEI in the proposed 40 CFR 197.21(b) and (c) (64 FR 46976 [DIRS 105065]) in contrast with the definition of the RMEI, living style of this receptor does not represent the average lifestyle of people residing in Amargosa Valley, but rather is characteristic of a person who spends a large portion of the day outdoors. This difference is insignificant for the groundwater release exposure scenario because consumption of locally produced food and water is the key contributor to the potential annual dose (CRWMS M&O 2001 [DIRS 152539], Table 15). (For the volcanic eruption scenario, the Alternative Amargosa Valley Receptor 3 is more conservative than the RMEI because of the greater inhalation exposure that results from more time spent outdoors breathing air containing higher concentrations of resuspended contaminated ash particles.)

To test the sensitivity of the annual doses to the receptor's diet, the average annual doses were calculated for all receptors listed in Table 13.3-2 for 25,000 years and 100,000 years after closure (Wu 2001 [DIRS 154894], Section 3.7; Wu 2001 [DIRS 155203], Section 2). The results in terms of pathway and total annual doses are summarized in Tables 13.3-3 and 13.3-4 for 25,000 years and 100,000 years, respectively (Wu 2001 [DIRS 154894], Section 3.7; Wu 2001 [DIRS 155203], Section 2). It should be emphasized that these are estimated annual doses produced only for comparison and were not used in the TSPA-SR analyses (CRWMS M&O 2000 [DIRS 153246]).

At 25,000 years, annual doses calculated for the receptor based on the NUREG/CR-5512 (Kennedy and Strenge 1992 [DIRS 103776]) consumption rates are the highest annual doses for all receptors considered. However, aquatic food consumption rate is the dominant pathway for this receptor because of the extremely high consumption rate of fish assumed for the screening scenario, exceeding the 99th percentile of U.S. freshwater fish consumption. If the aquatic food ingestion annual dose is disregarded, then the ratio between the highest annual dose (U.S. Average Receptor) and the annual dose to the current receptor is 4. At 100,000 years, the ratio between the highest annual dose and the annual dose to the current receptor is less than 2. Annual doses are the lowest for the Alternative Amargosa Valley Receptor 3, whose dietary attributes are consistent with those of the RMEI (proposed 40 CFR 197.21(b) and (c) [64 FR 46976 [DIRS 105065]]).

13.3.1.4 Effect of Critical Group Size

The annual dose to the average member of the exposed group depends on the critical group size. This concept is demonstrated in Figure 13.3-2, which shows the relationship between the annual dose to the average member of the hypothetical group of 158 farmers at 25,000 years and the number of members in the group (Wu 2001 [DIRS 154894], Section 3.8).

The data presented in Figure 13.3-2 were obtained by arranging the 25,000-year annual doses to the hypothetical farming group based on the Amargosa Valley population in descending order, then calculating the average annual dose for the increasing number of individuals in the group. As the group count increases, the average annual dose decreases because of the inclusion of lower annual doses in the average. The curve decreases more steeply when the number of group members is less than 20, then flattens out as the most probable values for annual dose are included. For the exposed group considered in this sensitivity assessment, the average annual dose may vary by up to a factor of 5, depending on the size of the group.

13.3.1.5 Effect of Temporal Changes of Exposure Conditions

The annual doses to the receptor of interest, depend on the number of circumstances and parameters that may change with time. One of the changing conditions of human exposure includes varying radionuclide concentrations at the source of contamination, such as groundwater. This effect has been apparent in the process of selecting one of the alternative receptors, described in Section 13.3.1.3. Based on the dietary characteristics of the Amargosa Valley population, the group of the most exposed individuals at 25,000 years was different than the group of the most exposed individuals at 100,000 years because of the different composition of radionuclide contaminants in groundwater.

As shown in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Figures 4.1-6 and 4.1-19b), different radionuclides are dominant, from the perspective of their contribution to the total annual dose to the receptor, at different times. Therefore, the contribution of exposure pathways to annual dose also varies with time.

Radionuclide buildup in soil is another example of the temporal evolution of exposure conditions. Some pathways, such as consumption of contaminated groundwater, do not depend on the concentration of radionuclides in the soil. However, many exposure pathways, such as inhalation exposure, external exposure, and some processes considered for the ingestion pathway (e.g., root uptake of radionuclides from soil), depend on the concentration of radionuclides in the soil. Therefore, consideration of radionuclide buildup in the soil may influence the process of selecting the receptor of interest.

The effect of climate change on receptor selection is yet another aspect of extrapolating into the future. It is conceivable that, if climate conditions change and the weather becomes wetter and cooler, the receptor may adapt its behavior in response to these changing environmental conditions. The types of crops grown, agricultural practices and parameters (e.g., the amount of water used for irrigation), crop growing seasons, and crop yields may also change. This effect was partly evaluated by considering selected agricultural parameters typical of Spokane, Washington, which was selected as an analogue of the evolved climate for up to 10,000 years (CRWMS M&O 2001 [DIRS 152539], Section 6.4). These parameters were used to calculate the BDCFs for the evolved climate (see Section 13.4.2).

13.3.1.6 Effect of the Exposure Scenario

A TSPA was conducted for the nominal scenario and two disruptive scenarios. As noted in Section 13.3.1.3.2, the probability-weighted consequences for both these types of scenarios are added together to evaluate the performance of the potential repository. At early times (before about 40,000 years), igneous disruption doses dominate the scenario combination. However, during later times (after about 40,000 years), the combined dose is dominated by the nominal dose (CRWMS M&O 2000 [DIRS 153246], Section 4.3.2).

The biosphere model for the nominal scenario used the groundwater release exposure scenario (see Section 13.1). The same exposure scenario is also used for the human intrusion and igneous intrusion groundwater transport scenarios. In the disruptive scenarios, the assessment is focused on a volcanic eruption (extrusive igneous event). The corresponding biosphere model uses the exposure scenario associated with the deposition of contaminated volcanic ash on the ground. The pathway analyses for the BDCFs for the two respective exposure scenarios (CRWMS M&O 2001 [DIRS 152539], Section 6.7; CRWMS M&O 2001 [DIRS 152536], Section 6.6) showed substantial differences between pathway compositions. In the groundwater release exposure scenario, the majority of the annual dose was contributed by drinking water and leafy vegetable consumption. In contrast, the dominant pathway for the volcanic eruption exposure scenario was inhalation of airborne, contaminated ash and soil. Thus, a unique receptor representative of the population most at risk cannot be defined *a priori*. The actual receptor is time- and scenario-dependent and requires a knowledge of TSPA results.

The consequence of such pathway contributions to the BDCFs, and thus the annual dose, is such that for a population exposed to high concentrations of airborne contaminants, the receptor could be determined based primarily on the inhalation exposure. The selection criteria associated with dietary habits, which were used to identify the receptor for the groundwater release exposure scenario, are of limited importance for the postulated volcanic eruption scenario. However, the condition that the receptor spends a considerable amount of time working outdoors, although not critical for identification of the receptor in the groundwater release scenario, is sufficient to substantiate the selection of the same receptor for an assessment of the consequences of a volcanic eruption.

Other conceivable exposure scenarios include the exposure conditions of a subsistence farmer receptor. The consideration of the subsistence farmer receptor is based on the assumption that subsistence farmers make a (reasonable) maximum use of local environmental resources. For example, exclusive reliance on local water supplies for all uses—including agricultural purposes—will tend to enhance radiological exposures compared with situations where more diverse sources are exploited. The deliberate recycling of materials and nutrients would also be expected to enhance the accumulation of radionuclides in environmental media, maximizing radiation exposure. Thus, such farmers might be expected to have the highest exposure risk (BIOMASS 1999 [DIRS 154523], Section 3.2.1).

It is not immediately evident, however, that such a group necessarily provides a fully sufficient basis for ensuring consistency of protection with that afforded by today's radiation protection practices, or that it would always be associated with the highest potential risks. Furthermore, there is little information available concerning biosphere systems and human behavior relating to true subsistence farming methods, compared with typical practices presently adopted. In this document, "true subsistence farming" refers to farming in which only local resources are available to the farmer. This would preclude the use of modern farming practices that make use of many imported resources (e.g., factory-produced equipment, fuel, and fertilizers). True subsistence farming would involve, for example, the use of farm animals for plowing or composting as the sole source of fertilizer (BIOMASS 1999 [DIRS 154523], Section 3.2.1).

13.3.1.7 Effect of the Critical Group Composition

Consideration of the age composition of the critical group could also affect selection. Non-adults are not considered appropriate for the analysis of long-term repository performance (ICRP 2000 [DIRS 152447]), Section 4.2). Considering the time scale of the assessment, it could be assumed that radioactive contamination of the biosphere from repository releases is likely to remain constant over periods considerably longer than the human life span. It is then reasonable to calculate the annual dose averaged over the lifetime of individuals, which means that it is not necessary to calculate doses to different age groups. This average can be adequately represented by the annual dose to an adult (ICRP 2000 [DIRS 152447]).

13.3.1.8 Conclusions

The definition of the receptor is a source of uncertainty. The process was shown to be complex because the relative concentrations of radionuclides affect the receptor selection. Therefore, any attempt to define the receptor before the TSPA concentration results are known is uncertain.

Evaluation of the sensitivity of the biosphere modeling results to the definition of the receptor of interest involved calculations of estimated annual doses. This dose assessment was conducted for sensitivity studies only and the resulting dose estimates were not used in the performance assessment process. Also, the dose assessment method (see Sections 13.3.1.3.1 and 13.3.1.3.2) was different from the one used in the TSPA.

Among the receptors whose dietary characteristics were based on the Amargosa Valley population, the estimated annual doses at 25,000 years for Alternative Amargosa Valley Receptors 1 and 2 (3.0×10^{-5} rem, and 3.1×10^{-5} rem, respectively) are higher than those for the current receptor (1.5×10^{-5} rem) by a factor of about 2, while the annual dose to the Alternative Amargosa Valley Receptor 3 (1.1×10^{-5} rem) is lower than that for the current receptor by about 27 percent. This difference can be put into perspective by considering that the stochastic BDCFs, where some quantifiable uncertainties are considered, are distributed about their mean values by a factor of about three.

As noted in Section 13.3.1.3.3, the Alternative Amargosa Valley Receptor 3 was consistent with the definition of the RMEI in the proposed 40 CFR Part 197 (64 FR 46976 [DIRS 105065]) and the final rule (66 FR 32074 [DIRS 155216]) with regard to the dietary characteristics (it was based on the average consumption rates of locally produced food and water for the Amargosa Valley population). Because of the lifestyle characteristics, such as employment associated with greater than the average potential for exposure outdoors, this alternative receptor would be more at risk than the RMEI, which is characterized by the average lifestyle characteristics (proposed 40 CFR 197.21(b), 64 FR 46976 [DIRS 105065]; 40 CFR 197.21(b), 66 FR 32074 [DIRS 155216]). The exposure to the Alternative Amargosa Valley Receptor 3 is therefore a conservative estimate of the exposure to the RMEI, as defined by the EPA. Based on the analysis for the Alternative Amargosa Valley Receptor 3, the estimated annual dose to the RMEI for the groundwater contamination exposure scenario at 25,000 years, would be lower than that for the current receptor (the average member of the critical group) by less than about 30 percent.

Given sensitivity and uncertainty consideration for the receptors based on the Amargosa Valley population, the exposures to average member of the critical group and the RMEI are consistent. Both of these receptors are considered to be composite individuals representing a group located in small area above the contaminated plume, and have comparable dietary characteristics, both with respect to the drinking water as well as the locally produced food. These similarities result in the expected exposures from the potential repository being comparable for these two receptors.

For a receptor approximating a subsistence farmer, where all food consumed is locally grown, the highest predicted annual dose at 25,000 years is 8.7×10^{-5} rem. However, even for this extreme receptor, the predicted annual dose is less than six times that predicted for the current receptor at 25,000 years and less than two times that predicted for the current receptor at 100,000 years. This factor should provide an upper limit on the uncertainty associated with using the current receptor of interest. However, for this value to be approached, several inhabitants would have to be identified whose entire food intake was all locally grown. While this has a probability of occurring, the survey data was not able to identify a single individual who approached such extreme eating habits. The likelihood of several such individuals being present in Amargosa Valley without a single example being observed is low.

By considering the individual annual doses for the people most at risk in the survey and forming the average of the highest individual annual doses, the variation of average annual dose with population size can be observed. As Figure 13.3-2 shows, the average annual dose is predicted to change by about a factor of two as the number of critical group members goes from one to about twenty. This approach to generating the critical group increases the mean annual dose by a factor of about three for a group consisting of about ten people.

By evaluating several alternative methods of defining the receptor, it appears likely that the annual dose uncertainty from the definition of the current receptor is approximately bounded by a factor of three to that used in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) and in the analysis presented in Volume 2 (McNeish 2001 [DIRS 155023]).

13.3.2 Comparison of Dose Assessment Methods

13.3.2.1 Introduction

Under 10 CFR Part 20 [DIRS 104787] and proposed 10 CFR Part 63 (64 FR 8640 [DIRS 101680]), the annual dose received by an individual as a result of radionuclide intake (ingestion and inhalation) and the external exposure to radioactive materials in a given year is referred to as the TEDE.

As defined by the NRC in 10 CFR 20.1003 [DIRS 104787], the TEDE is "the sum of the deep-dose equivalent (for external exposure) and the committed effective dose equivalent (for internal exposure)." The committed effective dose equivalent (CEDE) is defined by the NRC in 10 CFR 20.1003 [DIRS 104787] as the "sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to those organs or tissues."

The EPA rule (40 CFR 197.2 [DIRS 155216]) introduced the following definitions: "*Annual committed effective dose equivalent* means the effective dose equivalent received by an individual in one year from radiation sources external to the individual plus the committed effective dose equivalent," and the "*Committed effective dose equivalent* means the effective dose equivalent received over a period of time (e.g., 30 years), as determined by NRC, by an individual from radionuclides internal to the individual following a one-year intake of those radionuclides." Annual CEDE, as defined by the EPA, is equivalent to the TEDE resulting from one-year exposure.

The organ/tissue weighting factors used in the definition of CEDE were recommended by ICRP 30 (ICRP 1979 [DIRS 110386]; ICRP 1980 [DIRS 110351]; ICRP 1981 [DIRS 110352]). These weighting factors are used by the EPA to calculate the exposure-to-dose conversion factors for inhalation and ingestion presented in Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]). The exposure-to-dose conversion factor, more commonly referred to as a dose conversion factor (DCF), is one of the fundamental representations of a dosimetric model used in assessing potential radiation dose. Specifically, the DCF allows an exposure to a radionuclide to be converted to a dose.

After the incorporation of ICRP 30 methodology and associated weighting factors into various U.S. regulations, the ICRP introduced a new set of dose conversion factors in ICRP 72

(ICRP 1996 [DIRS 152446]). This set was based on updated biokinetic data and models and the revised method for computing radiation doses presented in ICRP 60 (ICRP 1991 [DIRS 101836]). In ICRP 60, a new dosimetric quantity—the effective dose—was introduced. To date, the revised ICRP dosimetric method and the new DCFs have not been incorporated into U.S. regulations.

13.3.2.2 Purpose of the Comparison

Because of the difference between the two dosimetric methods, a comparison was conducted to evaluate the impact of the revised methodology on previously calculated BDCFs (Tappen 2001 [DIRS 154890]). The analysis was also meant to determine the magnitude of changes the new dosimetry might have on calculations of annual dose, as well as improve confidence in the analysis results. The comparison estimates the potential impact on BDCFs if the revised ICRP method were incorporated into U.S. regulations.

The previously developed BDCFs were calculated using dosimetric models based on the conceptual approach recommended in ICRP 26 (ICRP 1977 [DIRS 101075]) and the dosimetric methods outlined in ICRP 30 (ICRP 1979 [DIRS 110386]; ICRP 1980 [DIRS 110351]; ICRP 1981 [DIRS 110352]). This method uses a set of tissue/organ weighting factors that reflect the organs' relative contribution to the total health detriment (risk) when the entire body is uniformly irradiated. These factors are based on the data and biokinetic models available at the time ICRP 30 was issued.

13.3.2.3 Development of Assessment

ICRP 72 (ICRP 1996 [DIRS 152446]) introduced a new set of dose conversion factors based on a revised method for computing radiation dose presented in ICRP 60 (ICRP 1991 [DIRS 101836]). The method introduced a new dosimetric quantity, the effective dose.

The effective dose considers an expanded list of tissues/organs, updated biokinetic data and models, and revised tissue/organ weighting factors. In computing the revised weighting factors, the ICRP made two fundamental changes. First, the application of the weighting factor was changed from consideration of absorbed dose at a point in the organ to consideration of absorbed dose averaged over the total organ (ICRP 1991 [DIRS 101836], p. 5). Second, the concept of detriment (risk) was expanded (ICRP 1991 [DIRS 101836], p. 13). Under this concept, detriment considers the risk of both fatal and nonfatal cancers, hereditary defects over all future generations, and the relative loss of life expectancy given the occurrence of a fatal cancer or severe genetic disorder (ICRP 1991 [DIRS 101836], p. 23). A comparison of the tissue/organ weighting factors used in the two dosimetric methods is presented in Table 13.3-5.

For the purpose of quantifying the magnitude of the potential impact of the revised ICRP dosimetric method (ICRP 1996 [DIRS 152446]) on previously calculated BDCFs, the BDCFs for two exposure scenarios were evaluated. These were (1) the mean BDCFs for the first irrigation period of the groundwater release scenario for the current climate (CRWMS M&O 2001 [DIRS 152539], Table 9), and (2) the mean BDCF for the volcanic eruption, transition phase, assuming a 1-cm ash layer and annual average mass loading (CRWMS M&O 2001 [DIRS 152536], Table 11).

In order to accomplish this, it was necessary to first calculate pathway-specific BDCFs for each radionuclide of interest. This was done by multiplying the previously calculated radionuclide-specific mean BDCF by the percent pathway contribution for each of the three primary pathways (CRWMS M&O 2001 [DIRS 152539], Table 15; CRWMS M&O 2001 [DIRS 152536], Table 16). Pathway-specific BDCFs were calculated for each pathway that contributed 1 percent or more to the total radionuclide-specific BDCF. Each of the pathway-specific BDCFs was then multiplied by the ratio of the ICRP 72 DCF (ICRP 1996 [DIRS 152446]) to the GENII-S V.1.4.8.5 DCF for that pathway. For each radionuclide, these pathway BDCFs were then added to obtain the BDCF for all pathways. This is what the modified BDCF would be for each radionuclide if the ICRP 72 DCFs were used.

13.3.2.4 Results of the Assessment

The results of this assessment are presented in Tables 13.3-6 and 13.3-7. It is important to note that the modified BDCFs were developed to quantify the impact of an alternative ICRP methodology and provide confidence to stakeholders, not to support any evaluation of regulatory compliance. The measure of the impact of the revised methodology is the BDCF ratio, which is the ratio of the modified BDCF for a radionuclide divided by the original mean BDCF for that radionuclide.

To assess the potential impact of the alternative dosimetric method, the effect of the method on each BDCF for the principal dose-contributing radionuclides in the nominal and disruptive scenarios was examined. In the nominal scenario out to 100,000 years, the TSPA-SR analysis identified four radionuclides—technetium-99, iodine-129, neptunium-237, and plutonium-239—as the primary contributors to annual dose (CRWMS M&O 2000 [DIRS 153246], Section 4.1). As shown in Table 13.3-6, the application of the alternative method increases the BDCF for iodine-129 by a factor of approximately 1.6 and the BDCF for technetium-99 by about 10 percent, while the BDCFs for neptunium-237 and plutonium-239 show decreases by factors of approximately 13 and 4, respectively. The annual dose associated with each of these radionuclides would show a similar change.

In the disruptive scenario, americium-241, plutonium-240, plutonium-239, and plutonium-239 are identified as the major contributors to annual dose during the first 2,000 years (CRWMS M&O 2000 [DIRS 153246]). Strontium-90 is identified as a significant contributor during the extremely early stage of the scenario, but rapidly decreases due to radioactive decay. Comparison of the modified BDCFs for these radionuclides with the BDCFs previously calculated for the volcanic eruption indicates that the annual dose associated with these radionuclides would decrease. The annual dose attributable to americium-241 would decrease by approximately 22 percent, while the annual dose associated with each of the plutonium isotopes would remain essentially unchanged (a decrease of only 3 percent). The BDCF for strontium-90 shows a decrease of approximately 12 percent.

After approximately 2,000 years, the annual dose from igneous activity would be dominated by radionuclides associated with groundwater releases from waste packages damaged by igneous intrusion (CRWMS M&O 2000 [DIRS 153246], Section 4.2.2). The impact of the revised ICRP methodology on the BDCF developed for this time period would be consistent with that described for the nominal scenario.

If the ICRP 72 DCF were used instead of the ICRP 30 DCFs, the nominal scenario doses would be slightly higher at the time when iodine-129 and technetium-99 are the dominant radionuclides (by less than a factor of 1.6). However, when neptunium-237 and plutonium-239 become dominant at the later time, the total annual dose would be several times lower if the ICRP 72 DCFs were used.

13.3.3 Uncertainties Associated with Radionuclide Removal from Soil by Leaching

13.3.3.1 Introduction

The GENII-S V.1.4.8.5 code considers radionuclide accumulation in and depletion from the surface soil in which crops are rooted. In the case of the groundwater release scenario, irrigation provides the source for accumulation. The removal mechanisms (Napier et al. 1988 [DIRS 100953], Section 4.6.2) are radioactive decay (the code contains half-life data that are used to derive the loss rate), crop uptake (the code calculates the rate of removal from the user-specified crops), and leaching. In the case of leaching, the user can specify fixed leaching coefficients for those elements under consideration. As discussed below, the leaching coefficient is derived from the partition coefficient of the element. The partition coefficient is subject to a degree of uncertainty, thereby implying that the leaching coefficient should be modeled as a range of values rather than a fixed value. This analysis assesses the effect of this uncertainty in partition coefficients on BDCF values. This section briefly reviews the leaching submodel and the data developed to support the calculation of BDCFs as a function of irrigation period. These data were discussed, developed, and reported in *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [DIRS 152517]).

13.3.3.2 Soil Leaching Model and Data

The leaching coefficient used by the GENII-S V.1.4.8.5 code is derived from the leaching model developed by Baes and Sharp (1983 [DIRS 109606]). This model was used to calculate leaching coefficients for radionuclide elements introduced to the soil through surface irrigation with contaminated groundwater. The Baes and Sharp (1983 [DIRS 109606], Equation 13-2) relationship is considered to be an appropriate and defensible model to calculate soil leaching coefficients for the TSPA-SR (CRWMS M&O 2001 [DIRS 152517], Section 6.2):

$$\lambda = \frac{P + I - E}{D \times \theta \times (1.0 + \rho / \theta \times K_d)} \qquad \text{(Eq. 13-2)}$$

where:

λ = the leaching coefficient (1/yr)

P, I, and E = the annual precipitation, irrigation, and evapotranspiration rates, respectively ($P + I - E$ = 15 cm/yr) (CRWMS M&O 2001 [DIRS 152517], Section 6.2)

D = depth of surface soil (the default value is 15 cm) (CRWMS M&O 2001 [DIRS 152434], Table 14)

θ = the volumetric water content of soil (the assumed value is 0.217 ml/cm^3 or cm^3/cm^3)

ρ = surface soil bulk density (225 kg/m^3) (CRWMS M&O 2001 [DIRS 152434], Table 14)

K_d = the surface soil solid/liquid partition coefficient for a specific radionuclide (isotope-independent) and soil type (L/kg or cm^3/g).

The only parameter that depends on the contamination species is the partition coefficient; the others are soil and irrigation parameters. *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [DIRS 152517]), from which the leaching coefficients were derived, uses the same values for $(P + I - E)$, D, and Δ that were used as inputs to the GENII-S V.1.4.8.5 code. Each of these values is subject to uncertainty. However, as these inputs are also used in GENII-S V.1.4.8.5, this stand-alone uncertainty assessment cannot evaluate the total effect on BDCF uncertainty. As discussed below, the uncertainty in the K_d values can be an order of magnitude or more. The values for K_d and *2* were obtained from scientific publications. Although both values are subject to some degree of uncertainty, they were both used as single-valued deterministic inputs to the GENII-S V.1.4.8.5 code. This was not done by choice, but because the GENII-S V.1.4.8.5 code cannot accept the leaching factor parameter (*8*) as a distribution that reflects its inherent uncertainty.

It should be apparent that the leaching process, which is driven by irrigation, is not a continuous process, but only occurs during and immediately after irrigation. At times of overwatering, performed to flush out any accumulated salts in the soil from previous irrigation, the upper layer of soil requires a high water content to allow downward transport to occur. Thus, at times when leaching is occurring, the moisture content of the soil has to be high and the value used for volumetric water content, *2*, is likely to be subject to a relatively small uncertainty. However, the values of K_d are subject to large potential uncertainty (International Atomic Energy Agency 1994 [DIRS 100458], pp. 30 to 31). Because of the inability of GENII-S V.1.4.8.5 to accept a distribution for leaching, this source of uncertainty has not been previously addressed.

Uncertainty in Current Model—As reported in *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [DIRS 152517], Section 6.2), published information on radionuclide-specific K_d measurements for soils in the Amargosa Valley does not exist. Therefore, there is a degree of uncertainty in how the K_d values used in the analysis (CRWMS M&O 2001 [DIRS 152517], Table 4) would differ from the values that would be obtained from actual experimental analysis on the Amargosa Valley soils considered. The data source used for the K_d values also provides an estimate of the range of values for each element. Using the values given in Table 13.3-8 as values used, lower limit and upper limit, in Equation 13-2, the respective leaching coefficient can be determined. Taking the inverse of the leaching coefficient provides an estimate of the characteristic time for the buildup of radionuclides in soil if only leaching is considered. The actual buildup time can be calculated by formulating a total removal rate that is the sum of the removal rates from all processes. In GENII-S V.1.4.8.5, the individual removal processes are leaching, radioactive decay, and harvest removal. The values for each of these parameters appropriate for Amargosa Valley soils, along with the radionuclides identified as the major total annual dose contributors (CRWMS M&O 2000 [DIRS 153246], Figure 4.1-6), are shown in Table 13.3-8. The K_d values were obtained from *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [DIRS 152517], Table 4), and the limiting K_d values were obtained from *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments* (International Atomic Energy Agency 1994 [DIRS 100458], pp. 30 to 31).

In assessing the impact on BDCFs of values of K_d sampled from over the suggested range, two cases have to be considered. The first arises when the value of K_d is below the value used in the calculations for existing BDCFs; the second occurs when the sampled value is above the value used.

If the correct K_d is lower than the value used, the leaching coefficient is increased and results in less radionuclide buildup in soil. Thus, BDCFs can only be decreased. However, for the BDCFs for the groundwater release scenario (CRWMS M&O 2001 [DIRS 153207], Table 3), a significant effect was only seen in the case of plutonium-239. Even in this case, the buildup only amounted to 50 percent. If the actual K_d values are lower than the K_d values used and shown in Table 13.3-8, the result is a small reduction in BDCFs and predicted annual doses.

The effect on BDCFs when the correct K_d is higher than the value used in calculations is more complex. In the case of plutonium, where the buildup is predicted to take many thousands of years (comparable to the values for characteristic removal time for leaching shown in Table 13.3-8), it can be shown (CRWMS M&O 2001 [DIRS 153206], Section 6.2.3) that contamination removal by other processes, such as soil removal by erosion, with its characteristic removal time of 250 years (CRWMS M&O 2001 [DIRS 153206], Section 6.2.2), will dominate the loss process. As the loss process is dominated by soil erosion, there will be no significant change in the BDCF values already used in TSPA calculations for which erosion was considered (CRWMS M&O 2001 [DIRS 153206]). However, for the other dominant radionuclides in the TSPA, further calculations had to be conducted. The results of these calculations for the 6th irrigation period are given in Table 13.3-9. This is the most conservative irrigation period of those calculated, where five-sixths of the buildup has been completed when considering leaching and radioactive decay.

13.3.3.3 Conclusions on the Effect of Partition Coefficient Uncertainty on Biosphere Dose Conversion Factors

For iodine-129 and neptunium-237, a large change in the assumed leaching coefficient (which is more than two orders of magnitude; see Table 13.3-8) results in a BDCF change of a few tens of percent even after long periods of continual irrigation. The underlying reason for this effect is that the transfer coefficient from soil to plant, in which the soil reservoir would play a part, is not a significant pathway for these elements. The dominant mechanism for these radionuclides to contaminate crops is through leaf absorption from contact with irrigation water.

In the case of technetium-99, the soil reservoir plays a more important role because the root uptake by vegetables is significant. Thus, in this case the net result is an increase of about a factor of five in the mean BDCF value. If the actual site-specific K_d for technetium-99 is higher than the value used to generate the revised BDCFs, there could be some underestimation of annual dose. To obtain an estimate for the net effect of the uncertainty in partition coefficients, a simple average can be generated by assuming equal probabilities of K_d being (1) around the present value used, (2) significantly below the value used, or (3) significantly above the value used (i.e., about the values used to generate the data in Table 13.3-9). If this sampling were done for the TSPA, the impact would be to increase the estimated average annual dose from technetium-99 by about a factor of 2.3 over the annual dose estimated from the BDCFs discussed in Section 13.2. The distribution width (i.e., the standard deviation) of the BDCFs would be increased once the uncertainty in K_d had been taken into account, thereby reflecting the increased total uncertainty. A similar weighting approach to the BDCFs for iodine-129, neptunium-237, and plutonium-239 estimates changes in the mean BDCF values of about 10 percent.

13.3.4 Uncertainties from Fixed Parameter Values

GENII-S V.1.4.8.5 has the capability to represent many input parameters as distributions and thereby incorporate uncertainty into the calculation of BDCF distributions. However, some parameters can only be represented by single values (Leigh et al. 1993 [DIRS 100464], Section 5.8). These fixed value parameters are known to be subject to potential uncertainty, but the construction of the code does not allow this uncertainty to be incorporated and propagated through to the distribution of BDCFs. This section evaluates the magnitude of one group of parameters and their uncertainties in the second most important ingestion pathway, leafy vegetables. For this assessment, attention was focused on the four radionuclides shown in the TSPA (CRWMS M&O 2000 [DIRS 153246], Table 4.1-6) to be the most significant contributors to annual dose: technetium-99, iodine-129, neptunium-237, and plutonium-239.

To identify the pathways of importance, a deterministic GENII-S V.1.4.8.5 run was conducted for each of the four important radionuclides in the groundwater release scenario. These calculations, reported in Wu (2001 [DIRS 154892]), were conducted using best estimate parameter values, with leaching and soil erosion included, and a sufficiently long period of previous irrigation such that BDCF equilibrium had been achieved. For each of the four radionuclides, the contribution of the significant pathways to BDCF values was determined (Table 13.3-10).

The drinking water pathway is dominant, but the leafy vegetable pathway is the second most important contributor to BDCFs for the groundwater release scenario. These two pathways together contribute more than 80 percent of the BDCF for all four radionuclides (Table 13.3-10). The only input parameter required to calculate the dose from drinking water is the quantity of water ingested. For leafy vegetables, several parameters must be defined. Any unquantified uncertainties in those parameters could propagate through the calculation and impact the BDCF values. To demonstrate the impact of these uncertainties, consider the case where the drinking water dose is known and the leafy vegetable contribution is allowed to vary. If the parameters used in the calculation of the leafy vegetable contribution were changed such that they caused this pathway to give a zero contribution to the BDCF value, there would be about a 25 percent change in the BDCFs. If the leafy vegetable input parameters were changed such that this pathway contribution were doubled, there would only be about a 25 percent increase in BDCFs. A similar elementary assessment can show that the uncertainties in other, smaller contribution pathways will have less impact on BDCF uncertainty for the same magnitude of pathway uncertainty. Because the vegetable (leafy and other) pathway was the second most significant contributor to the BDCF value for each of the four radionuclides, attention was directed to the uncertainties associated with this pathway.

Three of the GENII-S V.1.4.8.5 input parameters in the vegetable pathway are subject to large uncertainty, but these parameters can only be represented in GENII-S V.1.4.8.5 by fixed values. These parameters are:

A. The weathering half-life (removal of radionuclides from plant foliage by weathering)

B. The translocation factor (the fraction of contamination that is incorporated in the edible portion of the plant from its surfaces) for leafy vegetables

C. The leaching coefficient of radionuclides from soils by irrigation.

From literature surveys, the estimate for the weathering half-life value was justified to be 14 days (CRWMS M&O 2001 [DIRS 152434], Section 6.6). For this study, the values that were considered as lower and upper limits were 5 days and 56 days (CRWMS M&O 2001 [DIRS 152434], Table 10). The translocation factor, which was assigned a value of unity to generate the BDCFs for the *Yucca Mountain Science and Engineering Report* (DOE 2001 [DIRS 153849]), was estimated to have a range of variability between 0.1 and 1.0 (CRWMS M&O 2001 [DIRS 152434], Table 11). It should be noted that both parameters have a range of uncertainty that spans an order of magnitude.

The leaching coefficient, a function of the partition coefficient (K_d) (Equation 13-2), was determined from the expected variability of the K_d values (the values used in this evaluation are those presented in Table 13.3-8). These values depended on the element considered. For technetium-99, the range of leaching coefficients (from low to high) was a factor of 35; for plutonium-239, the range was a factor of almost 900. The range for the other two elements fell in between: iodine-129 had a range factor of 540, and neptunium-237 had a range factor of 420. For plutonium-239, using the lower limit of the leaching coefficient, the time required for continuous irrigation (in the absence of soil loss) to approach equilibrium is approximately 25,000 years. The approach used to calculate the period of radionuclide buildup in soils from a knowledge of the leaching coefficient and other rates of removal of radionuclides is discussed in *Abstraction of BDCF Distributions for Irrigation Periods* (CRWMS M&O 2001 [DIRS 153206], Sections 6.1 and 6.2). The other radionuclides require only a few hundred years of irrigation to reach the same degree of buildup in soil. Because of the long time needed for the plutonium buildup, the data for 25,000 years was disregarded because soil loss would dominate the process, causing much less radionuclide buildup (CRWMS M&O 2001 [DIRS 153206], Sections 6.2.2 and 6.5).

GENII-S V.1.4.8.5 was run using various combinations of the three parametric values discussed above. All other parameter values and distributions were the same as those used to generate the data for the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), as noted in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539], Section 6). Table 13.3-11 shows the mean BDCF value used in the *Yucca Mountain Science and Engineering Report* (DOE 2001 [DIRS 153849]) and the minimum and maximum mean BDCF values for the input parameter combinations taken from the extremes of the ranges.

The BDCF values provided to the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) correspond to the data shown in the row labeled "Long Irrigation" "Nominal" in Table 13.3-11 (CRWMS M&O 2001 [DIRS 153206], Section 7; CRWMS M&O 2001 [DIRS 153207], Section 7). The variations in the parameter values discussed above could increase the BDCF values to those shown in the row labeled "Long Irrigation" "Maximum." The parameter variations could also cause the BDCFs to be as low as the values shown in the row labeled "Zero Irrigation" "Minimum." These extreme values can be used with data in the row labeled "Long Irrigation" "Nominal" to derive multiplying factors for converting a groundwater release BDCF to an extreme value due to uncertainties (Table 13.3-12).

In conclusion, the large estimated uncertainty in each of three parameters that cannot be represented in GENII-S V.1.4.8.5 as distributions are estimated to impact BDCFs by approximately ±50 percent for iodine-129, neptunium-237, and plutonium-239. In the case of technetium-99, the BDCF uncertainty is larger and varies over the range of -20 percent to +400 percent. The large BDCF increase for technetium-99 is attributed to the more significant root uptake by vegetables after the radionuclide has accumulated in soil (see Section 13.3.3.3). It should be noted that the change in mean BDCF values is a result of the uncertainties in three input parameters, two with a range of a factor of 10 and one with a range greater than 30.

If these additional uncertainties have to be incorporated into an annual dose calculation, a simple algorithm can be used. The approach is based on the BDCF abstractions (CRWMS M&O 2001 [DIRS 153206], Section 7; CRWMS M&O 2001 [DIRS 153207], Section 7) and the uncertainty range defined in Table 13.3-12. Sample the most recent BDCF values (CRWMS M&O 2001 [DIRS 153206], Section 7; CRWMS M&O 2001 [DIRS 153207], Section 7) from the distribution (x). Then sample a random number triangularly distributed with the mode at unity and the lower and upper limits in Table 13.3-12 (z). For the modified BDCF in which the additional uncertainty is to be approximately incorporated, use the product ($x \times z$) to generate the BDCF value to use in calculating the annual dose for that radionuclide.

In this approach, the true but unknown distribution of the multiplying factor is assumed to be approximated by a triangular distribution, since this distribution provides some of the statistical requisites. The distribution mode is at unity (i.e., the most likely value corresponds to the value generated by using the expected values of each parameter). The distribution density function monotonically decreases as a sample is further from the mode, and the distribution is limited to the range defined by the lower and upper limits.

13.3.5 Uncertainty in Annual Groundwater Usage

13.3.5.1 Introduction

The annual water used for dose calculations is based on annual well withdrawal (CRWMS M&O 2000 [DIRS 144056]). For a sustainable year-round alfalfa yield, the state assumed water usage is below that estimated from the evapotranspiration requirements of alfalfa. One goal of this new analysis is to assess the impact of actual (and increased) alfalfa irrigation requirements on annual groundwater usage and the attendant decrease in radionuclide concentration and annual dose. A second goal is to estimate the possible impact of a reduced watering rate for a future cooler and wetter climate on anticipated annual groundwater usage. In this evolved climate, the radionuclide concentrations will increase and so will the predicted annual dose.

To avoid speculation regarding the relative locations of the wells used by the hypothetical farming community and the groundwater radionuclide contamination plume, the NRC allowed a bounding approach be taken. This approach says:

> "The concentration of radionuclides in the water, ... can be determined by dividing the annual release of radionuclides to the location of the farming community by the annual water demands of the farming community" (preamble to proposed 10 CFR Part 63 [64 FR 8640 (DIRS 101680), p. 8646]).

The annual water demands of the community (between 15 and 25 farms) were determined by using data published by the state of Nevada on water usage in Amargosa Valley (CRWMS M&O 2000 [DIRS 144056]). Analyzing data for agricultural usage (i.e., disregarding commercial, municipal, and mining usage) allows a statistical distribution of annual water usage per farm to be derived for the present assembly of farms. These data are then used to derive the anticipated distribution of water usage for the required community, documented in *Groundwater Usage by the Proposed Farming Community* (CRWMS M&O 2000 [DIRS 144056]). Domestic water usage is only a small perturbation on total agricultural usage and can be conservatively ignored.

In this approach, the most probable annual water usage (mode) by the community is 1,938 acre-feet per year. The lower and upper bounds on the usage distribution are 887 acre-feet per year and 3,367 acre-feet per year, respectively. The 1997 annual withdrawal for Amargosa Valley was 13,900 acre-feet. Thus, the predicted rate of water use by the proposed community is significantly below 1997 usage (CRWMS M&O 2000 [DIRS 144056], Table 12).

The values for groundwater usage are based on an irrigation rate for alfalfa of 5 acre-feet per year per acre. This crop-specific irrigation rate can be determined by referring to *Groundwater Usage by the Proposed Farming Community* (CRWMS M&O 2000 [DIRS 144056], Attachment II) and identifying in the "remarks" column those rows for which alfalfa is identified as the crop (i.e., 32, 38, 42, and 60). For each of these alfalfa entries, the annual groundwater usage can be determined by the entry in the column labeled "used." The column labeled "acres irr or use" provides the area in acres that receives the irrigation. For example, in row 32, H. Watson (column "owner of record") is identified as growing alfalfa on a land area of 172.90 acres (column "acres irr") and using an annual groundwater consumption of 864.50 acre-feet (column "used"). From these values, the annual irrigation rate per acre used by the owner of record can be determined by dividing the total volume of water used (864.50 acre-feet) by the crop area (172.9 acres). This gives an annual groundwater usage of 5 acre-feet per year. Similar calculations on other rows where the remarks column shows alfalfa to be the crop result in the same annual irrigation rate per acre of alfalfa.

13.3.5.2 Discussion of Groundwater Usage Findings

The water usage for the proposed farming community used in the TSPA calculations (CRWMS M&O 2000 [DIRS 153246]) from which radionuclide concentration in groundwater is derived is described by the following sampling algorithm (CRWMS M&O 2000 [DIRS 144056]):

1. Select a random number, R, distributed uniformly over the interval -1 to 1.

2. Determine the stochastic sample of the annual water usage, A, by forming A = mean + R □ uncertainty, where mean = 96.92 acre-ft/yr and uncertainty = 37.77 acre-ft/yr.

3. Select a random number, S, distributed uniformly over the interval 15 to 25 (the number of farms specified).

4. Determine the annual water usage by multiplying A and S.

The values used in this algorithm are based on alfalfa growers using 5 acre-feet per year per acre. If the actual irrigation usage were to change to a new value, then the result from the algorithm would change by the ratio of the new value to the old value. The approach given here assesses the validity of the estimated annual alfalfa irrigation rate of 5 acre-feet per year per acre (as explained in Section 13.3.5.1) to determine agricultural water usage in the Amargosa Valley for the present and future climate. These data are then used to derive scale factors to permit reasonable estimates of annual water for use in dilution calculations for both extreme climate conditions.

The *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539], Attachment 3) provides a relationship to derive irrigation requirements. The irrigation rate necessary for a crop is the sum of the crop's annual evapotranspiration and the deep percolation requirement (to prevent yield loss from salts building up in the soil) minus the annual precipitation rate. Table 13.3-13 gives estimates of these parameters for alfalfa for the present and future climate, as calculated in the *Nominal Performance Biosphere Dose Conversion Factor Analysis*.

The value of 60 inches per year estimated in Section 13.3.5.1 appears to be a low estimate to sustain a commercial alfalfa operation under present climatic conditions. In the projected cooler and wetter climate (Spokane was taken to be a present-day surrogate for the future clime), the alfalfa irrigation requirement is biased in the opposite direction. In this case, the estimated value for today's irrigation rate would overestimate future irrigation requirements. These differences in irrigation values will, for the present climate, increase dilution and decrease annual dose, but they will lead to decreased dilution with increased annual dose estimates in cooler and wetter times.

In conclusion, there is a systematic bias between the irrigation requirements of alfalfa and the pumping rate used to estimate the annual water usage of the proposed farming community. The implication of this bias for the present and future climates has been quantified. Specifically, for the present climatic conditions in the Amargosa Valley, the algorithm presented above underestimates water usage by a factor of 1.58. In the future, at times when the climate is wetter and cooler, the same algorithm provides an estimate of water usage that has to be reduced by multiplying by a factor of 0.70. For a given annual dose calculation based on the water usage sampled by using the algorithm, this uncertainty leads to an annual dose reduction for the present climate by a factor of 0.63. For the projected wetter and cooler future climatic conditions, the annual dose would be increased by a factor of 1.44.

13.3.6 Inhalation Exposure Pathway

Inhalation of resuspended particulate matter is one of the exposure pathways considered for both the groundwater release exposure scenario and the exposure scenario associated with volcanic eruption. In the groundwater release scenario, inhalation is a minor contributor to BDCFs for the case of no prior irrigation (CRWMS M&O 2001 [DIRS 152539], Table 15). However, inhalation may become an important contributor for some radionuclides (e.g., isotopes of thorium) after prolonged prior irrigation with contaminated water, which results in radionuclide buildup in soil (CRWMS M&O 2001 [DIRS 152539], Section 6.5.4.2).

Inhalation of resuspended particles is the dominant contributor to BDCFs in the exposure scenarios used to evaluate the consequences of a volcanic eruption. For most of the radionuclides and volcanic eruption scenarios evaluated, this pathway accounts for more than 90 percent of the BDCFs during, immediately following, and for several years after the event (CRWMS M&O 2001 [DIRS 152536], Section 6.6). Therefore, understanding and reducing uncertainty in the parameter values used to model this pathway is important for reducing uncertainty in the biosphere model used for the volcanic eruption exposure scenario (CRWMS M&O 2000 [DIRS 149736], Section 6.3.2). This section describes the analyses conducted to revise the parameter values for inhalation exposure and reduce their uncertainty. All assumptions and inputs for this analysis are identified in *Input Parameter Values for External and Inhalation Radiation Exposure Analysis* (CRWMS M&O 2000 [DIRS 152438]).

The atmospheric mass loading of contaminated ash particles is a result of resuspension and transport of the particles from the extended ash-fall region. The predicted mass loading was used to develop inhalation exposure. However, in developing the BDCFs the biosphere model did not consider the long-term effects of accumulation (from weathering processes) of contaminated ash in the vicinity of the proposed farming community. The removal and accumulation of contamination from the extrusive volcanic event is discussed in Section 14.3.6.7.

The inhalation pathway component of the biosphere model determines the contribution to BDCFs of inhaling contaminated ash during the ash fall or resuspended, contaminated dust or ash after the event. The GENII-S V.1.4.8.5 code requires three parameter values for that calculation:

1. Mass loading: mass of suspended particles per volume of air. This parameter is used to calculate the concentration of radionuclides in the air resulting from suspended contaminated ash or soil particles.

2. Inhalation exposure time: the amount of time a person inhales contaminated, suspended dust or ash.

3. Chronic breathing rate: the volume of air inhaled by a person per unit of time. This parameter is used to calculate the activity of suspended particles that are inhaled.

13.3.6.1 Inhalation Exposure Model Updates

The revision of inhalation exposure parameters was conducted because the mass loading values for the volcanic eruption scenario needed to account for much higher ash depths predicted by the modified model for an extrusive volcanic event. In addition, the revision had to consider mass loading conditions and associated uncertainties for farming communities and better reflect the annual dose resulting from inhalation of various-size particles (CRWMS M&O 2000 [DIRS 152438], Section 6.1; CRWMS M&O 2001 [DIRS 152536], Section 5.2). Also, refinement of the characteristics of the receptor resulted in a reevaluation of inhalation exposure time to consider behaviors and associated uncertainties of a group of farmers (CRWMS M&O 2000 [DIRS 152438], Section 6). The value for chronic breathing rate was not modified because it adequately addressed the proposed NRC requirements and would not be influenced by a volcanic event (CRWMS M&O 2000 [DIRS 152438], Section 6.3).

Mass Loading–To account for conditions specific to the groundwater release and volcanic eruption scenarios, separate distributions of mass loading were developed for each scenario. In addition, these distributions of mass loading were based on concentrations of total suspended particles (TSP) rather than small particles (i.e., PM_{10}), which is a more conservative approach.

Concentrations of TSP were used in developing revised mass loading distributions to account for inhalation of particles larger than 10 μm. This approach was considered conservative. The predicted distribution of the average size of ash particles resulting from a volcanic eruption at Yucca Mountain is log-triangular with a minimum of 10 μm, a mode of 100 μm, and a maximum of 1,000 μm (CRWMS M&O 2000 [DIRS 142657], Section 6.5.1). Thus, only a small fraction of particles (the smallest predicted average ash sizes have a very low probability of occurrence) would be available for resuspension. This distribution was based in part on measurements of particle size distributions from the Cerro Negro eruption, which was a violent Strombolian eruption. This is the type anticipated at Yucca Mountain in the unlikely event that an eruption occurs (CRWMS M&O 2000 [DIRS 142657], Section 6.5.1).

To calculate annual doses from inhalation, DCFs are used to convert predicted radionuclide intake by inhalation into predicted dose. DCFs for inhalation of suspended particles depend on particle size, represented by the activity median aerodynamic diameter. Although the size of resuspended particles ranges over several orders of magnitude, the GENII-S V.1.4.8.5 code can accommodate only one set of coefficients in converting radionuclide intake by inhalation to doses. Most commonly used DCFs for inhalation apply to particulates whose diameter is distributed lognormally with an activity median aerodynamic diameter of 1 μm (Eckerman et al. 1988 [DIRS 101069]). Such conversion factors are also built into GENII-S V.1.4.8.5. Applicability of these coefficients for a wider size range of particles that could become resuspended in the air was evaluated using methods described in ICRP 30 (ICRP 1979 [DIRS 110386]; CRWMS M&O 2001 [DIRS 152536], Section 5.2).

It was concluded that DCFs for particles with an activity median aerodynamic diameter of 1 μm adequately represent particle sizes expected to be deposited on the ground by volcanic eruption. Since the expected distribution contains a significant fraction of large particles, application of DCFs for 1 μm particles led, in most cases, to overestimates of the resulting dose (CRWMS M&O 2001 [DIRS 152536], Section 5.2).

To determine TSP concentrations for the groundwater release scenario, average annual outdoor distributions of PM_{10} from analogue arid farming communities were multiplied by the ratio of TSP to PM_{10} at Yucca Mountain to develop a distribution of mass loading representative of the reference biosphere farming community (CRWMS M&O 2000 [DIRS 152438], Section 6.1.1). Because no measurements of air quality have been made at the farming area in Amargosa Valley, analogue measurements from arid, rural, agricultural sites elsewhere in the United States were selected. The measurements selected were very high compared to those taken at Yucca Mountain and elsewhere in the United States: the average of the measurements was greater than 96 percent of over 10,000 other PM_{10} values reported for the United States between 1994 and 1999, and the maximum was greater than 99.7 percent of the other measurements. The selected PM_{10} measurements were multiplied by a factor of 2.5 to convert to TSP. That factor was based on 1,276 simultaneous measurements of PM_{10} and TSP taken at Yucca Mountain. The resulting mass loading distribution is normally distributed, with an average of 105 $\mu g/m^3$. This value is more than an order of magnitude larger than the one selected in *Input Parameter Values for External and Inhalation Radiation Exposure Analysis* (CRWMS M&O 2000 [DIRS 149880], Section 6.1). Because this distribution is based on analogue data from very dusty, arid farming communities, it likely bounds any uncertainties in future environmental conditions and farming practices in the reference biosphere.

Two distributions of mass loading were developed for the volcanic eruption scenario (CRWMS M&O 2000 [DIRS 152438], Section 6.1.2). The first is applicable to deep ash deposits, and describes changes in annual average mass loading through a 10-year transition period. The transition period is characterized by an increased concentration of airborne particulates compared with pre-eruption conditions. This distribution was developed to bound uncertainties in mass loading for extreme ash depths, the characteristic of a volcanic eruption likely to have the greatest influence on mass loading. The second distribution describes the relationship between ash depth and transition-period (i.e., 10-year) average mass loads, and is intended to account for uncertainties in mass loading caused by variations over all predicted ash depths.

Four assumptions were made to account for uncertainties in ash depth and other characteristics of a volcanic event, such as concentration of suspended particulates in air (CRWMS M&O 2000 [DIRS 152438], Section 5.1). First, an average annual particulate concentration of 1,000 $\mu g/m^3$ (PM_{10}) was assumed for the first year following a volcanic eruption. This annual level is high compared to most short-term concentrations of PM_{10} measured during farming and other activities following volcanic eruptions. Because exposure to much lower concentrations of particulate matter are known to cause health effects, it is likely that people would take precautions to avoid long-term exposure to concentrations as high or higher than 1,000 $\mu g/m^3$. This first-year annual average is therefore valid for even the largest ash depths predicted. Second, it was assumed that the concentration of ash particles decreases exponentially after an eruption. This assumption was based on mathematical functions commonly used in resuspension models and is more conservative (i.e., would result in a higher BDCF) than other functions that have been used to predict changes in resuspension of radionuclides. Third, the concentration of resuspended particles was assumed to decrease to background levels within ten years of a volcanic eruption. This rate of decrease results in a transition period that is more than an order of magnitude longer than the one measured after the Mount St. Helens eruption (CRWMS M&O 2000 [DIRS 152438], Section 5.1.3). Fourth, based on measurements of resuspended particulate concentrations during agricultural work following the Mount St. Helens eruption, a ratio of TSP to PM_{10} of 3.0 was assumed.

Based on these assumptions, mass loading concentrations experienced at the maximum ash depths were predicted to decrease exponentially, from an annual average of 3,000 $\mu g/m^3$ the first year following an eruption to 105 $\mu g/m^3$ within 10 years. The average value representing this 10-year period is 864 $\mu g/m^3$. This distribution is intended to represent the 10-year period following an eruption that deposits a large amount of ash at the location of the receptor population.

The distribution of transition-period mass loading concentrations applicable to all ash depths is predicted to be exponential, with a maximum of 864 $\mu g/m^3$ (the average of the distribution for maximum ash depth). Predicted low values of ash depths are so small (10^{-5} to 10^{-2} cm) that they will cause no detectable change in mass loading; therefore, the minimum value for this distribution is the same as the average mass loading for a farming community (105 $\mu g/m^3$). This distribution is intended for modeling the effects of ash depths and for sampling mass loading values that cover the range of all predicted depths.

Inhalation Exposure Time–The distribution of inhalation exposure time in *Input Parameter Values for External and Inhalation Radiation Exposure Analysis* (CRWMS M&O 2000 [DIRS 149880], Section 6.2) was based on the entire population of working adults in Amargosa Valley; therefore, an additional distribution was developed to represent behaviors of farmers and other outdoor workers (CRWMS M&O 2000 [DIRS 152438], Section 6.2.2). Because no adequate survey of the activity budgets of farmers has been conducted, and because of uncertainties in the recreational habits and other behaviors of Amargosa Valley farmers, this new distribution was intended to bound the likely inhalation exposure time of a group of farmers. The lower bound (5,794 hours/year) was based on the time-activity budget of a salaried farm or construction worker who works outdoors 40 hours per week, recreates outdoors, and resides in the contaminated area. This value is more than 60 percent higher than the lower bound for the distribution of Amargosa Valley residents. The upper bound (6,354 hours/year) was based on the time-activity budget of a farmer who spends 60 hours per week outdoors, recreates outdoors, and resides in the contaminated area. The values of inhalation exposure time include inhalation exposure time outdoors and indoors. The inhalation exposure time indoors is equal to 50 percent of the time spent indoors because it is assumed that the particulate concentration indoors is half of that outdoors. The upper bound is very conservative (i.e., will result in a high BDCF) because it is based on the assumption that a farmer would work outdoors year-round for a large number of hours and then spend more than two hours per day recreating outdoors. It is not reduced to account for time spent repairing equipment indoors, conducting business away from the farm, illnesses, vacations, or other weekday activities that would occur indoors or away from the farming community. Also, this bounding value is higher than the values from two other recent Yucca Mountain biosphere or performance assessment analyses. Thus, this distribution adequately bounds uncertainties in the behavior of farmers in Amargosa Valley.

13.3.6.2 Conclusions

Modification of the parameter values for mass loading and inhalation exposure time resulted in inhalation becoming the dominant pathway for the volcanic eruption scenario, accounting for

86 to 99 percent of the BDCFs for the transition phase for 13 of 17 radionuclides evaluated (CRWMS M&O 2001 [DIRS 152536], Section 6.6). This change was due primarily to the increase in mass loading values. Because the revised distribution of mass loading bounds uncertainties in ash depth and conservatively incorporates the whole range of particle sizes available for resuspension, the resulting BDCFs account for the most important uncertainties of this scenario.

Changing the values of mass loading and inhalation exposure time used in the analysis of the groundwater release scenario had little impact on BDCFs for no prior irrigation. Inhalation contributed 0.013 percent of the BDCFs for the most sensitive radionuclides (thorium-229 and uranium-232) when the original parameter values were used (CRWMS M&O 2000 [DIRS 144692], Section 6.3.3) and less than 0.3 percent when the revised values were used (CRWMS M&O 2001 [DIRS 152539], Table 15). The importance of the inhalation pathway increases significantly with the duration of prior irrigation for some radionuclides that show the effect of radionuclide buildup in soil. Therefore, using modified inhalation exposure parameter values provides a better bound on uncertainties associated with the inhalation exposure pathway of the biosphere model.

13.3.7 Impacts of Climate Change on Biosphere Dose Conversion Factors

As discussed in more detail below, it is predicted that precipitation and average temperature in southern Nevada will change over time (see Section 3.3.1). Any analysis of potential repository performance has to consider the impact of such climatic changes. The effect of such changes on the expected annual dose for the defined receptor has to be evaluated consistently to allow a complete analysis to be performed. This section reports the development of BDCFs for the predicted climatic change.

The climate of central and southern Nevada is basically arid, but the degree of aridity varies in space (mostly by elevation) and in time (seasonally and annually). Hence, the area is occasionally called "semiarid." However, the term "arid" should be used for general descriptions of the regional climate at Yucca Mountain (CRWMS M&O 2000 [DIRS 151945]). Geologic media provide a historical record of the types and periodicity of climate change in the Yucca Mountain region. The past-to-future climate analogue forecasts that the modern-day climate at Yucca Mountain should persist from 400 to 600 years, followed by a warmer and much wetter monsoon climate for 900 to 1,400 years and a cooler and wetter glacial-transition climate for 8,000 to 8,700 years (CRWMS M&O 2000 [DIRS 151945], p. 6.5-3). The analysis performed to estimate climatic variables for the next 10,000 years (USGS 2000 [DIRS 136368]) identified representative meteorological stations selected to represent future climates. The stations selected provided an upper and lower climate bound for each future climate. The forecasted future climate states, analogue sites (USGS 2000 [DIRS 136368], Table 2), and corresponding average long-term meteorological parameters are listed in Table 13.3-14 (CRWMS M&O 2001 [DIRS 152539]).

Conditions representative of a glacial-transition climate were selected to represent evolved climatic conditions at Yucca Mountain and evaluate the impact of climate change on BDCFs. A glacial-transition climate was selected because it is predicted to occur for most of the next 10,000 years (CRWMS M&O 2000 [DIRS 151945], p. 6.5-3). Also, the conditions at the

Spokane, Washington, analogue station differ the most from the current conditions in the Yucca Mountain region. In Spokane, the average maximum temperature is the lowest and the amount of overall precipitation (including snow) is the greatest from among the selected analogue sites. Therefore, this site was chosen to represent future climate conditions for the biosphere analysis.

The method used to calculate the BDCFs for the two climate conditions was the same, but selected input parameters representative of the two climates under consideration had to be developed. A preliminary evaluation is documented in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]). It was assumed that the receptor remained unchanged, which was consistent with proposed 10 CFR 63.115(b) (64 FR 8640 [DIRS 101680]).

13.3.7.1 Development of Input Parameters

To evaluate the change in BDCFs due to climate evolution, the impact of the cooler and wetter climate on all parameters was examined. It was determined that many ingestion exposure parameters, such as crop growing time, irrigation time, and irrigation rate, were affected by climate change. Crop irrigation requirements differ between the Spokane climate and the Amargosa Valley climate. In Amargosa Valley, irrigation is needed year-round, although the irrigation rate is lower during the winter season. In Spokane, no irrigation is necessary in winter because precipitation exceeds evapotranspiration (CRWMS M&O 2001 [DIRS 152539], Appendix III). In addition, few crops grow during that period of time in Spokane.

For the preliminary evaluation, only limited input parameters were redeveloped for the evolved climate, as documented in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539], Appendix III). Some conclusions of that analysis are:

- Crop growing times in Spokane are longer than those in Amargosa Valley due to cooler weather, except for winter wheat, which was assumed not to grow during winter months in Spokane.

- Most crop irrigation times in Spokane are longer than in Amargosa Valley, except for alfalfa and wheat, which do not grow in winter in Spokane.

- Irrigation rates in Spokane are 20 to 60 percent lower than in Amargosa Valley, except for leafy vegetables, which have comparable irrigation rates. This is because the growing requirements of leafy vegetables, especially as related to temperature, are similar for both areas, which results from different planting seasons for leafy vegetables.

- Crop yields in both areas are the same, except for alfalfa, a multiharvesting crop, which has a shorter growing season in Spokane.

13.3.7.2 Biosphere Dose Conversion Factor Results

BDCFs for both climate conditions were calculated using statistical simulations consisting of 150 individual model realizations for each radionuclide. Twenty-four radionuclides were evaluated. In addition, radionuclide buildup in soil was modeled by considering six different irrigation periods. These irrigation time models allow the calculation of BDCFs that include radionuclide buildup in soil irrigated with contaminated water.

The BDCF results for the current climate, the evolved climate, and irrigation periods 1 and 6 are listed in Table 13.3-15. To evaluate the degree of radionuclide buildup in soil, the buildup factors were calculated for each radionuclide. The buildup factor is a ratio of the mean value of period 6 (longest) to period 1 (no prior irrigation).

BDCFs for the evolved climate tend to increase with the duration of prior irrigation, similar to the BDCFs for the current climate. However, the amount of increase for the evolved climate is less than that for the current climate for every radionuclide. Leaching coefficients were not reevaluated for the evolved climate (i.e., the same set was used as the one for the current climate). Therefore, the 6th irrigation period was the same for both climate conditions.

Out of the 24 radionuclides analyzed, 11 do not show significant radionuclide buildup in soil (less than 15 percent) and their BDCFs remain relatively unchanged as the irrigation duration lengthens. The remaining 13 radionuclides show various degrees of buildup, up to the maximum buildup factor value of 39.8 for thorium-230. As in the current climate case, radionuclides showing the greatest degree of buildup need very long periods of continuous irrigation, on the order of thousands of years, to reach an equilibrium activity concentration in soil.

The BDCFs for the evolved climate are up to 10 percent lower than the BDCFs for the current climate, mainly because of the decreased irrigation rate. The difference is greater for the sixth irrigation period. The BDCFs for the evolved climate may be up to about 44 percent lower than the BDCFs for the current climate. The difference is the greatest for such radionuclides as isotopes of thorium, which build up slowly in soil.

13.3.7.3 Pathway Analysis for the Evolved Climate

The pathway analysis for the evolved climate was intended to find the relative change for each pathway compared with the current climate. It was assumed that the climate change does not affect drinking water consumption, a dominant pathway, because the same receptor was considered for both climates. Therefore, the overall BDCF decrease comes from the decrease of other pathway BDCFs. This results in an even greater contribution of the water consumption pathway BDCFs to the evolved climate BDCFs.

To analyze the combined effect of prior irrigation and climate change on the BDCFs, a graph was constructed that shows pathway BDCF ratios for plutonium-239 for the 1st and 6th irrigation periods in the evolved and current climates (Figure 13.3-3). This radionuclide exhibits a moderate degree of buildup, and it was identified as one of the key radionuclides in the TSPA-SR analysis (CRWMS M&O 2000 [DIRS 153246]). The ratios of pathway BDCFs for the evolved and current climate are less than one except in the water consumption and fish consumption pathways, which do not depend on radionuclide concentration in soil.

13.3.7.4 Conclusions

The anticipated future wetter climatic conditions are predicted to systematically reduce BDCF values from the values for the current climate. The reduction is predicted to be a maximum of a factor of two, with the majority of radionuclides showing a reduction of 20 percent or less. Only the current climate BDCFs were used in the TSPA analyses. The BDCFs for the evolved climate were not used because the current BDCFs were conservative.

13.3.8 Biosphere Dose Conversion Factors for Selenium-79 and Neptunium-237

13.3.8.1 Introduction

Since the generation of the TSPA-SR data (CRWMS M&O 2000 [DIRS 153246]), the parameters defining the reference biosphere and the receptor of interest have been reevaluated. These revised inputs were used to generate the updated BDCFs used in the analyses presented in Volume 2 (McNeish 2001 [DIRS 155023]). Both analyses are discussed in Section 13.2. These data are provided in Section 13.4 and are not discussed further in this section.

The BDCFs for the suite of radionuclides originally defined as being of potential importance for annual dose calculations in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) have been developed and documented in *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]). Since this work was completed, neptunium-237 has been identified as a potential contributor to annual dose not only for the nominal scenario, as previously considered, but also for the disruptive scenario (CRWMS M&O 2000 [DIRS 150561], Section 7). Therefore, BDCFs for neptunium-237 were developed for the volcanic eruption exposure scenario. Because BDCFs for neptunium-237 had been generated for the groundwater release exposure scenario, the input data had already been selected and justified. The inputs and assumptions were the same ones used for generating the BDCFs for the other radionuclides, as reported in *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]). In the case of selenium-79, Wu (2001 [DIRS 154893]) presents supporting documentation for the radionuclide-dependent parameters.

Discussions with independent review bodies, the IAEA, and the Electrical Power Research Institute indicated that selenium-79 may be a significant contributor to annual dose (Smith et al. 1996 [DIRS 101085], Section 5). Although selenium-79 was not identified as a significant contributor to annual dose in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]; CRWMS M&O 2000 [DIRS 150561], Section 7), it was considered prudent to provide the TSPA with the capability to include this radionuclide in the total annual dose calculations, if necessary. BDCFs for selenium-79 were developed for both scenarios. Because selenium-79 had not been previously considered, element-specific GENII-S V.1.4.8.5 input parameter values had to be developed. These data are presented below.

The objective of this new analysis was to provide the TSPA with the capability to evaluate the contributions from neptunium-237 and selenium-79 to the total annual dose for both scenarios.

13.3.8.2 Model Input Development

GENII-S V.1.4.8.5 was used to generate the required BDCF data. This code requires many parameters that quantify the transport of radionuclides through the multiple pathways that contribute to annual dose. The values for parameters that were not radionuclide-specific were the same ones used for the generation of the revised BDCFs in *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]).

In the case of selenium-79, which had not been previously considered in TSPA calculations, required data were derived from published sources. The approach to parameter selection and the data sources investigated were the same as those cited in the AMR supporting previous iterations.

13.3.8.2.1 Parameter Selection

The following parameters were evaluated and selected:

- Soil-to-plant transfer factors
- Animal feed-to-animal product transfer coefficients
- Bioaccumulation factors
- Leaching coefficients, removal constant, and prior irrigation period
- External dose coefficients for air submersion and exposure to contaminated soil
- Inhalation and ingestion dose conversion factors.

A summary of transfer factors, transfer coefficients, and bioaccumulation factors is listed in Table 13.3-16. The data selection was based on the same method used in *Transfer Coefficient Analysis* (CRWMS M&O 2000 [DIRS 152435]).

13.3.8.2.2 Parameters for Radionuclide Buildup in Soil

The leaching coefficient for selenium-79 was developed and documented in *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [DIRS 152517], Section 6.2). In order to evaluate the radionuclide buildup in soil, the BDCFs were calculated for six periods of prior irrigation. (The period of prior irrigation represents the number of years that the land has been irrigated with contaminated water before the exposure occurs.) The calculation method was documented in Section 6.3.2 of the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]). The results are shown in Table 13.3-17.

13.3.8.2.3 External Dose Coefficients

Federal Guidance Report No. 12 (Eckerman and Ryman 1993 [DIRS 107684]) was used as a source of dose coefficients for exposure to soil contaminated with selenium-79 to a depth of 15 cm and 1 cm. The same method as the one used previously and documented in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]) was used to develop input parameters for external exposure. The dose coefficients developed are listed in Table 13.3-18.

13.3.8.2.4 Inhalation and Ingestion Dose Conversion Factors

A GENII-S V.1.4.8.5 DOSINC.DAT file containing the inhalation and ingestion DCFs for the worst-case solubility, which was updated in 1993 (Rittmann 1993 [DIRS 107744]), was used for the BDCF calculations. The DOSINC.DAT is the binary file and contains detailed organ DCFs. A comparison of DCFs was made between GENII-S V.1.4.8.5 and Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]) for some radionuclides and documented in *Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods* (CRWMS M&O 1999 [DIRS 110635]). It was recommended that the GENII-S V.1.4.8.5 internal dose assessment be conducted with no modifications to the DOSINC.DAT file.

13.3.8.3 Results

The BDCFs for selenium-79 and neptunium-237 for the groundwater release scenario were developed using the methods documented in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]). The BDCFs for selenium-79 for the volcanic eruption exposure scenarios were developed using the methods documented in the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]).

For the volcanic eruption BDCF data, the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) was provided with an abstraction in the form of a table of percentiles, as it was done previously (CRWMS M&O 2001 [DIRS 152536]). These data are presented in Tables 13.3-19 and 13.3-20, respectively, for selenium-79 and neptunium-237. In the case of the groundwater release exposure scenario, Table 13.3-21 gives a summary of the output data for selenium-79 showing the mean values of BDCFs and their standard deviation for the six irrigation periods.

The abstraction approach (CRWMS M&O 2001 [DIRS 153206]), as done in previous iterations for the current climate, was to attempt to determine a distribution that could be statistically justified as an acceptable representation of the stochastic GENII-S V.1.4.8.5 data. The distributions tested were the normal, the lognormal, and the shifted lognormal. None of these distributions provided an acceptable representation of the BDCF data. Therefore, the percentile table approach to abstraction was used. The data are shown in Table 13.3-22.

The mathematical model for the radionuclide buildup process in soils was developed previously (CRWMS M&O 2001 [DIRS 153206], Section 6.1). It was shown that the time dependency of the buildup process is governed by an expression of $e^{-t/a}$. In this expression, t is time and a is a characteristic time defining the rate of the process that depends on the radionuclide. The inverse of a is the rate of loss of the radionuclide from the soil because of leaching, radioactive decay, and harvesting. For selenium-79, the value of a is about 80 years (this value is an inverse of the removal constant by leaching, shown in Table 13.3-17). Since this period is less than the characteristic time for erosion, 250 years (CRWMS M&O 2001 [DIRS 153206], Section 6.2.2), the effects of erosion on the BDCF values would be small, and were therefore not estimated. This approach is conservative and requires no further justification. The data for 146 years of irrigation were used to represent the BDCF for selenium-79 at all times. At this time, the buildup factor for the mean BDCF values was calculated to be 1.27. The asymptotic buildup factor (after an infinite period of irrigation) was estimated to be 32 percent. Therefore, the use of period 6 (146 years) data to represent the BDCF for selenium-79 could be underestimating the actual mean value by 4 percent or overestimating it by 27 percent. The magnitude of this error estimate can be put into perspective by realizing that the standard deviation of the BDCF distribution for period 6 (146 years of irrigation) arising from input parameter uncertainty is about 60 percent of the mean value.

All BDCF data were updated and documented in AMRs. The new abstractions (CRWMS M&O 2001 [DIRS 153207]; CRWMS M&O 2001 [DIRS 153206]) were developed under the quality assurance program and are in the Technical Database Management System, ready for use in a TSPA. The data discussed above for neptunium-237 and selenium-79 are documented in Wu (2001 [DIRS 154893]).

13.4 SUMMARY AND PARAMETERS PROVIDED TO TOTAL SYSTEM PERFORMANCE ASSESSMENT

This section provides a summary of the work performed and the data generated in the biosphere area to support the TSPA analyses presented in Volume 2 (McNeish 2001 [DIRS 155023]). This work was primarily documented in revisions of the AMRs listed in Section 13.2.1. Most of the supporting documents were updated to reflect improvements in modeling and a more comprehensive data assessment. These changes were propagated through the BDCF calculation process to produce new inputs for use in the TSPA. The biosphere inputs to the TSPA were in the form of BDCF abstractions and BDCF percentile tables. These parameters enable calculations of expected annual doses from predicted radionuclide concentrations at the source of contamination.

13.4.1 Biosphere Dose Conversion Factors for the Groundwater Release Exposure Scenario

The BDCFs for the groundwater release exposure scenario were developed in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]). Calculations of BDCFs were performed in a series of individual runs consisting of 150 model realizations for the 24 radionuclides under consideration: carbon-14, nickel-63, strontium-90, technetium-99, iodine-129, cesium-137, lead-210, radium-226, actinium-227, thorium-229, thorium-230, protactinium-231, uranium-232, uranium-233, uranium-234, uranium-236, uranium-238, neptunium-237, plutonium-238, plutonium-239, plutonium-240, plutonium-242, americium-241, and americium-243 (CRWMS M&O 2000 [DIRS 136383], Sections 7.1 and 7.2). This selection included 16 radionuclides identified as important in the nominal scenario during the compliance period of up to 10,000 years, 3 additional radionuclides considered for human intrusion, and 5 radionuclides used in estimating potential dose beyond the compliance period of 10,000 years to the expected time of peak dose or 1 million years. In addition, BDCFs for selenium-79 were calculated after revision of the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]), as described in Section 13.3.8.

In the groundwater release scenario, BDCFs are expressed in terms of TEDE from annual exposure (i.e., annual dose) per unit of activity concentration per radionuclide in groundwater, which is consistent with proposed 10 CFR 63.2 (64 FR 8640 [DIRS 101680]). The annual dose denotes the dose from one year of exposure (i.e., the sum of the committed dose from annual radionuclide intake by ingestion and inhalation, and the annual exposure to external sources). Although credited to one year of exposure, the annual dose includes the dose that would be received during the 50 years following the intake (ingestion and inhalation) of radionuclides. Therefore, it is inappropriate to equate the annual dose with the dose per year or the dose rate, which is the dose received during one year. The annual dose is expressed in units of rem, while the dose rate would be expressed in units of rem/yr.

BDCFs are measured per unit of activity concentration of a specific radionuclide in groundwater, and units typically are given as rem/(pCi/L). Similarly, the BDCF units for volcanic eruption are rem/(pCi/m^2). This approach is consistent with proposed regulations that express the performance objective (10 CFR 63.113 [64 FR 8640 (DIRS 101680)]) and the individual protection standard (40 CFR 197.20 [64 FR 46976 (DIRS 105065)]) in units of mrem.

13.4.1.1 Biosphere Dose Conversion Factors for the Current Climate

Radionuclide-specific BDCFs were developed for both the current climate and the representation near the upper bound of the glacial-transition climate (CRWMS M&O 2001 [DIRS 152539]). Each set included considerations of radionuclide buildup in soil due to previous irrigation. Probabilistic analysis was used to develop BDCF values based on the revised values of input parameters. To support the preliminary analysis of the BDCFs for an evolved climate, several parameter values characteristic of the cooler and wetter climate were developed. The analysis was augmented with pathway and uncertainty studies.

The outcome of the BDCF statistical calculation consisted of 150 results of individual model realizations for each radionuclide for every irrigation period, which was sufficient to obtain statistically valid results. The corresponding means and standard deviations are listed in Table 13.4-1 for the first and the sixth irrigation period. BDCFs for selenium-79 calculated after revision of the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]) can be found in Tables 13.3-21 and 13.3-22 of this document. The ratio of BDCFs for these two periods allows a determination of the degree of radionuclide buildup in soil, represented by the buildup factor. The buildup factor is a ratio of the mean value of period 6 (longest) to period 1 (no prior irrigation). Buildup factors are also listed in Table 13.4-1. For those radionuclides whose buildup factor was greater than 1.15, BDCFs were also calculated for the remaining irrigation periods (i.e., periods 2 through 5).

The analysis of model results indicates that for 10 radionuclides, the BDCFs increase relatively insignificantly with prior irrigation time (i.e., the buildup factor is less than 1.15). Among these radionuclides were technetium-99, iodine-129, and neptunium-237, which were considered among the key radionuclides in the TSPA-SR analysis (CRWMS M&O 2000 [DIRS 153246], Figure 4.1-6). The buildup factor for the remaining 14 radionuclides ranged from 1.17 for uranium-238 to 65.6 for thorium-230. However, some radionuclides with a buildup factor greater than 1.15 were associated with thousands of years of continuous irrigation before the equilibrium for radionuclide concentrations in soil is achieved. In addition, radionuclide removal by soil erosion has not been factored in because this mechanism was addressed in the abstraction phase of biosphere modeling.

13.4.1.2 Biosphere Dose Conversion Factor Abstraction

The statistical sampling approach adopted for generating the BDCFs allows the uncertainties in the input parameters to be incorporated into the BDCF predictions. The uncertainties in many of the input parameters defining both the reference biosphere and the processes therein, as well as the receptor, were represented by distributions. These parametric distributions were subsequently sampled within GENII-S V.1.4.8.5 to arrive at stochastic BDCFs representing the reference biosphere and the receptor.

The abstraction method used to provide the stochastic BDCFs to the TSPA-SR model (CRWMS M&O 2000 [DIRS 153246]) and to enable the effects of soil erosion to be taken into account was the approximation of statistical distributions. With the exception of a single radionuclide (carbon-14, which is discussed later in this section), three distributions provided acceptable abstractions of all BDCFs: normal, lognormal, and shifted lognormal distributions.

Of all the radionuclides considered in the distribution fitting exercise, carbon-14 was the only one for which an acceptable distribution not found. Carbon-14 did not show any significant buildup in BDCF due to protracted irrigation. In this case, an empirical distribution for the BDCFs was provided to the TSPA in the form of a table giving the cumulative distribution function in terms of the percentile values (defined at each fifth percentile starting at 0 percent, the minimum BDCF value generated by GENII-S V.1.4.8.5). These empirical data for carbon-14 are shown in Table 13.4-2.

For those radionuclides where soil buildup effects produced an increase in the mean BDCF value of less than 15 percent, the distributions used in the TSPA assessment were the abstractions for period 6. The distribution and associated parameters used in the TSPA are given in Table 13.4-3.

Some of the radionuclides have BDCFs that were significantly influenced by radionuclide buildup in soil. Examples are americium-243, thorium-229, and uranium-232, none of which had been significant contributors to the annual dose in previous TSPA evaluations (see Section 13.1.1). In addition, for thorium-229 and americium-243, the period needed for buildup to approach the maximum level was thousands of years. For such extended periods, it could be considered speculative but conservative to assume continuous farming activity on a single plot of irrigated land. In addition, the calculations did not include radionuclide removal by soil erosion. The time constant for erosion loss was estimated to be 250 years (CRWMS M&O 2001 [DIRS 153206], Section 6.2.2). Therefore, for radionuclides where a predicted buildup period without soil erosion was several hundred years or more, the buildup was limited by erosion. Table 13.4-4 gives buildup factors for some representative radionuclides with and without consideration of soil erosion.

To avoid introducing speculation by having to define an appropriate period for the prior irrigation (or to develop a model to allow a justifiable distribution for this period to be sampled), the same approach was used as that for radionuclides with a small buildup factor. The BDCF distributions provided to the TSPA were those with asymptotic buildup factors derived with the inclusion of erosion.

The recommended distributions and geometric parameters for the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) for those radionuclides that show a small degree of buildup are presented in Table 13.4-3. Statistical distributions for these radionuclides are given for the maximum period of previous irrigation (period 6). For the 14 radionuclides with a significant (i.e., greater than 15 percent) buildup, statistical distributions of BDCFs were determined after incorporation of the soil loss effect. The recommended BDCF distributions and parameters for these radionuclides are summarized in Tables 13.4-5 to 13.4-7 for radionuclides having a normal distribution, a lognormal distribution, and a shifted lognormal distribution, respectively (CRWMS M&O 2001 [DIRS 153206], Tables 8 and 9). The values cited in the references were adjusted for the scale factor.

13.4.1.3 Modeling Output for the Evolved Climate

To evaluate the effect of future climate variations on biosphere, BDCFs were developed for the climatic conditions corresponding to the upper bound of the glacial-transition climate (CRWMS M&O 2001 [DIRS 152539], Section 6.5.5), as described in Section 13.3.7. Also, following the same calculation technique as the one used for the current climate, BDCFs were calculated in a series of GENII-S V.1.4.8.5 simulations for each of the 24 radionuclides. Each simulation resulted in 150 model realizations.

The outcome of the BDCF statistical calculation for the evolved climate also consisted of 150 results of individual model realizations for each radionuclide for all or selected irrigation periods, depending on the value of buildup factor. The corresponding means and standard deviations for the evolved climate are listed in Table 13.4-8 for the 1^{st} and the 6^{th} irrigation period. The summary of the BDCFs for selenium-79 for the evolved climate calculated after revision of the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]) can be found in Table 13.3-21. To evaluate the degree of radionuclide buildup in soil, the buildup factors were calculated for each radionuclide (Table 13.4-8). For those radionuclides whose buildup factor was greater than 1.15, BDCFs were also calculated for the remaining irrigation periods (i.e., periods 2 through 5). The modeling results for the evolved climate and a comparison with the BDCFs for the current climate are discussed in Section 13.3.7.

13.4.1.4 Results of Pathway Analysis

Results of the pathway analysis are documented in *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539], Section 6.7). This section summarizes the findings.

For all radionuclides except carbon-14 and cesium-137, consumption of drinking water was the dominant pathway, accounting for 55 to 69 percent of the BDCF, depending on the radionuclide. Leafy vegetable consumption ranked second, contributing from 23 to 27 percent, depending on the radionuclide. Together, consumption of drinking water and leafy vegetables accounted for 82 to 96 percent of the BDCF values for radionuclides. The remaining consumption pathways accounted for up to a few percent of the BDCFs. Inhalation and external exposure pathways were not significant, and neither of them contributed more than a few tenths of a percent for all radionuclides except cesium-137 (7.7 percent) and radium-226 (2.5 percent). For carbon-14, consumption of fish was by far the most important pathway (93 percent of the BDCF). Pathway contributions to BDCFs for cesium-137 include 23 percent from consumption of drinking water, 12 percent from leafy vegetables, 12 percent from meat, 36 percent from fish, and 8 percent from external exposure.

Contribution of the specific pathways to the BDCFs was affected by radionuclide buildup in soil because some pathways depend on radionuclide concentrations in soil. Among the pathways unaffected by radionuclide buildup in soil was consumption of drinking water, which was the major pathway for most radionuclides. Also, the contribution to BDCFs from consumption of fish and that fraction of the BDCF that results from activity deposition on a plant's surfaces from irrigation water were unrelated to radionuclide concentration in soil.

For many radionuclides for which the effect of radionuclide buildup in soil was insignificant, such as technetium-99, iodine-129, and neptunium-237, pathway contributions to BDCFs remain virtually unchanged regardless of the previous irrigation practices. This, however, was not the case for radionuclides whose levels in soil increase significantly with prolonged irrigation.

The effect of radionuclide buildup in soil on pathway contributions to the BDCFs was evaluated for selected radionuclides whose BDCFs increase with the duration of prior irrigation. This analysis was carried out assuming a constant level of activity concentration in water for the entire length of time needed to obtain steady-state conditions of radionuclide concentrations in soil (thousands of years for some radionuclides). In addition, other removal mechanisms, such as soil removal by erosion, were not factored in because they were considered in the abstraction process. The addition of soil removal from erosion would considerably shorten the time needed to obtain an equilibrium radionuclide concentration in soil and make the analysis of the BDCFs for very long periods of prior irrigation (such as those for thorium-230) irrelevant.

The graph shown in Figure 13.4-1 shows percentage pathway contributions to BDCF for plutonium-239 at different periods of prior irrigation. Contributions to BDCF from consumption of all crop types and contributions from consumption of all animal products were portrayed as their respective category. Plutonium-239 was a radionuclide that shows a moderate degree of radionuclide buildup in soil. The graph shows the decreasing importance of the water consumption pathway with irrigation time and the growing inhalation and soil ingestion components.

13.4.2 Groundwater Withdrawal by the Farming Community

The annual groundwater usage by the proposed community has not been reevaluated. The predicted distribution for groundwater usage by the farming community was given in Section 13.4.1.2. However, the average groundwater withdrawal by the farming community was reviewed, as described in Section 13.3.5, for consistency between the irrigation rate of 5 acre-feet per year per acre estimated by the state of Nevada and irrigation levels based on area-specific evapotranspiration values. The result of this assessment was a simple scalar multiplier for the present-day climate or the glacial-transition climate. Water usage was estimated to increase by a factor of 1.58 in the present-day climate, while usage was predicted to be reduced by a factor of 0.63 in the cooler and wetter future glacial-transition climate.

13.4.3 Biosphere Dose Conversion Factors for the Volcanic Eruption Exposure Scenarios

BDCFs that apply to the direct release of radionuclides from the potential repository as a result of volcanic eruption are described in the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536], Section 6.5). BDCF calculations were done for seventeen radionuclides: strontium-90, cesium-137, lead-210, radium-226, actinium-227, thorium-229, thorium-230, protactinium-231, uranium-232, uranium-233, uranium-234, plutonium-238, plutonium-239, plutonium-240, plutonium-242, americium-241, and americium-243. The selection included radionuclides that may be significant dose contributors during the compliance period of up to 10,000 years, as well as radionuclides of importance for up to 1 million years after closure of the potential repository. In addition, BDCFs for selenium-79 and neptunium-237 were calculated after revision of the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]), as described in Section 13.3.8.

From the perspective of BDCF calculation for volcanic eruption, three different human exposure scenarios were specified for different phases during and following volcanic eruption: (1) eruption, (2) transition, and (3) steady-state (CRWMS M&O 2001 [DIRS 152536], Section 6.3.1). The eruption phase refers to the conditions during the volcanic eruption. Because of the expected high concentration of particulates in air during this phase, inhalation of airborne, contaminated ash particles was the only primary pathway considered in the calculation.

The transition phase is characterized by resuspension of volcanic ash deposited on the ground during the eruption phase. The contaminated ash is thus available for inhalation. Resuspended ash, if deposited on plant surfaces, may cause contamination on crops used for human consumption and animal feed. Contamination of crops may also occur through the root uptake of radioactivity in the soil. Contaminated animal feed results in contamination of animal products such as milk, meat, and eggs. It was postulated that contaminated ash was not mixed into the soil below the ash layer for the duration of the entire transition phase. This was a conservative approach that maximized inhalation of resuspended particles but did not affect other pathways, such as root uptake. Concentration of resuspended particles in air during the transition phase was assumed to decrease exponentially until it reached pre-eruption conditions (CRWMS M&O 2000 [DIRS 152438], Section 5.1.2). The process of reduction of initially high dust concentrations in air was assumed to take up to 10 years (CRWMS M&O 2000 [DIRS 152438], Section 5.1.3). When the biosphere system returns to pre-eruption dust levels, the third and steady-state phase begins. This phase is characterized by the same levels of suspended particulates in the air as those used for the development of the groundwater release BDCFs. In the steady-state phase, radioactivity previously deposited on the ground from a volcanic eruption was assumed to be uniformly mixed into a 15-cm layer of topsoil, regardless of the initial thickness of the ash deposit.

13.4.3.1 Dose Factors for the Eruption Phase

For the eruption phase, dose factors were developed rather than BDCFs. Dose factors represent the TEDE resulting from a one-day intake of radionuclides (called here a daily dose, by analogy with the annual dose) by inhalation of air containing unit activity concentration of a radionuclide under consideration (1 pCi/m^3). It was assumed that inhalation exposure time was equal to

6,073.5 hours per year (CRWMS M&O 2000 [DIRS 152438], Section 6.2.2), which includes time spent outdoors and half of the time spent indoors in that area, as described in Section 13.3.3.2.2. Such inhalation exposure time resulted in an inhalation exposure factor of 0.693, calculated by dividing 6073.5 hours of inhalation exposure time per year by the total number of hours per year (8,760 hours). Inhalation exposure time and, subsequently, the inhalation exposure factor do not reflect actual time spent outdoors. Rather, they are scaling factors that include inhalation exposure both outdoors and indoors.

Dose factors for the eruption phase were developed using DCFs for inhalation from Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069], Table 2.1). When more than one DCF was given for a particular radionuclide, the most conservative was used. Dose factors are listed in Table 13.4-9. Eruption-phase dose factors for selenium-79 and neptunium-237, calculated after revision of the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]), can be found in Tables 13.3-19 and 13.3-20, respectively.

The use of dose factors to calculate daily dose for the eruption phase is (CRWMS M&O 2001 [DIRS 152536], Equation 5):

$$Dose\ (rem) = S\left(\frac{g}{m^3}\right) \times C_{ash}\left(\frac{pCi}{g}\right) \times DF\left(\frac{rem\ m^3}{pCi}\right) \qquad \text{(Eq. 13-3)}$$

where:

S = average daily mass concentration of particulates in air (i.e., TSP), $\frac{g}{m^3}$

C_{ash} = activity concentration of radionuclide in ash, $\frac{pCi}{g}$.

13.4.3.2 Biosphere Dose Conversion Factors for the Transition and Steady-State Phases

Volcanic eruption BDCFs were developed for the transition and steady-state phases. The most important parameter distinguishing these two phases was mass loading, a GENII-S V.1.4.8.5 parameter that quantifies mass concentration of suspended particulates in air. In the steady-state phase, the distribution of mass loading was assumed to be the same as the distribution used for the groundwater source of contamination. (The steady-state phase begins when the mass loading returns to pre-eruption conditions.) In calculations of transition-phase BDCFs, two distributions of mass loading were considered. Detailed descriptions of these distributions are documented in *Input Parameter Values for External and Inhalation Radiation Exposure Analysis* (CRWMS M&O 2000 [DIRS 152438], Section 6.1.2). The first was a distribution of possible annual average values of mass loading following the deposition of a deep ash layer at the location of the receptor. This distribution describes changes in average annual mass loading conditions during one 10-year transition period, and was intended to bound uncertainties in mass loading due to variation in ash depth. The second was a distribution of transition-period (10-year) average values of mass loading that correspond to differences in predicted ash depth at the location of the receptor.

Another parameter important in the biosphere modeling for the volcanic eruption was the thickness of ash layer at the location of interest. The thickness of the ash layer that could be deposited 20 km from the potential repository was uncertain (CRWMS M&O 2000 [DIRS 153246], Section 3.10.5.1). The median eruptive event was predicted to produce an ash layer less than 1 cm thick 20 km downwind. The minimum ash layer calculated for the midpoint of the plume at 20 km was less than 0.1 mm, corresponding to a relatively small eruption that produces only a dusting of ash at that distance. The maximum ash layer was 36 cm, corresponding to a large eruption that produces a major ash fall covering a large area (CRWMS M&O 2000 [DIRS 153246], Section 3.10.5.1).

Because of the wide range of ash thicknesses, transition-phase BDCFs were developed for two different thicknesses of ash: 1 cm, representing the more likely conditions, and 15 cm, representing thicker ash deposits. The thicker ash layer was chosen to be 15 cm because this thickness corresponds to the depth of surface soil constituting the plant growing zone (it was assumed that 100 percent of a plant's roots were in the surface soil layer) (CRWMS M&O 2001 [DIRS 152434], Sections 6.4.1 and 6.4.4), which is one of the input parameters in GENII-S V.1.4.8.5. Greater thicknesses do not have a significant effect on the calculation outcome because it was assumed that plant roots do not extend past 15 cm in depth. The BDCFs for the steady-state phase use the 15-cm thickness for the ash or soil layer.

Taking into consideration the possible combinations of mass loading and ash thicknesses, the following sets of BDCFs were developed:

- Transition-phase, 1 cm ash layer and annual average mass loading
- Transition-phase, 1 cm ash layer and 10-year average mass loading
- Transition-phase, 15 cm ash layer and annual average mass loading
- Transition-phase, 15 cm ash layer and 10-year average mass loading
- Steady-state phase.

BDCFs were calculated in a series of GENII-S V.1.4.8.5 simulations for each of the 17 radionuclides. Each simulation resulted in 150 model realizations. These results were converted into discrete cumulative probability distributions, which were used in the TSPA with other input parameters to evaluate expected annual doses following a volcanic eruption.

Table 13.4-10 gives the summary of the BDCF calculations for the volcanic eruption. The table includes the means, standard deviations, minimums, and maximums for the BDCFs. The BDCFs for selenium-79 and neptunium-237, calculated after revision of the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]), can be found in Tables 13.3-19 and 13.3-20, respectively. For most radionuclides, BDCFs differ between the scenarios under consideration. The highest BDCFs were for the transition phase, 1-cm ash layer and the annual average mass loading. This set of BDCFs can be compared with the transition-phase BDCFs for a 15-cm ash layer and annual average mass loading. The reason for the difference is that in the 1-cm contaminated ash layer, radionuclides are concentrated in the upper soil. Therefore, the activity concentration in air from resuspended contaminated material is higher than that for the 15-cm layer of ash, where the same radioactivity is diluted in 15 times more material; thus, the resuspended particles would contain less radioactivity. This effect can be observed predominantly for those radionuclides whose BDCF contribution from the inhalation pathway was significant, such as isotopes of plutonium, thorium, uranium, and americium. For radionuclides whose BDCFs do not depend on the inhalation pathway, such as strontium-90, the difference was less significant (CRWMS M&O 2001 [DIRS 152536], Section 6.5.4).

The two sets of transition phase BDCFs for 10-year average mass loading showed a similar relationship: the values for a 1-cm ash layer were higher than those for the 15-cm ash layer for radionuclides with a significant contribution from the inhalation pathway. Overall, BDCFs developed using 10-year average mass loading were lower than those developed using annual average mass loading. This is because annual average mass loading conditions include the high mass loading values characteristic of the initial period of the transition phase, when the concentration of particulates in air is high. BDCFs developed using annual average mass loading apply to the annual average condition for any time during the eruption phase. BDCFs developed using 10-year averages do not include extreme dustiness conditions because the mass loading values they use are integrated over the entire transition phase (CRWMS M&O 2001 [DIRS 152536], Section 6.5.4).

13.4.3.3 Volcanic Eruption Biosphere Dose Conversion Factor Abstraction

In the case of volcanic dispersion of radionuclides, the same mechanisms for radionuclide loss from soil that are included in GENII-S V.1.4.8.5 were considered, that is, leaching, harvest removal, and radioactive decay (Napier et al. 1988 [DIRS 100953], Section 4.6.2). In this case, the losses were only considered during a single year of agricultural land use (the receptor uptake period). In contrast to the approach used for the groundwater release exposure scenario, no attempt was made to address the effect of leaching losses due to prolonged irrigation and precipitation over many years. This approach is conservative because it assumes no continual radionuclide removal from the root zone of plants by leaching, harvesting, or decay. An issue resolution status report on volcanic activity (NRC 1999 [DIRS 151592]) recommended that the consequence of the eruptive event be evaluated in a probabilistic manner by calculating the expected (i.e., probability-weighted) dose from events assumed to occur in each of the preceding years. The additional loss mechanisms over the intervening years could be used to justifiably reduce the expected annual dose from such an event.

13.4.3.4 Pathway Analysis

BDCF values include contributions from various radiological exposure pathways in the biosphere. The evaluation of the degree to which different pathways contribute to BDCFs was the subject of an independent assessment. To determine the contributions from different exposure pathways to BDCF values, a single GENII-S V.1.4.8.5 deterministic assessment was performed for each radionuclide and for each of five cases (CRWMS M&O 2001 [DIRS 152536], Section 6.5).

For most radionuclides (except strontium-90, cesium-137, lead-210, and radium-226), inhalation of resuspended particulates was a dominant pathway for all four cases for the transition phase, accounting for over 90 percent of the BDCFs. Inadvertent soil ingestion ranked second, contributing less than 7 percent to the BDCFs. Together, inhalation and inadvertent soil ingestion accounted for over 99 percent of most transition-phase BDCF values for these radionuclides. Consumption of leafy vegetables was usually the third-ranking pathway, but its contribution was normally less than one percent. Pathway contributions to the transition-phase BDCFs for strontium-90, cesium-137, lead-210, and radium-226 were different. Consumption of vegetables was a dominating pathway for strontium-90, external exposure ranks first for cesium-137, and pathway contributions for lead-210 and radium-226 were more evenly balanced among inhalation and crop consumption.

Pathway contributions for the remaining four cases showed a similar pattern for the transition phase, 1-cm ash layer, and annual average mass loading. For most of the radionuclides, the inhalation pathway tends to dominate the overall exposure, with the remaining pathways contributing only to a small degree. The contribution of other pathways, especially the inadvertent soil ingestion pathway, was most significant in the steady-state phase. Pathway contributions to the BDCFs for strontium-90, cesium-137, lead-210, and radium-226 remained more diversified than those for the heavier radionuclides.

In the steady-state phase, inhalation was still a dominant pathway for most radionuclides other than strontium-90, cesium-137, lead-210, and radium-226. However, the percentage contribution to the BDCFs was less than that in the transition phase. Vegetable consumption pathways dominate for strontium-90, lead-210, and radium-226, while the BDCF for cesium-137 was due almost entirely to external exposure.

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Table 13.2-1. Comparison of the Assessment Context for the Yucca Mountain Project and BIOMASS Biosphere Models

	YMP Assessment Context	BIOMASS Assessment Context	Comparison
Assessment Endpoint	Biosphere dose conversion factor based on total effective dose equivalent (TEDE)	Annual individual effective dose (ED)	Equivalent YMP – TEDE from ICRP 30[a]; BIOMASS – ED from ICRP 72[b] (see Section 13.3.2)
Assessment Philosophy	Contaminant transport pathways based on reasonable conservative values; human exposure pathways based on cautious approach	Equivalent except with respect the critical group definition	Equivalent Both models consider the reasonable values of input parameters for the critical group
Repository Type	Deep repository for long-lived solid radioactive waste	Deep repository for long-lived solid radioactive waste	Same
Site Context	Amargosa valley, groundwater usage and limited climate change	Generic inland repository, with aquifer at accessible depth, no biosphere change	Equivalent YMP – Site-specific BIOMASS – generic
Geosphere/ Biosphere Interface	Groundwater from wells for drinking, agriculture and domestic use	Well intruding into aquifer plume with abstraction at a rate consistent with domestic and agricultural use	Same
Source Term	Constant unit concentration for each radionuclide	Constant unit concentration for each radionuclide	Same
Societal Assumptions	Farming community, with vegetable garden and animal farms and fisheries	Agricultural community, adopting modern practices for cultivation and animal husbandry	Equivalent Similar ingestion pathways for the locally produced food
Time Frame	10,000 years, up to 1 million years	Up to 1 million years	Same

NOTES: [a] ICRP 1979 [DIRS 110386]; ICRP 1980 [DIRS 110351]; ICRP 1981 [DIRS 110352].
[b] ICRP 1996 [DIRS 152446].

Table 13.2-2. Comparison of the Pathways and Methodologies Used in the Yucca Mountain Project Groundwater Release and BIOMASS Biosphere Models

Pathways		YMP Model Groundwater Release	BIOMASS ERB 2A[a]	Notes
External Exposure	Contaminated soil	X	X	Same method
	Water immersion	---	X	---
Inhalation Dose	Air dust	X	X	Same method
	Aerosols/spray	---	X	---
Ingestion Dose	Soil	X	X	Same method
	Drinking water	X	X	Same method
	Leafy vegetables	X	X	Same method for root uptake, different for leaf deposition
	Root vegetables	X	X	
	Fruit	X	---	---
	Grain	X	X	Same method for root uptake, different for leaf deposition
	Fresh feed for cows	X	X	
	Stored feed for poultry	X	---	---
	Meat	X	X	Same for feed and water, no soil and inhalation in YMP model
	Milk	X	X	
	Offal	---	X	---
	Poultry	X	---	---
	Eggs	X	---	---
	Fish	X	---	---
Total Dose		X	X	---

NOTES: × = included in model.
[a] Example Reference Biosphere 2A.

Table 13.3-1. Pathway Factors

Nuclide	Water	Leafy Veg	Other Veg	Fruit	Grain	Meat	Poultry	Milk	Eggs	Fish	Soil Ing.	External	Inhale
C-14	2.1E-09	3.0E-08	4.0E-08	2.6E-08	1.0E-07	6.7E-08	1.1E-07	1.9E-08	8.7E-08	1.0E-04	0.0E+00	0.0E+00	0.0E+00
Tc-99	2.2E-09	5.6E-08	1.4E-08	3.7E-09	1.2E-08	9.1E-10	1.1E-10	6.4E-08	1.1E-08	4.5E-08	6.7E-09	4.1E-14	2.6E-15
I-129	2.5E-07	4.8E-06	6.9E-07	3.3E-07	1.1E-06	3.8E-06	6.4E-09	3.1E-06	1.1E-06	1.0E-05	3.5E-06	1.9E-11	2.1E-13
Pb-210	5.4E-06	9.4E-05	1.5E-05	7.8E-06	2.5E-05	5.5E-06	3.8E-07	2.0E-06	7.4E-06	1.6E-03	1.3E-03	1.4E-10	4.0E-10
Ra-226	9.8E-07	3.8E-05	1.8E-05	7.4E-06	2.6E-05	6.1E-06	2.6E-07	4.7E-06	3.9E-06	4.9E-05	9.7E-03	1.4E-06	3.9E-09
Ac-227	1.4E-05	2.7E-04	4.1E-05	1.7E-05	5.6E-05	8.2E-07	7.9E-08	4.8E-07	3.8E-08	3.6E-04	3.1E-03	4.4E-08	1.6E-07
Th-229	3.5E-06	7.5E-05	1.1E-05	5.0E-06	1.5E-05	4.9E-07	2.6E-08	7.9E-07	9.8E-09	3.5E-04	7.4E-03	3.0E-07	4.2E-07
Th-230	5.4E-07	1.3E-05	3.1E-06	1.3E-06	4.4E-06	4.3E-07	2.5E-08	3.3E-07	3.9E-07	5.3E-05	2.0E-03	1.4E-07	6.4E-08
Pa-231	1.1E-05	2.2E-04	3.2E-05	1.5E-05	5.1E-05	4.2E-07	6.6E-08	5.8E-07	3.2E-08	1.2E-04	4.1E-02	3.2E-07	1.3E-06
U-233	2.9E-07	5.8E-06	1.0E-06	3.9E-07	1.2E-06	2.0E-07	5.1E-07	2.2E-07	4.2E-07	2.9E-06	1.2E-04	6.5E-10	5.7E-09
U-234	2.8E-07	5.7E-06	1.0E-06	3.9E-07	1.2E-06	1.9E-07	5.0E-07	2.1E-07	4.1E-07	2.9E-06	1.0E-04	1.5E-11	4.8E-09
U-236	2.7E-07	5.4E-06	9.6E-07	3.7E-07	1.1E-06	1.8E-07	4.7E-07	2.0E-07	3.9E-07	2.7E-06	9.7E-05	8.3E-12	4.6E-09
U-238	2.6E-07	5.1E-06	9.7E-07	3.6E-07	1.1E-06	1.8E-07	4.5E-07	2.0E-07	3.7E-07	2.6E-06	9.7E-05	4.4E-09	4.4E-09
Np-237	5.2E-06	1.0E-04	1.5E-05	7.1E-06	2.1E-05	1.2E-05	2.9E-08	3.3E-08	1.5E-08	1.6E-04	3.1E-04	6.5E-09	3.7E-09
Pu-238	3.2E-06	6.1E-05	9.0E-06	3.9E-06	1.2E-05	7.0E-08	1.8E-08	4.2E-09	3.5E-08	9.5E-05	2.1E-03	1.0E-11	2.5E-08
Pu-239	3.6E-06	7.0E-05	1.0E-05	4.5E-06	1.4E-05	7.8E-08	2.0E-08	4.8E-09	3.9E-08	1.1E-04	5.6E-03	5.0E-11	6.8E-08
Pu-240	3.6E-06	7.0E-05	1.0E-05	4.5E-06	1.4E-05	7.8E-08	1.9E-08	4.8E-09	3.9E-08	1.1E-04	5.5E-03	2.5E-11	6.8E-08
Pu-242	3.3E-06	6.5E-05	9.2E-06	4.2E-06	1.3E-05	7.2E-08	1.8E-08	4.5E-09	3.7E-08	9.8E-05	5.4E-03	2.2E-11	6.5E-08
Am-241	3.6E-06	7.2E-05	1.0E-05	4.6E-06	1.5E-05	1.6E-07	3.0E-08	8.7E-09	2.0E-08	1.1E-04	5.0E-03	6.5E-09	6.1E-08
Am-243	3.6E-06	7.2E-05	1.1E-05	4.6E-06	1.5E-05	1.6E-07	3.1E-08	8.8E-09	2.0E-08	1.1E-04	6.8E-03	1.7E-07	8.1E-08

Source: Wu 2001 [DIRS 154894], Table 2.

NOTE: Units are rem/(pCi/L) per kg, L, or hr.

Table 13.3-2. Annual Pathway Exposure Levels for the Current Receptor and Alternative Receptors

Exposure Pathway	Annual Pathway Exposure Levels					
	Current Receptor [a]	U.S. Average Receptor [a]	NUREG/ CR-5512 Receptor [a]	Alternative Amargosa Valley Receptor 1 [a]	Alternative Amargosa Valley Receptor 2 [a]	Alternative Amargosa Valley Receptor 3 [b]
Water (L/yr)	753	511	730	730	1118	730
Leafy vegetables (kg/yr)	15	28	11	24	11	4
Root/other vegetables (kg/yr)	8	85	51	21	8	5
Fruit (kg/yr)	16	89	46	53	24	13
Grain (kg/yr)	0	108	69	0	0	0
Meat (kg/yr)	3	29	59	18	8	3
Poultry (kg/yr)	1	16	9	3	0	0
Milk (L/yr)	4	131	100	30	38	5
Eggs (kg/yr)	7	8	10	25	11	6
Fish (Freshwater) (kg/yr)	0	2	10	2	2	0
Soil (kg/yr)	0.0183	0.0183	0.0183	0.0183	0.0183	0.0183
External Exposure (hr/yr)	3387	3387	3387	3387	3387	3387
Inhalation Exposure (hr/yr)	6074	6073.5	6074	6074	6074	6074

Sources: [a] Wu 2001 [DIRS 154894] Table 3.
[b] Wu 2001 [DIRS 155203] Table 1.

NOTE: Consumption rates were rounded to the nearest kilogram or liter.

Table 13.3-3. Average Annual Doses to the Current Receptor and to Alternative Receptors at 25,000 Years Postclosure

Exposure Pathway	Total Annual Dose (rem)					
	Current Receptor [a]	U.S. Average Receptor [a]	NUREG/ CR-5512 Receptor [a]	Alternative Amargosa Valley Receptor 1 [a]	Alternative Amargosa Valley Receptor 2 [a]	Alternative Amargosa Valley Receptor 3 [b]
Water	7.4E-06	5.0E-06	7.2E-06	7.2E-06	1.1E-05	7.2E-06
Crop Ingestion	4.1E-06	1.8E-05	9.4E-06	7.2E-06	3.3E-06	1.3E-06
Animal Products Ingestion	1.4E-06	3.0E-05	2.5E-05	8.5E-06	9.0E-06	1.5E-06
Aquatic Food Ingestion	2.1E-06	9.0E-06	4.5E-05	6.8E-06	7.4E-06	1.2E-06
Total Ingestion	5.4E-06	4.8E-05	3.4E-05	1.6E-05	1.2E-05	2.8E-06
Inhalation	2.5E-08	2.5E-08	2.5E-08	2.5E-08	2.5E-08	2.5E-08
External Exposure	3.2E-09	3.2E-09	3.2E-09	3.2E-09	3.2E-09	3.2E-09
Total	1.5E-05	6.2E-05	8.7E-05	3.0E-05	3.1E-05	1.1E-05

Sources: [a] Wu 2001 [DIRS 154894], Table 4.
[b] Wu 2001 [DIRS 155203] Table 2.

Table 13.3-4. Average Annual Doses to the Current Receptor and to Alternative Receptors at 100,000 Years Postclosure

Exposure Pathway	Total Annual Dose (rem)					
	Current Receptor [a]	U.S. Average Receptor [a]	NUREG/ CR-5512 Receptor [a]	Alternative Amargosa Valley Receptor 1 [a]	Alternative Amargosa Valley Receptor 2 [a]	Alternative Amargosa Valley Receptor 3 [b]
Water	3.8E-02	2.6E-02	3.7E-02	3.7E-02	5.6E-02	3.7E-02
Crop Ingestion	1.8E-02	6.9E-02	3.6E-02	3.1E-02	1.4E-02	5.5E-03
Animal Products Ingestion	4.0E-04	6.3E-03	7.8E-03	2.5E-03	1.8E-03	4.1E-04
Aquatic Food Ingestion	7.3E-04	3.1E-03	1.5E-02	2.3E-03	2.5E-03	4.2E-04
Total Ingestion	1.8E-02	7.5E-02	4.4E-02	3.3E-02	1.6E-02	5.9E-03
Inhalation	2.1E-03	2.1E-03	2.1E-03	2.1E-03	2.1E-03	2.1E-03
External Exposure	3.8E-04	3.8E-04	3.8E-04	3.8E-04	3.8E-04	3.8E-04
Total	5.9E-02	1.1E-01	9.9E-02	7.5E-02	7.8E-02	4.6E-02

Sources: [a] Wu 2001 [DIRS 154894], Table 5.
[b] Wu 2001 [DIRS 155203] Table 3.

Table 13.3-5. Comparison of International Commission on Radiological Protection Tissue Weighting Factors

Tissue/Organ	Weighting Factor ICRP 26	Weighting Factor ICRP 60
Gonads	0.25	0.20
Bone marrow (red)	0.12	0.12
Colon	N/A	0.12
Lung	0.12	0.12
Stomach	N/A	0.12
Bladder	N/A	0.05
Breast	0.15	0.05
Liver	N/A	0.05
Esophagus	N/A	0.05
Thyroid	0.03	0.05
Skin	N/A	0.01
Bone Surface	0.03	0.01
Remainder	0.30	0.05

Sources: ICRP 1977 [DIRS 101075]; ICRP 1991 [DIRS 101836].

Table 13.3-6. Comparison of Biosphere Dose Conversion Factors for the Groundwater Release Scenario

Radionuclide	Previously Developed Mean BDCF	Modified Mean BDCF	BDCF Ratio
Carbon-14	5.2E-05	5.2E-05	1.0E+00
Nickel-63	7.2E-07	7.2E-07	1.0E+00
Strontium-90	1.6E-04	1.3E-04	8.5E-01
Technetium-99	3.3E-06	3.6E-06	1.1E+00
Iodine-129	3.1E-04	5.0E-04	1.6E+00
Cesium-137	1.3E-04	1.3E-04	1.0E+00
Lead-210	6.7E-03	3.1E-03	4.6E-01
Radium-226	1.1E-03	1.2E-03	1.1E+00
Actinium-227	1.5E-02	4.4E-03	2.9E-01
Thorium-229	4.0E-03	2.1E-03	5.1E-01
Thorium-230	6.1E-04	8.4E-04	1.4E+00
Protactinium-231	1.2E-02	2.8E-03	2.4E-01
Uranium-232	1.5E-03	1.4E-03	9.4E-01
Uranium-233	3.2E-04	2.1E-04	6.5E-01
Uranium-234	3.1E-04	2.0E-04	6.4E-01
Uranium-236	3.0E-04	1.9E-04	6.4E-01
Uranium-238	2.9E-04	1.8E-04	6.4E-01
Neptunium-237	5.8E-06	4.5E-07	7.8E-02
Plutonium-238	3.5E-03	9.2E-04	2.6E-01
Plutonium-239	3.9E-03	1.0E-03	2.6E-01
Plutonium-240	3.9E-03	1.0E-03	2.6E-01
Plutonium-242	3.6E-03	9.6E-04	2.7E-01
Americium-241	4.0E-03	8.1E-04	2.0E-01
Americium-243	4.0E-03	8.1E-04	2.0E-01

Source: Tappen 2001 [DIRS 154890], Table 1.

Table 13.3-7. Comparison of Biosphere Dose Conversion Factors for the Volcanic Eruption Scenario (Transition Phase, 1-cm Ash Layer, Annual Average Mass Loading)

Radionuclide	Previously Developed Mean BDCF	Modified Mean BDCF	BDCF Ratio
Strontium-90	9.0E-09	8.0E-09	8.8E-01
Cesium-137	1.9E-09	1.8E-09	9.5E-01
Lead-210	1.9E-08	1.5E-08	7.5E-01
Radium-226	5.9E-09	1.7E-08	2.9E+00
Actinium-227	2.3E-06	6.9E-07	3.1E-01
Thorium-229	7.2E-07	3.0E-07	4.1E-01
Thorium-230	1.1E-07	1.2E-07	1.2E+00
Protactinium-231	4.5E-07	1.8E-07	3.9E-01
Uranium-232	2.3E-07	4.8E-08	2.1E-01
Uranium-233	4.6E-08	1.2E-08	2.7E-01
Uranium-234	4.5E-08	1.2E-08	2.7E-01
Plutonium-238	1.4E-07	1.3E-07	9.7E-01
Plutonium-239	1.5E-07	1.5E-07	9.7E-01
Plutonium-240	1.5E-07	1.5E-07	9.7E-01
Plutonium-242	1.4E-07	1.4E-07	9.7E-01
Americium-241	1.5E-07	1.2E-07	7.8E-01
Americium-243	1.5E-07	1.2E-07	7.8E-01

Source: Tappen 2001 [DIRS 154890], Table 2.

Table 13.3-8. Parameters Used to Characterize the Leaching Process for Sandy Soils

Element	Parameter	Parameter value for a given K_d		
Technetium		K_d Value Used 0.1 L/kg	Lower K_d Limit 0.0037 L/kg	Upper K_d Limit 5 L/kg
	Leaching coefficient (1/yr)[a]	2.77E+00	4.57E+00	1.32E-01
	Characteristic removal time for leaching (yr)	3.67E-01	2.19E-01	7.58E+00
Iodine		K_d Value Used 1 L/kg	Lower K_d Limit 0.013 L/kg	Upper K_d Limit 85 L/kg
	Leaching coefficient (1/yr)[a]	5.92E-01	4.30E+00	7.96E-03
	Characteristic removal time for leaching (yr)	1.72E+00	2.33E-01	1.26E+02
Neptunium		K_d Value Used 5 L/kg	Lower K_d Limit 0.14 L/kg	Upper K_d Limit 120 L/kg
	Leaching coefficient (1/yr)[a]	1.32E-01	2.38E+00	5.64E-03
	Characteristic removal time for leaching (yr)	7.58E+00	4.20E-01	1.77E+02
Plutonium		K_d Value Used 550 L/kg	Lower K_d Limit 18 L/kg	Upper K_d Limit 16,000 L/kg
	Leaching coefficient (1/yr)[a]	1.23E-03	3.74E-02	4.24E-05
	Characteristic removal time for leaching (yr)	8.13E+02	2.67E+01	2.36E+04

Source: Wu 2001 [DIRS 154892], Table 2.

NOTE: [a] Calculated from Equation 13-2.

Table 13.3-9. Impact of Leaching Factor Changes on Biosphere Dose Conversion Factor Mean Values

Radionuclide	Leaching Coefficient 1/yr [a]	Mean BDCF rem/(pCi/L)[b]	Fractional Increase in BDCF [c]
Technetium-99	2.77	3.39E-6	4.9
	0.132	1.67E-5	
Iodine-129	0.592	3.1E-4	1.4
	0.00796	4.4E-4	
Neptunium-237	0.132	5.84E-3	1.3
	0.00564	7.84E-3	

Source: Wu 2001 [DIRS 154892].

NOTES: [a] Wu 2001 [DIRS 154892], Table 2.
[b] Wu 2001 [DIRS 154892], Tables 5, 6, and 7.
[c] Ratio of high to low Mean BDCF values.

Table 13.3-10. Pathway Contribution (Percent) to Biosphere Dose Conversion Factors

Pathway	Radionuclide			
	Technetium-99	Iodine-129	Neptunium-237	Plutonium-239
Drinking water	55.3	61.1	67.9	68.4
Leafy vegetables	27.9	23.6	26.2	26.3
Other vegetables	3.5	1.8	2.0	2.0
Other pathways	13.3	13.5	3.9	3.3

Source: CRWMS M&O 2001 [DIRS 152539], Table 15.

Table 13.3-11. Mean Biosphere Dose Conversion Factor Values (rem/(pCi/L))

Irrigation Period	BDCF Values	Radionuclide			
		Technetium-99	Iodine-129	Neptunium-237	Plutonium-239
Zero Irrigation	Nominal	3.34E-06	3.10E-04	5.76E-03	3.88E-03
	Minimum	2.75E-06	2.10E-04	4.12E-03	2.79E-03
	Maximum	4.63E-06	4.70E-04	8.01E-03	5.38E-03
Long Irrigation	Nominal	3.39E-06	3.11E-04	5.84E-03	5.78E-03
	Minimum	2.80E-06	2.40E-04	4.47E-03	3.94E-03
	Maximum	1.67E-05	4.70E-04	8.09E-03	7.28E-03

Source: Wu 2001 [DIRS 154892], Tables 5, 6, 7, and 8.

Table 13.3-12. Lower and Upper Limit of the Multiplying Factor to be Applied to Groundwater Release Biosphere Dose Conversion Factors to Reflect Additional Uncertainty in Input Parameter Uncertainty

Limit of Multiplying Factor	Radionuclide			
	Technetium-99	Iodine-129	Neptunium-237	Plutonium-239
Lower	0.81	0.68	0.71	0.48
Upper	4.93	1.52	1.39	1.26

Source: Calculated using values from Table 13.3-11.

Table 13.3-13. Parameters Forming a Basis for Alfalfa Irrigation for the Present and Future Climate

Parameter	Value Present Climate [a] (in/yr)	Value Future Climate [b] (in/yr)
Annual evapotranspiration	92.7	43.3
Precipitation during growing season	4.0	7.5
Deep percolation	6.0	6.0
Annual irrigation [c]	95	42

NOTES: [a] CRWMS M&O 2001 [DIRS 152539], Table III-1 and Section III.2.3.
[b] CRWMS M&O 2001 [DIRS 152539], Table III-6 and Section III.2.3.
[c] Annual irrigation was rounded to the nearest inch.

Table 13.3-14. Annual Average Meteorological Parameters for Potential Future Climate States at Yucca Mountain and the Analogue Sites for the Climate Change Analysis

Climate State	Representative Meteorological Stations	Max Temperature (°F)	Min Temperature (°F)	Snowfall (inches)	Precipitation (inches)
Monsoon Climate Average Upper Bound	Nogales 6N, Arizona Hobbs, New Mexico	79.4 76.5	42.7 47.8	0.45 5.18	17.55 16.44
Monsoon Climate Average Lower Bound	Yucca Mountain site and regional meteorological stations (e.g., Amargosa Farms)	81.9	48.3	0.10	4.48
Glacial Transition Climate Average Upper Bound	Spokane, Washington Rosalia, Washington St. John, Washington	58.1 58.1 60.9	38.1 36.1 35.8	42.14 24.34 25.78	16.15 18.10 17.06
Glacial Transition Climate Average Lower Bound	Beowawe, Nevada Delta, Utah	65.0 65.4	30.8 34.8	14.39 25.15	8.64 7.79
Modern Interglacial Climate	Yucca Mountain site and regional meteorological stations (e.g., Amargosa Farms)	81.9	48.3	0.10	4.48

Source: CRWMS M&O 2001 [DIRS 152539], Table 4.

Table 13.3-15. Comparison of the Biosphere Dose Conversion Factors (rem per pCi/L) and Buildup Factors for the Current and Evolved Climate[a]

Radionuclide	1st Irrigation Period			6th Irrigation Period			Buildup Factor[b]	
	BDCF for Current Climate	BDCF for Evolved Climate	Evolved/ Current BDCF Ratio	BDCF for Current Climate	BDCF for Evolved Climate	Evolved/ Current BDCF Ratio	Current Climate	Evolved Climate
C-14	5.19E-05	5.11E-05	0.99	5.19E-05	5.11E-05	0.99	1.00	1.00
Ni-63	7.22E-07	6.60E-07	0.91	1.16E-06	9.72E-07	0.84	1.61	1.47
Sr-90	1.55E-04	1.41E-04	0.91	2.57E-04	2.23E-04	0.87	1.66	1.58
Tc-99	3.34E-06	3.00E-06	0.90	3.39E-06	2.99E-06	0.88	1.01	1.00
I-129	3.10E-04	2.81E-04	0.91	3.11E-04	2.82E-04	0.91	1.00	1.00
Cs-137	1.26E-04	1.13E-04	0.90	4.54E-04	2.81E-04	0.62	3.60	2.49
Pb-210	6.67E-03	6.24E-03	0.94	6.86E-03	6.38E-03	0.93	1.03	1.02
Ra-226	1.10E-03	1.01E-03	0.92	1.81E-02	1.08E-02	0.60	16.5	10.7
Ac-227	1.54E-02	1.43E-02	0.93	1.64E-02	1.49E-02	0.91	1.06	1.04
Th-229	4.01E-03	3.74E-03	0.93	4.91E-02	2.71E-02	0.55	12.2	7.25
Th-230	6.05E-04	5.66E-04	0.94	3.97E-02	2.25E-02	0.57	65.6	39.8
Pa-231	1.15E-02	1.07E-02	0.93	4.55E-02	2.84E-02	0.62	3.96	2.65
U-232	1.45E-03	1.34E-03	0.92	2.34E-03	1.80E-03	0.77	1.61	1.34
U-233	3.19E-04	2.96E-04	0.93	3.62E-04	3.19E-04	0.88	1.13	1.08
U-234	3.13E-04	2.90E-04	0.93	3.52E-04	3.12E-04	0.89	1.12	1.08
U-236	2.97E-04	2.75E-04	0.93	3.33E-04	2.95E-04	0.89	1.12	1.07
U-238	2.86E-04	2.65E-04	0.93	3.36E-04	2.92E-04	0.87	1.17	1.10
Np-237	5.76E-03	5.37E-03	0.93	5.84E-03	5.42E-03	0.93	1.01	1.01
Pu-238	3.50E-03	3.27E-03	0.93	3.73E-03	3.38E-03	0.91	1.07	1.03
Pu-239	3.88E-03	3.63E-03	0.94	5.78E-03	4.59E-03	0.79	1.49	1.26
Pu-240	3.88E-03	3.62E-03	0.93	5.66E-03	4.53E-03	0.80	1.46	1.25
Pu-242	3.61E-03	3.37E-03	0.93	5.41E-03	4.29E-03	0.79	1.50	1.27
Am-241	3.96E-03	3.69E-03	0.93	5.28E-03	4.39E-03	0.83	1.33	1.19
Am-243	3.95E-03	3.69E-03	0.93	1.44E-02	9.05E-03	0.63	3.65	2.45

NOTES: [a] CRWMS M&O 2001 [DIRS 152539], Tables 9, 12, and 14.
[b] Ratio of mean BDCF for 6th irrigation period to mean BDCF for 1st (no prior irrigation) period.

Table 13.3-16. Recommended Transfer Parameter Values for Selenium

Soil-to-Plant Transfer Factors				Animal Feed Transfer Coefficients				Bioaccumulation Factor for Fish (L/kg)
Leafy Vegetables	Root Vegetables	Fruit	Grain	Beef (d/kg)	Poultry (d/kg)	Milk (d/L)	Eggs (d/kg)	
2.5E-02	2.5E-02	2.5E-02	2.5E-02	1.5E-02	9.0E+00	4.0E-03	9.3E+00	1.7E+02

Source: Wu 2001 [DIRS 154893], Table 10.

Table 13.3-17. Removal Constants and Prior Irrigation Time Periods for Selenium-79

Removal constant, 1/y			Prior Irrigation Periods, y[a]					
Radioactive Decay[b]	Leaching[c]	Effective[d]	1	2	3	4	5	6
1.07E-05	1.23E-2	1.23E-02	0	15	33	56	89	146

Source: Wu 2001 [DIRS 154893], Table 11.

NOTES: [a] Prior irrigation periods were calculated using CRWMS M&O 2001 [DIRS 152539], Equation 2.

[b] Rittmann 1993 [DIRS 107744], p. 2-5; removal constant for radioactive decay = (ln 2)/(half-life).

[c] CRWMS M&O 2001 [DIRS 152517], Section 6.2.

[d] Effective removal constant = sum of radioactive decay and leaching removal constants.

Table 13.3-18. Dose Coefficients for Exposure to Soil Contaminated with Selenium-79

Contamination Depth	Dose Coefficient	
	Sv/s per Bq/m^3 [a]	Sv/y per Bq/m^3 [b]
15 cm	9.96E-23	3.14E-15
1 cm	5.77E-23	1.82E-15

NOTES: [a] Source: Wu 2001 [DIRS 154893], Table 12.

[b] (Sv/s per Bq/m^3) $\times$ (3.15×10^7 s/y) = Sv/y per Bq/m^3.

Table 13.3-19. Selenium-79 Biosphere Dose Conversion Factors for the Three Volcanic Eruption Exposure Scenarios

	Dose Factor for Eruption Phase (rem/(pCi/m^3))	BDCFs for Transition Phase (rem/(pCi/m^2))				BDCFs for Steady-State Phase (rem/(pCi/m^2))
		1-cm Ash Layer, Annual Average Mass Loading	1-cm Ash Layer, 10-year Average Mass Loading	15-cm Ash Layer, Annual Average Mass Loading	15-cm Ash Layer, 10-year Average Mass Loading	
Mean	1.56E-07	4.93E-11	4.37E-11	3.10E-11	3.07E-11	3.05E-11
STD	---	5.97E-11	5.78E-11	5.67E-11	5.67E-11	5.67E-11
Min.	---	1.15E-11	1.12E-11	8.78E-13	8.56E-13	8.20E-13
5%	---	1.25E-11	1.19E-11	1.54E-12	1.39E-12	1.34E-12
10%	---	1.54E-11	1.37E-11	2.16E-12	1.99E-12	1.91E-12
15%	---	1.72E-11	1.50E-11	3.23E-12	2.89E-12	2.77E-12
20%	---	1.92E-11	1.66E-11	4.86E-12	4.59E-12	4.47E-12
25%	---	2.09E-11	1.78E-11	6.29E-12	5.94E-12	5.66E-12
30%	---	2.18E-11	1.97E-11	7.52E-12	7.19E-12	7.08E-12
35%	---	2.51E-11	2.08E-11	8.47E-12	7.95E-12	7.90E-12
40%	---	2.62E-11	2.16E-11	9.10E-12	8.69E-12	8.52E-12
45%	---	2.81E-11	2.29E-11	1.11E-11	1.03E-11	1.01E-11
50%	---	3.04E-11	2.55E-11	1.24E-11	1.18E-11	1.14E-11
55%	---	3.35E-11	2.94E-11	1.49E-11	1.46E-11	1.44E-11
60%	---	3.70E-11	3.07E-11	1.82E-11	1.80E-11	1.77E-11
65%	---	4.29E-11	3.44E-11	2.07E-11	2.03E-11	2.03E-11
70%	---	4.78E-11	3.99E-11	2.69E-11	2.68E-11	2.67E-11
75%	---	5.24E-11	4.76E-11	3.59E-11	3.58E-11	3.57E-11
80%	---	6.37E-11	5.69E-11	4.34E-11	4.30E-11	4.29E-11
85%	---	7.43E-11	7.16E-11	5.77E-11	5.75E-11	5.74E-11
90%	---	1.31E-10	1.18E-10	1.05E-10	1.04E-10	1.04E-10
95%	---	2.41E-10	2.38E-10	2.24E-10	2.24E-10	2.24E-10
Max.	---	5.26E-10	5.16E-10	4.96E-10	4.96E-10	4.96E-10

Source: Wu 2001 [DIRS 154893], Table 14.

Table 13.3-20. Neptunium-237 Biosphere Dose Conversion Factors for the Three Volcanic Eruption Exposure Scenarios

	Dose Factor for Eruption Phase (rem/(pCi/m^3))	BDCFs for Transition Phase (rem/(pCi/m^2))				BDCFs for Steady-State Phase (rem/(pCi/m^2))
		1-cm Ash Layer, Annual Average Mass Loading	1-cm Ash Layer, 10-year Average Mass Loading	15-cm Ash Layer, Annual Average Mass Loading	15-cm Ash Layer, 10-year Average Mass Loading	
Mean	8.61E-03	2.28E-07	1.03E-07	2.16E-08	1.32E-08	9.01E-09
STD	---	1.91E-07	5.33E-08	1.83E-08	1.44E-08	1.42E-08
Min.	---	3.50E-08	3.44E-08	2.75E-09	2.61E-09	1.77E-09
5%	---	3.76E-08	3.60E-08	3.15E-09	2.86E-09	2.07E-09
10%	---	4.45E-08	3.97E-08	4.38E-09	3.78E-09	2.53E-09
15%	---	5.42E-08	4.53E-08	5.21E-09	4.52E-09	2.73E-09
20%	---	6.19E-08	4.88E-08	6.58E-09	5.12E-09	2.95E-09
25%	---	7.34E-08	5.65E-08	7.98E-09	6.10E-09	3.22E-09
30%	---	8.13E-08	6.05E-08	9.55E-09	7.08E-09	3.53E-09
35%	---	1.04E-07	6.78E-08	1.10E-08	7.68E-09	3.85E-09
40%	---	1.12E-07	7.43E-08	1.23E-08	8.01E-09	4.14E-09
45%	---	1.31E-07	8.01E-08	1.43E-08	8.73E-09	4.48E-09
50%	---	1.58E-07	8.97E-08	1.58E-08	9.74E-09	4.94E-09
55%	---	1.88E-07	1.00E-07	1.94E-08	1.09E-08	5.35E-09
60%	---	2.21E-07	1.15E-07	2.09E-08	1.22E-08	5.81E-09
65%	---	2.57E-07	1.27E-07	2.53E-08	1.31E-08	6.34E-09
70%	---	3.00E-07	1.33E-07	2.85E-08	1.41E-08	7.58E-09
75%	---	3.59E-07	1.50E-07	3.13E-08	1.54E-08	8.87E-09
80%	---	4.15E-07	1.60E-07	3.59E-08	1.66E-08	1.13E-08
85%	---	5.02E-07	1.78E-07	4.28E-08	1.83E-08	1.28E-08
90%	---	5.95E-07	2.00E-07	5.03E-08	2.80E-08	2.19E-08
95%	---	7.12E-07	2.14E-07	6.20E-08	5.79E-08	5.48E-08
Max.	---	7.85E-07	2.22E-07	1.15E-07	1.13E-07	1.11E-07

Source: Wu 2001 [DIRS 154893], Table 15.

Table 13.3-21. Biosphere Dose Conversion Factors for Selenium-79, Groundwater Release Scenario, for the Current Climate and the Evolved Climate

Irrigation Period	BDCFs for the Current Climate (rem/(pCi/L))		BDCFs for the Evolved Climate (rem/(pCi/L))	
	Mean	STD	Mean	STD
1	1.18E-5	6.64E-6	1.05E-5	5.78E-6
2	1.24E-5	6.90E-6	1.08E-5	5.86E-5
3	1.31E-5	7.33E-6	1.12E-5	6.00E-6
4	1.37E-5	7.85E-6	1.16E-5	6.20E-6
5	1.43E-5	8.52E-6	1.20E-5	6.44E-6
6	1.50E-5	9.23E-6	1.24E-5	6.77E-6

Source: Wu 2001 [DIRS 154893], Table 13.

Table 13.3-22. Biosphere Dose Conversion Factors for Selenium-79, Groundwater Release Scenario, for the Current Climate

Irrigation Period	1	2	3	4	5	6
Time (yr)	0	15	33	56	89	146
Percentile	**Biosphere Dose Conversion Factor (rem/(pCi/L))**					
0%	1.84E-06	2.03E-06	2.03E-06	2.21E-06	2.24E-06	2.27E-06
5%	3.78E-06	3.92E-06	3.92E-06	4.14E-06	4.24E-06	4.40E-06
10%	4.63E-06	4.89E-06	4.89E-06	5.34E-06	5.47E-06	5.71E-06
15%	5.14E-06	5.71E-06	5.71E-06	6.22E-06	6.48E-06	6.88E-06
20%	6.20E-06	6.58E-06	6.58E-06	7.19E-06	7.37E-06	7.47E-06
25%	6.97E-06	7.63E-06	7.63E-06	8.36E-06	8.42E-06	8.76E-06
30%	7.77E-06	8.35E-06	8.35E-06	9.30E-06	9.53E-06	9.87E-06
35%	8.48E-06	9.12E-06	9.12E-06	1.03E-05	1.07E-05	1.12E-05
40%	9.54E-06	1.01E-05	1.01E-05	1.12E-05	1.18E-05	1.21E-05
45%	1.02E-05	1.10E-05	1.10E-05	1.18E-05	1.22E-05	1.24E-05
50%	1.10E-05	1.14E-05	1.14E-05	1.20E-05	1.26E-05	1.28E-05
55%	1.16E-05	1.19E-05	1.19E-05	1.28E-05	1.33E-05	1.39E-05
60%	1.23E-05	1.27E-05	1.27E-05	1.35E-05	1.43E-05	1.50E-05
65%	1.34E-05	1.42E-05	1.42E-05	1.49E-05	1.50E-05	1.56E-05
70%	1.42E-05	1.48E-05	1.48E-05	1.57E-05	1.62E-05	1.64E-05
75%	1.47E-05	1.54E-05	1.54E-05	1.64E-05	1.69E-05	1.75E-05
80%	1.54E-05	1.62E-05	1.62E-05	1.92E-05	1.98E-05	2.01E-05
85%	1.63E-05	1.82E-05	1.82E-05	2.15E-05	2.19E-05	2.29E-05
90%	1.96E-05	2.09E-05	2.09E-05	2.32E-05	2.49E-05	2.59E-05
95%	2.38E-05	2.41E-05	2.41E-05	2.93E-05	3.14E-05	3.36E-05
100%	3.76E-05	4.27E-05	4.27E-05	5.37E-05	5.96E-05	6.47E-05

Source: Results from GENII-S statistical runs documented in files listed in Attachment I.1 of Wu 2001 [DIRS 154893].

Table 13.4-1. Summary of the Biosphere Dose Conversion Factors for the Groundwater Release Scenario for the Current Climate and the Corresponding Buildup Factors

Radionuclide	BDCF, 1st Irrigation period (rem/(pCi/L))		BDCF, 6th Irrigation Period (rem/(pCi/L))			Buildup Factor [a]
	Mean	Standard Deviation	Duration of Irrigation Period, yr	Mean	Standard Deviation	
Carbon-14	5.19E-5	1.40E-4	14	5.19E-5	1.40E-4	1.00
Nickel-63	7.22E-7	4.20E-7	208	1.16E-6	1.04E-6	1.61
Strontium-90	1.55E-4	8.21E-5	26	2.57E-4	2.57E-4	1.66
Technetium-99	3.34E-6	2.26E-6	5	3.39E-6	2.34E-6	1.01
Iodine-129	3.10E-4	1.62E-4	5	3.11E-4	1.62E-4	1.00
Cesium-137	1.26E-4	1.47E-4	71	4.54E-4	1.72E-4	3.60
Lead-210	6.67E-3	4.02E-3	53	6.86E-3	4.08E-3	1.03
Radium-226	1.10E-3	5.61E-4	1005	1.81E-2	8.36E-3	16.5
Actinium-227	1.54E-2	8.07E-3	54	1.64E-2	8.09E-3	1.06
Thorium-229	4.01E-3	2.14E-3	5848	4.91E-2	1.13E-2	12.2

Table 13.4-1. Summary of the Biosphere Dose Conversion Factors for the Groundwater Release Scenario for the Current Climate and the Corresponding Buildup Factors (Continued)

Radionuclide	BDCF, 1st Irrigation period (rem/(pCi/L))		BDCF, 6th Irrigation Period (rem/(pCi/L))			Buildup Factor [a]
	Mean	Standard Deviation	Duration of Irrigation Period, yr	Mean	Standard Deviation	
Thorium-230	6.05E-4	3.23E-4	8108	3.97E-2	1.64E-2	65.6
Protactinium-231	1.15E-2	6.05E-3	1432	4.55E-2	1.10E-2	3.96
Uranium-232	1.45E-3	7.49E-4	62	2.34E-3	7.87E-4	1.61
Uranium-233	3.19E-4	1.66E-4	93	3.62E-4	1.68E-4	1.13
Uranium-234	3.13E-4	1.63E-4	93	3.52E-4	1.65E-4	1.12
Uranium-236	2.97E-4	1.54E-4	93	3.33E-4	1.56E-4	1.12
Uranium-238	2.86E-4	1.49E-4	93	3.36E-4	1.51E-4	1.17
Neptunium-237	5.76E-3	3.02E-3	14	5.84E-3	3.04E-3	1.01
Plutonium-238	3.50E-3	1.84E-3	196	3.73E-3	1.84E-3	1.07
Plutonium-239	3.88E-3	2.04E-3	1423	5.78E-3	2.14E-3	1.49
Plutonium-240	3.88E-3	2.04E-3	1341	5.66E-3	2.12E-3	1.46
Plutonium-242	3.61E-3	1.90E-3	1455	5.41E-3	1.99E-3	1.50
Americium-241	3.96E-3	2.08E-3	915	5.28E-3	2.16E-3	1.33
Americium-243	3.95E-3	2.08E-3	3983	1.44E-2	3.19E-3	3.65

Source: CRWMS M&O 2001 [DIRS 152539], Table 9.

NOTE: [a] Ratio of mean BDCF for 6th irrigation period to mean BDCF for 1st (no prior irrigation) period.

Table 13.4-2. The Biosphere Dose Conversion Factor Distribution for Carbon-14 Given as an Empirical Percentile Table

Percentile	BDCF (rem/(pCi/L))	Percentile	BDCF (rem/(pCi/L))
0%	6.73E-07	55%	5.14E-06
5%	1.58E-06	60%	5.66E-06
10%	2.14E-06	65%	6.03E-06
15%	2.49E-06	70%	7.40E-06
20%	2.89E-06	75%	1.14E-05
25%	3.22E-06	80%	2.56E-05
30%	3.53E-06	85%	5.47E-05
35%	3.83E-06	90%	1.30E-04
40%	4.30E-06	95%	3.36E-04
45%	4.60E-06	100%	8.12E-04
50%	4.93E-06	---	---

Source: CRWMS M&O 2001 [DIRS 153207], Table 10.

Table 13.4-3. Distributions and Parameters for Abstracted Biosphere Dose Conversion Factors for those Radionuclides Exhibiting Less than a 15 Percent Build-Up Due to Continuing Irrigation

Radionuclide	Distribution			
	Normal		Log-normal	
	Arithmetic Mean (rem/(pCi/L))	Arithmetic SD (rem/(pCi/L))	Geometric Mean (rem/(pCi/L))	Geometric SD (dimensionless)
Actinium-227	1.58E-02	8.34E-03	---	---
Iodine-129	3.03E-04	1.61E-04	---	---
Neptunium-237	5.68E-03	3.14E-03	---	---
Lead-210	---	---	5.84E-03	1.76E+00
Plutonium-238	3.59E-03	1.90E-03	---	---
Technetium-99	---	---	2.84E-06	1.84E+00
Uranium-233	3.53E-04	1.74E-04	---	---
Uranium-234	3.42E-04	1.70E-04	---	---
Uranium-236	3.25E-04	1.61E-04	---	---

Source: CRWMS M&O 2001 [DIRS 153207], Table 9.

NOTE: SD = Standard Deviation.

Table 13.4-4. Asymptotic Buildup Factors for Those Radionuclides Showing Significant Buildup Before and After the Inclusion of the Soil Erosion Mechanism

Radionuclide	Asymptotic Buildup Factor with Leaching No Erosion	Asymptotic Buildup Factors with One Dominant Removal Mechanism (Leaching or Erosion)
Americium-241	1.4	1.2
Americium-243	4.6	1.4
Cesium-137	5.9	5.6
Nickel-63	1.4	1.4
Protactinium-231	5.0	2.2
Plutonium-239	1.6	1.2
Plutonium-240	1.6	1.2
Plutonium-242	1.6	1.2
Radium-226	20.2	8.9
Strontium-90	1.5	1.5
Thorium-229	15.7	2.1
Thorium-230	NM (>60)	3.9
Uranium-232	3.2	3.2
Uranium-238	1.2	1.2

Source: CRWMS M&O 2001 [DIRS 153206], Table 7.

NOTES: NM = Not meaningful.

For thorium-230, the concentration increase of decay products into the soil did not permit the actual asymptotic value of buildup to be accurately determined. The buildup factor was, however, greater than 60. When erosion was considered with its characteristic removal time of 250 years, decay product in-growth was of no consequence.

Table 13.4-5. Recommended Biosphere Dose Conversion Factor Parameters for the Radionuclides Having a Normal Distribution for the Groundwater Release Scenario and the Current Climate

Radionuclide	Normal Distribution	
	Arithmetic Mean (rem/(pCi/L))	Arithmetic Standard Deviation (rem/(pCi/L))
Americium-241	4.40E-03	2.16E-03
Plutonium-239	4.47E-03	2.13E-03
Plutonium-240	4.45E-03	2.13E-03
Plutonium-242	4.16E-03	1.98E-03
Thorium-230	2.26E-03	6.37E-04
Uranium-232	4.63E-03	9.41E-04
Uranium-238	3.38E-04	1.56E-04

Source: CRWMS M&O 2001 [DIRS 153206], Table 8.

Table 13.4-6. Recommended Biosphere Dose Conversion Factor Parameters for the Radionuclides Having a Log-normal Distribution for the Groundwater Release Scenario and the Current Climate

Radionuclide	Log-normal Distribution	
	Geometric Mean (rem/(pCi/L))	Geometric Standard Deviation (dimensionless)
Americium-243	4.81E-03	1.59E+00
Radium-226	3.22E-02	7.87E-01
Strontium-90	2.27E-04	2.08E+00
Thorium-229	6.24E-03	1.54E+00

Source: CRWMS M&O 2001 [DIRS 153206], Table 9.

Table 13.4-7. Recommended Biosphere Dose Conversion Factor Parameters for the Radionuclides Having a Shifted Log-normal Distribution for the Groundwater Release Scenario and the Current Climate

Radionuclide	Shifted Log-normal Distribution		
	Geometric Mean (rem/(pCi/L))	Geometric Standard Deviation (dimensionless)	Shift (rem/(pCi/L))
Cesium-137	1.39E-04	1.53E+00	3.32E-04
Nickel-63	2.57E-06	1.18E+00	-1.21E-06
Protactinium-231	5.30E-02	1.14E+00	-3.02E-02

Source: CRWMS M&O 2001 [DIRS 153206], Table 9.

Table 13.4-8. Summary of Biosphere Dose Conversion Factors for the Groundwater Release Scenario for the Evolved Climate and their Corresponding Buildup Factors

Radionuclide	BDCF, 1st Irrigation Period (rem/(pCi/L))		BDCF, 6th Irrigation Period (rem/(pCi/L))			Buildup Factor [a]
	Mean	Standard Deviation	Time, y	Mean	Standard Deviation	
^{14}C	5.11E-5	1.41E-4	14	5.11E-5	1.41E-4	1.00
^{63}Ni	6.60E-7	3.67E-7	208	9.72E-7	7.63E-7	1.47
^{90}Sr	1.41E-4	7.36E-5	26	2.23E-4	2.15E-4	1.58
^{99}Tc	3.00E-6	1.89E-6	5	2.99E-6	1.95E-6	1.00
^{129}I	2.81E-4	1.46E-4	5	2.82E-4	1.46E-4	1.00
^{137}Cs	1.13E-4	1.43E-4	71	2.81E-4	1.52E-4	2.49
^{210}Pb	6.24E-3	3.84E-3	53	6.38E-3	3.87E-3	1.02
^{226}Ra	1.01E-3	5.23E-4	1005	1.08E-2	6.88E-3	10.7
^{227}Ac	1.43E-2	7.55E-3	54	1.49E-2	7.56E-3	1.04
^{229}Th	3.74E-3	2.01E-3	5848	2.71E-2	6.57E-3	7.25
^{230}Th	5.66E-4	3.03E-4	8108	2.25E-2	1.35E-2	39.8
^{231}Pa	1.07E-2	5.66E-3	1432	2.84E-2	7.69E-3	2.65
^{232}U	1.34E-3	6.99E-4	62	1.80E-3	7.11E-4	1.34
^{233}U	2.96E-4	1.55E-4	93	3.19E-4	1.55E-4	1.08
^{234}U	2.90E-4	1.52E-4	93	3.12E-4	1.52E-4	1.08
^{236}U	2.75E-4	1.44E-4	93	2.95E-4	1.44E-4	1.07
^{238}U	2.65E-4	1.39E-4	93	2.92E-4	1.39E-4	1.10
^{237}Np	5.37E-3	2.82E-3	14	5.42E-3	2.82E-3	1.01
^{238}Pu	3.27E-3	1.72E-3	196	3.38E-3	1.72E-3	1.03
^{239}Pu	3.63E-3	1.91E-3	1423	4.59E-3	1.94E-3	1.26
^{240}Pu	3.62E-3	1.91E-3	1341	4.53E-3	1.93E-3	1.25
^{242}Pu	3.37E-3	1.78E-3	1455	4.29E-3	1.80E-3	1.27
^{241}Am	3.69E-3	1.95E-3	915	4.39E-3	1.98E-3	1.19
^{243}Am	3.69E-3	1.94E-3	3983	9.05E-3	2.38E-3	2.45

Source: CRWMS M&O 2001 [DIRS 152539], Table 12.

NOTE: [a] Ratio of mean BDCF for 6th irrigation period to mean BDCF for 1st (no prior irrigation) period.

Table 13.4-9. Dose Factors for the Eruption Phase

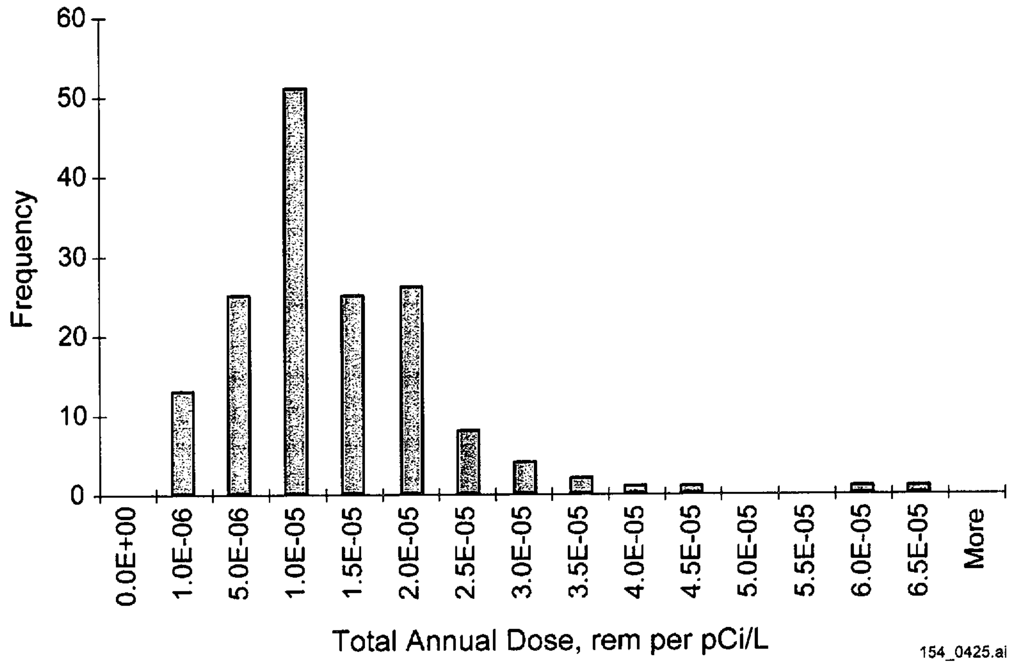
Radionuclide	Dose Factors rem-m^3/pCi
Strontium-90	3.82E-06
Cesium-137	5.09E-07
Lead-210	2.17E-04
Radium-226	1.37E-04
Actinium-227	1.07E-01
Thorium-229	3.42E-02
Thorium-230	5.19E-03
Protactinium-231	2.05E-02
Uranium-232	1.05E-02
Uranium-233	2.16E-03
Uranium-234	2.11E-03
Plutonium-238	6.25E-03
Plutonium-239	6.84E-03
Plutonium-240	6.84E-03
Plutonium-242	6.55E-03
Americium-241	7.08E-03
Americium-243	7.02E-03

Source: CRWMS M&O 2001 [DIRS 152536], Table 5.

Table 13.4-10. Volcanic Eruption Biosphere Dose Conversion Factors (rem/(pCi/m^2))

	90Sr	137Cs	210Pb	226Ra	227Ac	229Th	230Th	231Pa	232U	233U	234U	238Pu	239Pu	240Pu	242Pu	241Am	243Am
Transition Phase, 1-cm Ash Layer, Annual Average Mass Loading																	
Mean	9.01E-09	1.86E-09	1.93E-08	5.86E-09	2.27E-06	7.20E-07	1.08E-07	4.50E-07	2.27E-07	4.58E-08	4.51E-08	1.36E-07	1.51E-07	1.51E-07	1.41E-07	1.54E-07	1.54E-07
STD	2.03E-08	2.43E-09	1.28E-08	3.92E-09	2.02E-06	6.42E-07	9.65E-08	3.89E-07	2.02E-07	4.06E-08	4.00E-08	1.18E-07	1.31E-07	1.31E-07	1.22E-07	1.33E-07	1.33E-07
Min.	2.30E-10	1.01E-09	7.73E-09	1.67E-09	3.00E-07	9.43E-08	1.42E-08	6.79E-08	3.06E-08	6.21E-09	6.11E-09	2.06E-08	2.28E-08	2.28E-08	2.12E-08	2.33E-08	2.33E-08
Max.	1.85E-07	2.79E-08	9.55E-08	2.31E-08	8.10E-06	2.57E-06	3.87E-07	1.59E-06	8.09E-07	1.63E-07	1.61E-07	4.81E-07	5.34E-07	5.33E-07	4.97E-07	5.44E-07	5.43E-07
Transition Phase, 1-cm Ash Layer, 10-year Average Mass Loading																	
Mean	8.92E-09	1.82E-09	1.52E-08	4.01E-09	9.57E-07	3.03E-07	4.56E-08	1.95E-07	9.61E-08	1.94E-08	1.91E-08	5.92E-08	6.56E-08	6.55E-08	6.11E-08	6.70E-08	6.69E-08
STD	2.03E-08	2.39E-09	1.17E-08	3.13E-09	5.53E-07	1.76E-07	2.64E-08	1.06E-07	5.52E-08	1.11E-08	1.10E-08	3.23E-08	3.58E-08	3.58E-08	3.34E-08	3.65E-08	3.64E-08
Min.	2.24E-10	1.01E-09	7.53E-09	1.62E-09	3.00E-07	9.43E-08	1.41E-08	6.77E-08	3.02E-08	6.13E-09	6.03E-09	2.05E-08	2.27E-08	2.27E-08	2.12E-08	2.32E-08	2.32E-08
Max.	1.85E-07	2.75E-08	9.21E-08	2.17E-08	2.24E-06	7.12E-07	1.07E-07	4.47E-07	2.24E-07	4.52E-08	4.45E-08	1.36E-07	1.50E-07	1.50E-07	1.40E-07	1.53E-07	1.53E-07
Transition Phase, 15-cm Ash Layer, Annual Average Mass Loading																	
Mean	8.71E-09	5.81E-09	6.71E-09	1.86E-09	1.52E-07	4.87E-08	7.24E-09	3.07E-08	1.57E-08	3.19E-09	3.13E-09	9.13E-09	1.01E-08	1.01E-08	9.43E-09	1.05E-08	1.06E-08
STD	2.02E-08	2.45E-09	1.13E-08	3.06E-09	1.34E-07	4.26E-08	6.40E-09	2.57E-08	1.33E-08	2.69E-09	2.65E-09	7.82E-09	8.67E-09	8.66E-09	8.08E-09	8.82E-09	8.80E-09
Min.	7.17E-11	4.33E-09	5.77E-10	1.85E-10	2.03E-08	6.86E-09	9.55E-10	4.94E-09	2.09E-09	4.25E-10	4.17E-10	1.40E-09	1.55E-09	1.55E-09	1.45E-09	1.67E-09	1.80E-09
Max.	1.83E-07	3.17E-08	8.23E-08	1.98E-08	5.20E-07	1.66E-07	2.48E-08	1.02E-07	5.20E-08	1.05E-08	1.03E-08	3.09E-08	3.43E-08	3.42E-08	3.19E-08	3.50E-08	3.51E-08
Transition Phase, 15-cm Ash Layer, 10-year Average Mass Loading																	
Mean	8.70E-09	5.81E-09	6.44E-09	1.74E-09	6.44E-08	2.09E-08	3.06E-09	1.37E-08	6.97E-09	1.42E-09	1.40E-09	3.98E-09	4.41E-09	4.40E-09	4.11E-09	4.68E-09	4.83E-09
STD	2.02E-08	2.45E-09	1.13E-08	3.06E-09	3.66E-08	1.17E-08	1.75E-09	7.07E-09	3.81E-09	7.75E-10	7.63E-10	2.14E-09	2.37E-09	2.37E-09	2.21E-09	2.42E-09	2.42E-09
Min.	7.17E-11	4.33E-09	5.63E-10	1.80E-10	2.00E-08	6.76E-09	9.48E-10	4.81E-09	2.02E-09	4.12E-10	4.04E-10	1.37E-09	1.52E-09	1.51E-09	1.41E-09	1.62E-09	1.76E-09
Max.	1.83E-07	3.17E-08	8.23E-08	1.98E-08	1.50E-07	4.80E-08	7.13E-09	3.01E-08	1.52E-08	3.12E-09	3.06E-09	9.04E-09	1.00E-08	1.00E-08	9.34E-09	1.03E-08	1.05E-08
Steady-State Phase																	
Mean	8.70E-09	5.81E-09	6.30E-09	1.68E-09	2.03E-08	6.84E-09	9.53E-10	5.18E-09	2.56E-09	5.33E-10	5.23E-10	1.38E-09	1.53E-09	1.53E-09	1.42E-09	1.75E-09	1.90E-09
STD	2.02E-08	2.45E-09	1.13E-08	3.06E-09	4.05E-09	1.25E-09	1.88E-10	1.17E-09	1.35E-09	2.97E-10	2.91E-10	2.35E-10	2.60E-10	2.60E-10	2.43E-10	4.02E-10	4.02E-10
Min.	7.02E-11	4.33E-09	5.28E-10	1.67E-10	1.09E-08	3.86E-09	5.04E-10	3.15E-09	1.21E-09	2.49E-10	2.44E-10	8.40E-10	9.32E-10	9.31E-10	8.68E-10	1.07E-09	1.23E-09
Max.	1.83E-07	3.17E-08	8.22E-08	1.98E-08	3.02E-08	1.01E-08	1.43E-09	1.10E-08	1.24E-08	2.70E-09	2.65E-09	1.98E-09	2.20E-09	2.19E-09	2.04E-09	3.98E-09	4.15E-09

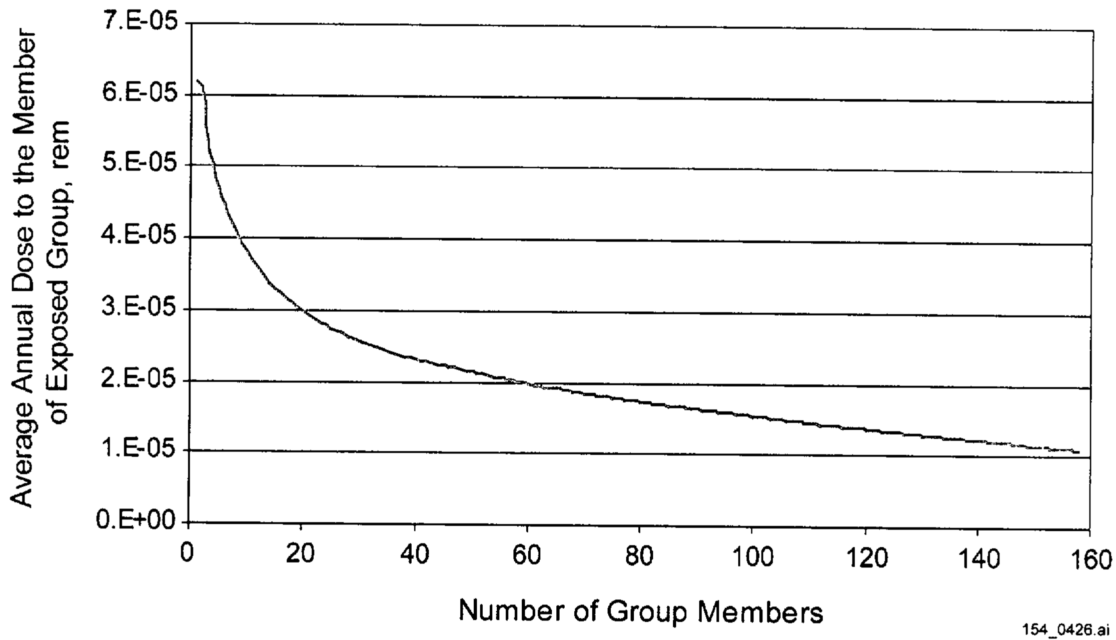
Source: CRWMS M&O 2001 [DIRS 152536], Tables 11 to 15.



154_0425.ai

Source: Wu 2001 [DIRS 154894], Figure 1.

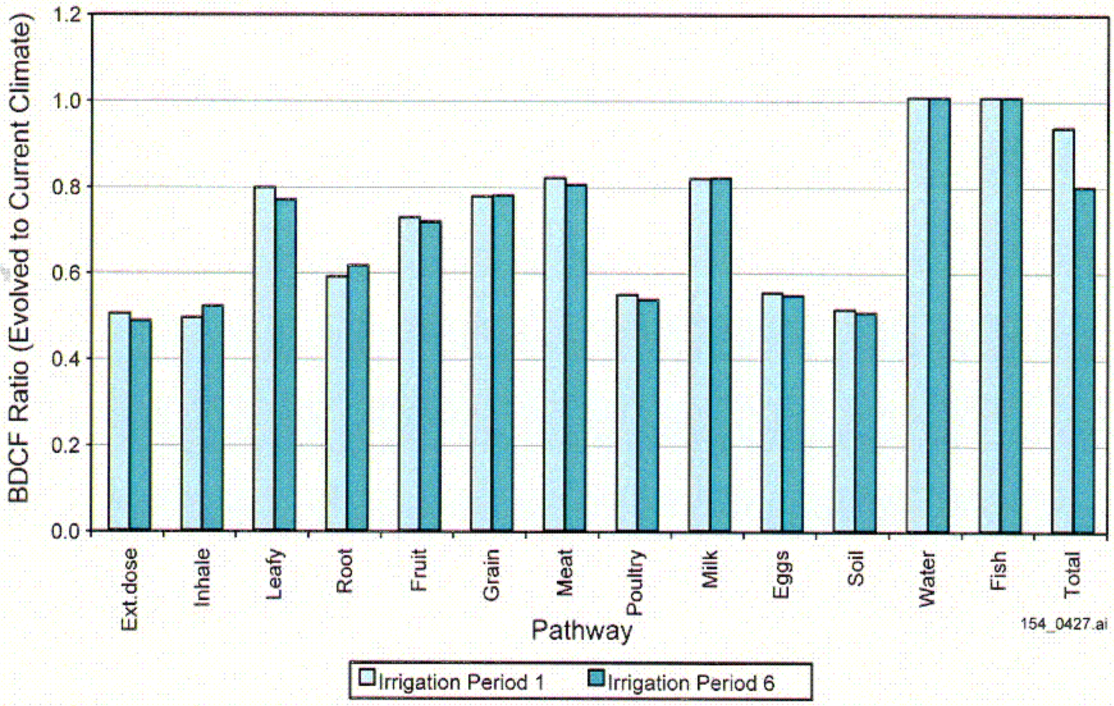
Figure 13.3-1. Distribution of Annual Doses at 25,000 years for a Hypothetical Group of Farmers Based on Amargosa Valley Population



154_0426.ai

Source: Wu 2001 [DIRS 154894], Figure 2.

Figure 13.3-2. Dependence of the Average Annual Dose to the Members of the Exposed Group at 25,000 years on the Group Size

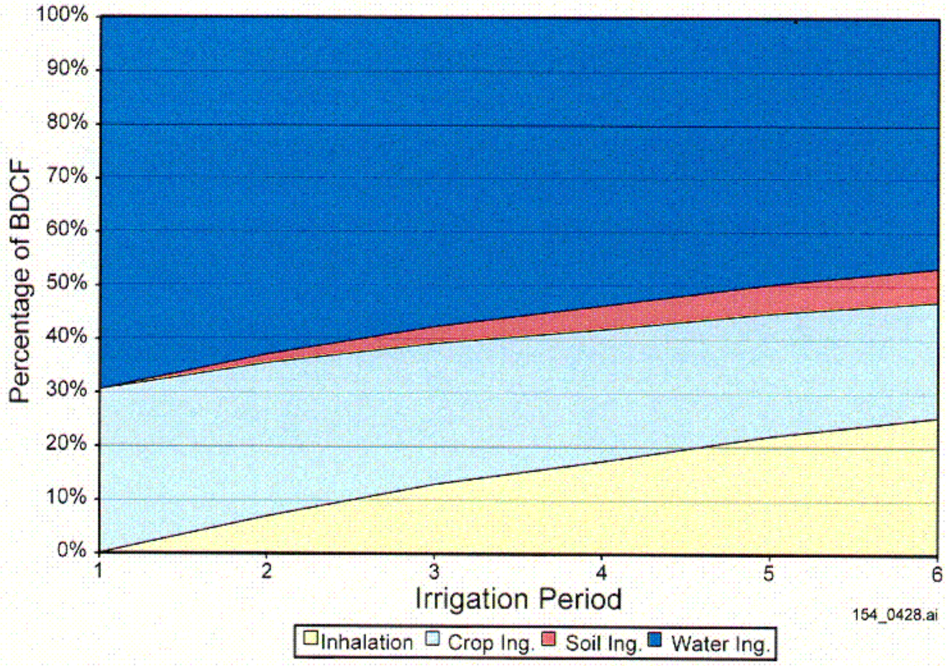


154_0427.ai

Source: CRWMS M&O 2000 [DIRS 152539], Figure 11.

Figure 13.3-3. Pathway Biosphere Dose Conversion Factor Ratios for Plutonium-239 for Groundwater Release of Evolved and Current Climates

C01



154_0428.ai

Source: CRWMS M&O 2001 [DIRS 152539], Figure 7.

Figure 13.4-1. Contributions of Major Exposure Pathways to Biosphere Dose Conversion Factors for Plutonium-239 for Groundwater Release at Different Irrigation Periods

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14. VOLCANIC AND SEISMIC DISRUPTIVE EVENTS

The *Yucca Mountain Science and Engineering Report* (S&ER) identifies disruptive conditions that were considered in evaluating the performance of a potential repository at Yucca Mountain (DOE 2001 [DIRS 153849], Section 4.3.2). These conditions (e.g., igneous activity, seismic activity, and human intrusion) are extremely unlikely to occur, but could, if they were to happen, significantly reduce the capability of a repository to isolate waste. In addition, a fourth disruptive condition, nuclear criticality, was considered but determined not to have a significant impact on repository performance (DOE 2001 [DIRS 153849], Section 4.3.3.2).

This section supplements the information on disruptive events presented in the S&ER for the conditions of igneous activity and seismic activity. It presents a discussion of how uncertainties were addressed for disruptive events and the impacts of considering a range of thermal operating modes. It describes new data and provides additional lines of evidence that increase confidence in existing analyses.

14.1 INTRODUCTION

Proposed 10 CFR 963.17(b) (64 FR 67054 [DIRS 124754]) identifies four disruptive processes and events for consideration in evaluating the total system performance of a geologic repository at Yucca Mountain: (1) volcanism, (2) seismic events, (3) nuclear criticality, and (4) inadvertent human intrusion. This section addresses the first two of these. A qualitative discussion of criticality is found in the *Total System Performance Assessment for the Site Recommendation* (TSPA-SR) (CRWMS M&O 2000 [DIRS 153246], Section 4.5.6). Inadvertent human intrusion is analyzed separately from the probabilistic total system performance assessment (TSPA) analysis. Proposed 10 CFR 963.16(a)(2) describes human intrusion as a stylized event that is assigned prescribed conditions. Analysis of human intrusion is contained in Section 4.4 of the TSPA-SR.

Analysis of volcanism includes both intrusive and extrusive igneous activity. The geologic aspect of intrusive igneous activity that is of primary interest is the development of dikes that may interact with the potential repository's emplacement drifts. For extrusive (eruptive) activity, the geologic aspect of primary interest is the development of a conduit (or conduits) that may interact with the emplacement drifts in the potential repository and feed a volcano on the surface. Such a volcano may incorporate waste into an erupting plume of volcanic ash.

Analysis of seismic events focuses on the vibratory ground motion and fault displacement associated with earthquakes. Of interest are the consequences of these effects on emplacement drift stability, rockfall, and shaking or shearing of components of the natural or engineered barrier systems.

Since completion of the S&ER (DOE 2001 [DIRS 153849]), additional analyses of disruptive events have been carried out to better characterize uncertainties, to incorporate new information, and to examine analysis sensitivities (Table 14-1). Sensitivities examined include those associated with a range of thermal operating modes.

Table 14-1. Summary of Supplemental Models and Analyses

Key Attributes of System	Process Model (Section of S&ER)	Topic of Supplemental Scientific Model or Analysis	Reason For Supplemental Scientific Model or Analysis			Section of Volume 1	Performance Assessment Treatment of Supplemental Scientific Model or Analysis[a]	
			Unquantified Uncertainty Analysis	Update in Scientific Information	Lower-Temperature Operating Mode Analysis		TSPA Sensitivity Analysis	Included in Supplemental TSPA Model
Low Mean Annual Dose Considering Potentially Disruptive Events	Volcanism/ Igneous Activity (4.3.2)	Probability of dike intersection of repository for the operating mode described in S&ER		X		14.3.3.1		X
		Scaling factors to evaluate impacts of repository design changes			X	14.3.3.2		
		Contribution to release of Zones 1 and 2		X		14.3.3.3	X	
		Sensitivity to waste particle size distribution		X		14.3.3.4	X	
		New wind speed data		X		14.3.3.5	X	X
		Explanation of method for handling ash/waste particle size and density		X		14.3.3.6		
		Volcanism inputs for Supplemental TSPA Model		X		14.3.3.7		X
		New aeromagnetic data		X		14.3.3.8		

NOTE: S&ER = *Yucca Mountain Science and Engineering Report* (DOE 2001 [DIRS 153849]).

[a] Performance assessment treatment of supplemental scientific model or analysis discussed in SSPA Volume 2 (McNeish 2001 [DIRS 155023]).

14.1.1 Repository Operating Mode Alternatives and Disruptive Events Analyses

For disruptive events analyses, the two key aspects of the operating mode are the layout of emplacement drifts, including the location and overall extent of the repository footprint, and whether backfill of emplacement drifts is included. The layout and footprint affect the calculation of the annual probability that an igneous dike will intersect an emplacement drift. They also influence calculation of the number of volcanic conduits that might develop through a repository and analysis of the number of waste packages that might be damaged. Inclusion or exclusion of backfill from an operating mode affects the analysis of magma interactions with emplacement drifts and the evaluation of the effects of seismically induced rockfall.

To place in context some of the new analyses of igneous disruptive events discussed in later sections of this report, it is useful to summarize the operating mode alternatives that have been considered. Three alternatives have been examined in disruptive events analyses to support consideration of a site recommendation:

1. Enhanced Design Alternative (EDA) II higher-temperature operating mode (CRWMS M&O 1999 [DIRS 150421], Item 1; CRWMS M&O 1999 [DIRS 107292], Figure 5.9, Tables 6.2 and 6.3, Section 7.1)

2. *Yucca Mountain Science and Engineering Report* higher-temperature operating mode (DOE 2001 [DIRS 153849]; CRWMS M&O 2000 [DIRS 146021], Sections 4.2.1.5 and 6.3.1, Figure 11, Table 28)

3. Lower-temperature operating mode (e.g., BSC 2001 [DIRS 154548]).

All of these alternatives are designed to store 70,000 metric tons of heavy metal (MTHM), but they have different layouts and footprints (Figure 14.1-1). The EDA II operating mode includes backfill in the emplacement drifts, while the operating mode described in the S&ER does not. The lower-temperature operating mode also does not include backfill in emplacement drifts. Table 14.1-2 summarizes some attributes of the layouts for different thermal operating modes.

Igneous disruptive events analyses to support TSPA-SR are based on the operating mode addressed in the *Yucca Mountain Science and Engineering Report*. Earlier analyses for the TSPA model (CRWMS M&O 2000 [DIRS 143665], Section 3.10) were carried out for the EDA II higher-temperature operating mode alternative. In this report, an analysis is presented for a lower-temperature operating mode (Section 14.3.3.2) to examine the sensitivity of the annual probability of igneous dike intersection to changes in operating mode.

14.1.2 Section Organization

First, the treatment of disruptive events in the S&ER (DOE 2001 [DIRS 153849]) is summarized (Section 14.2). Then the disruptive condition of volcanism is addressed (Section 14.3). The treatment of uncertainties for volcanism is discussed (Section 14.3.1) and new analyses are described (Section 14.3.3). Because all applicable lines of evidence were used in developing the analysis of volcanism, no additional lines of evidence are available to support the model. Section 14.3.2 explains that continuing analysis of the lines of evidence already gathered (i.e., analogues) focuses on clarifying the applicability of portions of the analogue where the entire analogue is not applicable. The disruptive condition of seismic events is addressed in Section 14.4. Treatment of uncertainties is discussed in Section 14.4.1, and an additional line of evidence pertaining to vibratory ground motion is presented in Section 14.4.2. No new work has been carried out in the area of seismic events.

14.2 PREVIOUS TREATMENT OF DISRUPTIVE EVENTS

In evaluating the postclosure performance of a potential repository at Yucca Mountain, disruptive events were considered in developing scenarios of the most plausible evolution of the geologic system and the occurrence of unlikely adverse conditions (DOE 2001 [DIRS 153849], Section 4.3.2). The specific disruptive conditions considered were inadvertent human intrusion, volcanism, and seismic events. For the condition of human intrusion, a stylized scenario was considered in a separate TSPA calculation (CRWMS M&O 2000 [DIRS 153246], Section 4.4) to provide a basis for judging the resilience of the repository system to this type of disruptive event. This approach is prescribed in proposed 10 CFR Part 963 (64 FR 67054 [DIRS 124754], Section 963.16(a)(2)).

For the conditions of volcanism and seismic events, an evaluation of features, events, and processes (FEPs) was carried out (CRWMS M&O 2000 [DIRS 151553]) using the probability and consequence criteria in proposed 10 CFR Part 963 (64 FR 67054 [DIRS 124754], Sections 963.16(b)(4) and 963.16(b)(5), respectively) to determine whether they should be included in the TSPA. Based on this evaluation, igneous disruptive scenarios (i.e., volcanic eruption and igneous intrusion groundwater transport) were developed and vibratory ground motion damage to commercial spent nuclear fuel (SNF) rod cladding was incorporated into the nominal scenario (CRWMS M&O 2000 [DIRS 153246]).

Key documents supporting the S&ER (DOE 2001 [DIRS 153849]) and TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) include the *Disruptive Events Process Model Report* (CRWMS M&O 2000 [DIRS 151968]), eight analysis model reports (AMRs), and two calculations. These documents are listed in Table 14.2-1.

Two of the disruptive events AMRs summarize the results of expert elicitation projects that provided the technical basis for assessing hazards related to volcanism and seismic events (CRWMS M&O 2000 [DIRS 151551]; CRWMS M&O 2000 [DIRS 142321]). The two documents produced by these projects were the *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* (referred to as the PVHA for both the document and the study) (CRWMS M&O 1996 [DIRS 100116]) and the *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (referred to as the probabilistic seismic hazard analysis (PSHA) for the document and the study) (Wong and Stepp 1998 [DIRS 103731]). The PVHA expert elicitation project produced estimates of the annual probability of a volcanic event (dike intrusion) intersecting the repository. The PSHA produced estimates of the annual probability of exceedance of specified levels of vibratory ground motion and fault displacement associated with seismic events. Both analyses include in their results the associated uncertainty. Figure 14.2-1 shows the location of post-Miocene volcanoes in the Yucca Mountain region, and Figures 14.2-2a and 14.2-2b show the location of known or suspected significant faults in the region.

14.2.1 Volcanism

Two disruptive event scenarios for igneous activity are described in the S&ER (DOE 2001 [DIRS 153849], Section 4.4.3): a volcanic eruption scenario and an igneous intrusion groundwater transport scenario. The volcanic eruption scenario (CRWMS M&O 2000 [DIRS 153246], Section 3.10) assumes that an igneous dike or dike swarm rises through the crust of the earth and intersects one or more drifts in the potential repository. Along this dike, one or more eruptive conduits form within the repository footprint, producing a volcano at the surface. (It is also possible that no conduits will form within the repository footprint.) Waste packages in the path of the conduit are damaged to the extent that they provide no further protection for the waste, and the waste is available to be entrained in the eruption. Volcanic ash with waste particles attached to it is erupted and then transported by wind, with the wind direction fixed to the south toward the critical group (see proposed 10 CFR 63.115(b) [64 FR 8640 [DIRS 101680]] for a description of the critical group). Ash settles out of the plume as it is transported downwind, resulting in an ash layer on the land surface. The receptor (average member of the critical group) receives a radiation dose from various pathways associated with the contaminated ash (Section 13.2).

The igneous intrusion groundwater transport scenario describes the possible effects of a basaltic dike that intersects a section of the potential repository and partially or completely engulfs some waste packages in magma (CRWMS M&O 2000 [DIRS 153246], Section 3.10). Waste packages near the point of intersection are damaged such that they provide no further protection for the waste (Zone 1); packages farther down the intersected drifts are damaged, but still provide some protection for the waste (Zone 2). Radionuclides are then released from waste packages damaged by the intrusion and become available for transport in groundwater. Because analogue studies indicate that hydrothermal circulation and alteration is limited to the region in the immediate vicinity of intrusive dikes (Valentine et al. 1998 [DIRS 119132], Section IV.C), groundwater flow and radionuclide transport in this disruptive scenario are represented using models from the nominal scenario.

14.2.2 Seismic Events

In addition to evidence of Quaternary volcanism, the Yucca Mountain region is also characterized by faults (Figure 14.2-2), some of which have experienced repeated displacements in the Quaternary Period (CRWMS M&O 2000 [DIRS 151945], Section 12.3). Thus, consequences of seismic events have also been analyzed for possible impacts to the performance of a potential repository (DOE 2001 [DIRS 153849], Section 4.3.2.2). These analyses considered the potential effects of fault displacement on emplacement drifts and on engineered barriers in the drifts (CRWMS M&O 2000 [DIRS 151954]), potential fault displacement effects on radionuclide transport through the unsaturated zone at the mountain scale (CRWMS M&O 2000 [DIRS 151953]), potential rockfall resulting from vibratory ground motion (CRWMS M&O 2000 [DIRS 151635]), and the effects of vibratory ground motion on engineered barriers (CRWMS M&O 2000 [DIRS 154694]). The results of these analyses and calculations led to the conclusion that seismic-related FEPs, with the exception of damage to cladding, could be screened out of the TSPA-SR (CRWMS M&O 2000 [DIRS 151553], Table 4). Seismically induced damage to cladding is included within the nominal scenario in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]).

14.3 VOLCANISM

This section focuses on three topics for the disruptive condition of volcanism. First, it discusses the treatment of uncertainty in volcanism analyses. Second, it describes the lines of evidence used to develop and evaluate conceptual models of igneous activity in the Yucca Mountain region. It points out that because of the low rate of occurrence of volcanoes in the Yucca Mountain region during the Quaternary Period, there is little site-specific evidence to support characterization of potential igneous activity and eruptive processes at Yucca Mountain. Thus, analogue data are relied on extensively. Third, new work to address aspects of volcanism is presented.

14.3.1 Treatment of Uncertainty for Volcanism

Discussion of the treatment of uncertainty associated with the impact of volcanism on dose to the critical group presented in this section covers several areas. There is uncertainty in the probability of a volcanic event occurring and the probability that it will affect the potential repository. For volcanism, this source of uncertainty was analyzed in an expert elicitation (CRWMS M&O 1996 [DIRS 100116]). There is uncertainty in parameters and the value ranges of the parameters that together characterize volcanism scenarios. This uncertainty is usually represented by development of parameter distributions (CRWMS M&O 2000 [DIRS 151560], Section 6). For consequence analysis, there is uncertainty in the response of engineered barrier elements to the impacts of either intrusive or eruptive volcanism. To support disruptive events analysis, documents have been developed by engineering groups that discuss this aspect of the problem, (e.g., CRWMS M&O 1999 [DIRS 121300]). Process model reports provide a high-level summary of these analyses and calculations (CRWMS M&O 2000 [DIRS 150707]; CRWMS M&O 2000 [DIRS 151804]). The discussion of sensitivities associated with a range of repository layouts is deferred to Section 14.3.3.2.1, in which the impact of various repository thermal operating modes on probability and consequence is analyzed. The discussion that follows focuses on uncertainty related to conceptualizing volcanism scenarios and the parameters associated with those scenarios, beginning with the uncertainties to be considered in probability analyses.

The process model for volcanic hazard was developed through an expert elicitation project, (CRWMS M&O 1996 [DIRS 100116]). To ensure appropriate quantification of scientific uncertainty in the hazard analysis, the U.S. Department of Energy identified ten experts to evaluate data, volcanic processes, and features. The product of the expert elicitation (PVHA) was a quantitative assessment of the probability of a basaltic dike intersecting the potential repository and discussion of the uncertainty associated with that assessment, reflecting a diversity and range of alternative scientific interpretations. A probability distribution of the annual frequency of intersection of the repository footprint by a dike was computed for each of the ten experts' interpretations (CRWMS M&O 1996 [DIRS 100116], Figure 4-31); these distributions typically spanned approximately 2 orders of magnitude. The ten experts' results were aggregated to form a quantitative assessment of the probability of a basaltic dike intersecting the potential repository. Specifically, the hazard is a probability distribution for the annual frequency of intersection of a basaltic dike with the repository footprint. The PVHA fully documents the treatment of uncertainty in all aspects of the assessment. A summary of the

PVHA process is contained in the *Disruptive Events Process Model Report* (CRWMS M&O 2000 [DIRS 151968], Section 2.1.2).

The PVHA probability distribution for volcanic hazard defined a volcanic disruption as the intersection of the potential repository by a dike. Based on the PVHA results, the report *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]) calculated the probability of an eruption intersecting the repository, conditional on dike intersection. That report quantifies the uncertainty by using clearly documented inputs, such as the number of eruptive centers per volcanic event (based on the PVHA), to develop a probability distribution for the annual frequency of a volcanic event that produces one or more eruptive centers (conduits) within the repository. The calculation considers a model that allows conduit formation anywhere along a dike and one stating that conduits will preferentially form within intersected drifts (CRWMS M&O 2000 [DIRS 151551], Section 6.3.2). This aspect of the distribution calculation quantifies the uncertainty between two different conceptual models for conduit formation.

Volcanic processes are characterized largely from field observation and expert interpretation, so they necessarily contain some degree of uncertainty. In most cases, distributions and point values representing volcanic processes are based on documented data sources from analogue volcanic systems, some in the Yucca Mountain region. The report *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 142657]) examines analogues, discusses various attributes of the eruptive process, and gives a range of values for parameters that characterize the eruptive process. The report provides magma characteristics, including temperature, chemistry, and volatile (including water) content, that support analysis of the interaction of the magma with repository elements, as well as contribute to characterization of the eruption. The report uses analogue sources to characterize the expected geometry of the volcanic intrusion through conduit diameter, dike width, and number of dikes to be expected. Eruption duration and erupted particle size are also provided. The uncertainties for all of the preceding parameters and others developed by the report were quantified.

The TSPA-SR contains the results of sensitivity analyses that examined the effects of several parameters, including fixed wind direction, wind speed, removal of contaminated soil by erosion, volume of material erupted, and number of waste packages damaged by volcanic eruption and intrusion (CRWMS M&O 2000 [DIRS 153246], Section 5.2.9). An analysis showing sensitivity to an alternative model for the probability of igneous activity was also performed. This analysis fixed the annual probability of dike intrusion at 10^{-7} (CRWMS M&O 2000 [DIRS 153246], Section 5.2.9.1).

14.3.1.1 Treatment of Uncertainty in the Igneous Intrusion Groundwater Transport Model

The igneous intrusion groundwater transport model estimates the amount of waste that could be exposed by disruption of waste packages from exposure directly to magma from a dike or from shock wave pressure, pyroclastics, and heat from the dike intrusion. In this model, waste is picked up by groundwater that has percolated in after the magma has cooled. Movement of the groundwater and any dissolved waste is modeled using the unsaturated zone (UZ) and the saturated zone (SZ) flow and transport models (CRWMS M&O 2000 [DIRS 153246], Sections 3.7, 3.8 and 3.10). The igneous intrusion groundwater transport model has several components: magma and dike characteristics, assumptions regarding the interaction of the magmatic dike with the drift and drift elements, assumptions regarding the behavior of waste packages and other engineered barrier system (EBS) elements exposed to the magmatic environment, and flow and transport of waste released using the UZ and SZ models. Disruptive events analyses provide distributions for parameters used by the first two components of the model (CRWMS M&O 2000 [DIRS 151551]; CRWMS M&O 2000 [DIRS 142657]). For the components listed, the parameters most significant to the model were those related to dike geometry (i.e., dike width, number of dikes in a swarm, and dike spacing in a swarm) and those related to dike-drift interaction (i.e., the number of waste packages contacted directly by magma from a dike and the down-drift effects of magma-repository interactions). These parameters are most important in determining the number of waste packages hit, and, therefore, the amount of waste potentially made available for transport.

Uncertainty about magma and dike properties (the first component of the igneous intrusion groundwater transport model) was quantified using analogue data, as discussed in Section 14.3.1. *Characterize Eruptive Processes at Yucca Mountain, Nevada* contains the results of these analyses (CRWMS M&O 2000 [DIRS 142657], Section 7). The analyses considered the possibility that a new volcano would be accompanied by emplacement of more than one dike, which is known as a "dike swarm." Uncertainties such as the number of dikes in a swarm were handled by developing a distribution (CRWMS M&O 2000 [DIRS 142657], Section 6.1). The geologic basis (observations of eroded volcanic centers in the Yucca Mountain region) for this distribution is described in *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 142657]).

Uncertainty associated with parameters for the second component of the model (i.e., interaction of the magmatic dike, the drift, and drift elements) was addressed with bounding assumptions because data from tests or analogues are lacking. These parameters and bounding assumptions are described in *Dike Propagation Near Drifts* (CRWMS M&O 2000 [DIRS 151552]), which describes the theoretical interaction of the dike with the host rock surrounding the repository; the potential effects of the higher-pressure dike intrusion reacting with the lower-pressure emplacement drift, and the effect those interactions could have on waste packages not in direct contact with magma; and the interaction of the magma flow with the drift, drip shields, and waste packages. The report uses inputs for magma characteristics (CRWMS M&O 2000 [DIRS 142657]), the behavior of waste packages under extreme heat (CRWMS M&O 1999 [DIRS 121300]), and assumptions supported by representative data distributions.

The treatment of uncertainty for the third component (behavior of waste packages in the magmatic environment) of the igneous intrusion groundwater transport model was also addressed by using a bounding assumption. There is limited information on the behavior of waste packages, drip shields, and other drift elements in a magmatic environment. Therefore, it was assumed that the waste packages in direct contact with the magma are damaged to the extent that they provide no further protection for the waste. In addition, it was assumed that all waste packages in the drifts crossed by a dike, but not in direct contact with the magma, suffer some damage that impacts their ability to contain waste. Shock wave pressure, pyroclastics, and heat from the dike intrusion were assumed to cause the damage. A range of openings in endcap welds sampled from a distribution was used to characterize the damage in this zone. The minimum opening is a small hole and the maximum is a hole the size of the entire endcap. Therefore, the possible range of endcap damage was bounded by the most extreme end member for this type of damage (e.g., the entire endcap is compromised) (CRWMS M&O 2000 [DIRS 151560], Section 6.2).

The fourth component of the model (flow and transport of waste released) used the UZ and SZ flow and transport models, and therefore had the uncertainties associated with the UZ and SZ flow and transport models (see Sections 3, 11, and 12). A sensitivity analysis in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Section 5.2.9.7) shows that performance is only moderately sensitive to the total number of packages that are damaged by intrusion, with peak dose increasing by less than a factor of two.

14.3.1.2 Treatment of Uncertainty in the Volcanic Eruption Model

The volcanic eruption release model assumptions about the number of waste packages exposed to potential damage by eruption are based on a combination of the geometry and characteristics of volcanic dikes and conduits. In addition, a modeling code (ASHPLUME V1.4LV-dll) was implemented as part of the TSPA model (CRWMS M&O 2000 [DIRS 151560]) to capture the nature of the eruptive column and waste dispersal. Therefore, for the volcanic eruption release model, key parameters with significant impacts on performance assessment include volcanic conduit diameter, number of eruptive centers (conduits) on a dike, eruption volume, and wind direction and speed.

Uncertainty in conduit diameter is quantified by the development of a distribution for this parameter on the basis of analogue information in *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 142657], Section 6.1). Uncertainties in this parameter are related mainly to a limited amount of published data on conduit diameters for volcanoes having volume, composition, and eruptive mechanisms similar to those in the Yucca Mountain region. The number of conduits on a dike is calculated assuming that any dike reaching shallow crustal levels, such as the level of the repository, will result in the formation of one or more conduits feeding a volcano or volcanoes. All, some, or none of these conduits may form within the repository. The possibility of multiple volcanoes forming along the length of a dike is included to reflect the presence of chains of volcanoes within the Quaternary geologic record of the Yucca Mountain region. Although it is not clear that the volcanoes that make up an individual chain all erupted from the same dike and erupted contemporaneously, that possibility cannot be ruled out. The variation in the number of volcanic centers along a dike is based on the interpretations of PVHA experts and other considerations, as described in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]). Because conduits form on dikes, uncertainties associated with dikes affect conduit location. Uncertainty in dike location was quantified by the PVHA project (CRWMS M&O 1996 [DIRS 100116]), while uncertainties associated with the number of conduits on a dike and conduit location along dikes is quantified in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]).

The response of EBS elements to the eruptive conduit environment is treated by making an assumption. The characteristics of magma erupting through a conduit (e.g., temperature, chemistry, and abrasive properties), combined with the duration of eruption, support the assumption that any waste packages directly contacted by the conduit are degraded. It is assumed that they are degraded to the extent that they would provide no further protection for the waste (CRWMS M&O 2000 [DIRS 142657], Sections 6.1, 6.2, and 6.3). There are no data available to support a different assumption.

Sensitivity of overall performance to uncertainty about the diameter of eruptive conduits, their location, and the number of eruptive conduits within the repository is described in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Section 5.2.9.6, Figure 5.2-22). Performance is moderately sensitive to the total number of packages damaged as a result of conduit parameters, and peak dose may be increased by a factor of 1.5.

The ASHPLUME code and its application to the volcanic eruption release model are discussed in detail in *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560], Sections 5.4 and 6.1) and in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246], Sections 3.10 and 4.2). The volume of ash erupted is a key input parameter to the model used in the ASHPLUME code to calculate eruption power and eruptive column height. The range for this parameter expected in the Yucca Mountain area is defined in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551], Section 6.2 and Table 4). The U.S. Nuclear Regulatory Commission (NRC) issue resolution status report for igneous activity (Reamer 1999 [DIRS 119693], p. 129) defines an eruptive volume range with a higher maximum end member. *Igneous Consequence Modeling for the TSPA-SR* captures both of these ranges in defining the range for use in the ASHPLUME code by using the NRC maximum value for the upper end member of the range.

The TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) documented a sensitivity analysis for the volume of material erupted and reported that the total annual dose rate is insensitive to the range of values selected for erupted volume. The model runs used the 5^{th} and 95^{th} percentile of the distribution (CRWMS M&O 2000 [DIRS 153246], Section 5.2.9.5). In ASHPLUME, the total erupted volume determines the column height and energy of the event; therefore, the dose calculation was shown to be insensitive to uncertainty regarding these parameters as well.

The wind speed used by ASHPLUME for ash dispersal modeling is related to erupted volume. Erupted volume is used to calculate the eruptive column height, and wind speed varies with eruptive column height. Wind speed, paired with direction, is a parameter with a distribution derived from site data (CRWMS M&O 2000 [DIRS 151560], Section 6.1.2.2.1). In the TSPA-SR model (CRWMS M&O 2000 [DIRS 153246]), the erupted volume used as input for ASHPLUME (V1.4LV-dll) results in a calculated eruptive column height that exceeds the maximum height for wind speed obtained from site data (CRWMS M&O 2000 [DIRS 151560], Section 6.1.2.2.1). Because wind speeds tend to increase with height, the wind speed used with larger erupted volumes may be underestimated in the TSPA-SR. Therefore, new data were examined and used as the basis of a sensitivity study described in the next paragraph.

To assess the sensitivity of the TSPA-SR model (CRWMS M&O 2000 [DIRS 153246]) to the wind speed distribution, a sensitivity analysis has been performed using a different wind speed distribution derived from data taken at the Desert Rock airstrip (NOAA n.d. [DIRS 154435]). These data were taken at elevations that would cover the ASHPLUME (V1.4LV-dll)-calculated eruption column height. Details of this new wind distribution are given in Section 14.3.3.5.

A comparison of the TSPA model doses (DOE 2001 [DIRS 153849]) to doses obtained using the Desert Rock wind speed distribution is provided in Volume 2 (McNeish 2001 [DIRS 155023], Section 3). The new wind speed distribution better captures the uncertainty in wind speed by providing data points from heights as high as or higher than the maximum column heights calculated by ASHPLUME (V1.4LV-dll).

14.3.1.3 Treatment of Uncertainty in Other Volcanism Analyses

The geologic conceptual model for volcanism was developed in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]) and *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 142657]). The conceptual model assumes that if a dike intrusion rises in the crust of the earth to the elevation of the potential repository, the dike will continue propagating upward to the surface of the earth and a conduit will form, feeding a volcano. In all versions of a TSPA conducted to date, when the number of waste packages hit is calculated for the igneous intrusion groundwater release model there is no subtraction of waste packages to account for those that were calculated as being impacted by the volcanic eruption release model. The same applies when the number of waste packages hit by a conduit is calculated for the volcanic eruption release model. The number of waste packages available to be impacted is assumed to be the total number in the repository. This assumption represents conservatism in modeling releases caused by volcanism.

14.3.2 Lines of Evidence Supporting the Volcanism Conceptual Model

For many of the models developed to describe processes operating at Yucca Mountain, there exist multiple lines of evidence that are relevant. The models are developed on the basis of some of the lines of evidence, while other lines provide corroborative information or additional confidence in the results of the model. For volcanism, however, additional lines of evidence are not available because all available data have been used in developing the model.

The rate of Quaternary volcanism in the Yucca Mountain region is low. Thus, there exist few site data from which to characterize potential future igneous activity. To define parameter values and ranges for igneous models at Yucca Mountain, therefore, observations of analogous volcanoes in other regions of the world are used. It is for this reason that other, independent lines of evidence are unavailable to support volcanism models. Continuing analysis of the information already gathered will focus on clarifying the applicability of portions of the analogues where the entire analogue is not applicable.

14.3.3 New Work for Volcanism Analysis

This section contains discussions of new work that supplements the information presented in the S&ER (DOE 2001 [DIRS 153849]). The new work described was performed for several purposes. One analysis is documented in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]) and provides the results of a new analysis of the probability of dike intrusion performed for the higher-temperature operating mode described in the S&ER (DOE 2001 [DIRS 153849], Section 14.3.3.1). New work was performed to address the impacts of considering a range of thermal operating modes

(Section 14.3.3.2). Other analyses were performed to elucidate the relative releases from different damage zones associated with the igneous intrusion groundwater transport scenario (Section 14.3.3.3), to examine the sensitivity to dose of waste particle size distribution (Section 14.3.3.4), and to characterize a new wind speed distribution for use in the volcanic eruption scenario (Section 14.3.3.5). The discussion in Section 14.3.3.6 is presented to clarify how the ASHPLUME code treats the density of waste entrained in ash in the eruptive plume for the volcanic eruption scenario. Other volcanic input values revised since completion of the analyses supporting the S&ER, and used in the TSPA are described in Volume 2 (McNeish 2001 [DIRS 155023]), and in Section 14.3.3.7. Evaluation of new aeromagnetic data and its potential impact on the probability that an igneous dike will intersect a repository is addressed in Section 14.3.3.8.

14.3.3.1 Recalculate Probability of Dike Intrusion for the Operating Mode Addressed in the S&ER

This section contains a summary of the results of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]), which were not represented in the S&ER (DOE 2001 [DIRS 153849]). The results described were used as input to the TSPA supplemental model presented in Volume 2 (McNeish 2001 [DIRS 155023]).

The PVHA produced a probability distribution for volcanic hazard that only addressed the intrusive portion of a volcanic event (CRWMS M&O 1996 [DIRS 100116], Section 3.1.1). *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]) calculates the probability of a conduit or conduits forming on a dike, conditional on dike intersection. This probability calculation supports the volcanic eruption scenario. *Characterize Framework for Igneous Activity at Yucca Mountain,* recalculates the dike intersection probability for two potential repository operating modes: (1) the EDA II higher-temperature operating mode, Figure 14.1-1a (CRWMS M&O 1999 [DIRS 107292]); and (2) the higher-temperature operating mode described in the S&ER (DOE 2001 [DIRS 153849]), Figure 14.1-1b (CRWMS M&O 2000 [DIRS 146021]). The report documents probability distributions for the annual frequency of intersection of the potential repository footprint by a dike for the primary block and for the primary and contingency blocks combined. It also documents distributions for length (inside of repository) and azimuth of an intersecting dike and for the number of eruptive centers (conduits) within the potential repository footprint.

In *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]), the output probabilities for the length and orientation of dikes intersecting the repository footprint of the S&ER (DOE 2001 [DIRS 153849]) operating mode alternative reflect a changed geographic location for the repository footprint from the EDA II operating mode alternative. The new input probabilities reported (CRWMS M&O 2000 [DIRS 151551], Section 7.1, Tables 13 and 13a) differ slightly from the results reported in the initial report (CRWMS M&O 2000 [DIRS 141044]), although the typical difference is only a small percentage. For example, the mean frequency of intersection for the combined primary and contingency blocks in the initial report was 1.55×10^{-8}/yr, rounded to a value of 1.6×10^{-8}/yr. The mean frequency of intersection in the updated report is 1.62×10^{-8}/yr, rounded to a value of 1.6×10^{-8}/yr.

This update (CRWMS M&O 2000 [DIRS 151551], Section 6.5.2.2) uses a distribution for average spacing of eruptive centers (conduits) to calculate the number of eruptive centers within the repository footprint. This change from the single point estimate used in the initial report (CRWMS M&O 2000 [DIRS 141044]) results in an increase in the total number of eruptive centers. In the initial report, the highest number of eruptive centers within the repository was five. In the updated report, the maximum possible number of eruptive centers is twelve for the primary block and thirteen for the primary and contingency blocks combined.

The change in repository footprint and inclusion of additional uncertainty in the conceptual model of conduit formation also result in an increase to 0.77 in the probability that at least one conduit will form within the repository footprint. In TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), a probability value of 0.36 was used.

These results were incorporated into the igneous inputs provided to Volume 2 (McNeish 2001 [DIRS 155023]) for the TSPA supplemental model.

14.3.3.2 Scaling Factors to Evaluate the Impact of Repository Footprint and Layout Changes on Total System Performance Assessment Model Results

Evaluation of the effects of igneous activity depends in part on the footprint of the potential repository, the layout of drifts, and the size and spacing of waste packages in the drifts. These attributes vary for different repository operating mode temperatures. Lower-temperature operating modes generally have larger footprints and greater spacing between waste packages, drifts, or both.

In general, the larger the repository footprint, the higher the probability that an igneous dike will intersect it. Based on the spatial distribution of volcanic sources defined in the PVHA, extension of the repository footprint to the north or south would likely have a greater impact on the probability of intersection than an extension of the footprint to the east (assuming an equal increase in footprint area). The geographic position of the footprint relative to the volcanic sources also affects the probability of intersection.

However, while the probability of intersection may increase for lower-temperature operating modes, the number of waste packages affected per drift by an intersecting igneous dike decreases because fewer waste packages are located in each drift. The net result of these competing effects (i.e., higher probability of intersection, fewer waste packages per intersected drift) depends on the specific footprint and layout being considered. In the following sections, approximate scaling factors are examined for lower-temperature operating modes based on simplifying approaches. The analysis is presented as supplemental information to support decision-makers and does not contribute to analyses in Volume 2 (McNeish 2001 [DIRS 155023]).

This section presents a new analysis that allows an approximation of the effect on the probability of a dike intrusion when footprint size and location, drift spacing, or waste package spacing are varied (Section 14.3.3.2.2). It provides a similar approximation of the effect on the number of waste packages damaged (and therefore, the consequences of waste release) for the two volcanism scenarios: volcanic eruption (Section 14.3.3.2.3) and igneous intrusion groundwater transport (Section 14.3.3.2.4). A discussion of the repository thermal operating mode parameters that are most important to the probability and consequences of volcanism introduces the analysis (Section 14.3.3.2.1). Changes in these parameters translate to changes in the impact of volcanism. These thermal operating mode parameters, or combinations of them, are referred to as scaling factors in the analysis that is presented. The results of the analysis of the release associated with volcanism for an operating mode with these factors specified (e.g., a storage capacity of 70,000 MTHM, no backfill, higher-temperature operating mode (CRWMS M&O 2000 [DIRS 146021]) has been determined (CRWMS M&O 2000 [DIRS 153246], Sections 4.2 and 4.3). Therefore, the proportional, or scaled, response of the release can be approximated by assessment of the effects of proportional changes in these thermal operating mode parameters.

14.3.3.2.1 Repository Thermal Operating Mode Parameters Important to Releases Associated with Volcanism

Various repository thermal operating mode parameters, singly and in combination, influence the impact of volcanism on repository performance. Changes in these parameters can result in changes in the release from waste packages damaged by volcanism, and therefore, impact calculations of dose to the critical group. Repository thermal operating mode parameters critical to the evaluation of volcanism effects on repository performance include:

- Repository footprint (location, length, and width)
- Total repository area and total number of waste packages
- Combined waste package length and waste package spacing
- Drift spacing
- Number of emplacement drifts.

The external geometry of the system, or repository footprint (i.e., location, length, and width), and total repository area are closely related in their effect on the probability and consequences associated with the volcanism scenarios. Dike intrusions (or dike swarms) are narrow, linear features that would encounter the emplacement drifts of a potential repository at an angle (DOE 2001 [DIRS 153849], Figure 4-160). The magma source generating them has a greater likelihood of arising in certain locations in relation to the repository location (CRWMS M&O 2000 [DIRS 151551], Section 6.4.2). The probability and consequence of a dike intrusion arise from the geometric relationships between the dikes as they fan out from their point of origin and the repository location and shape. Changes in these geometric relationships result in changes to the probability. The consequences of dike intersection are affected by the internal geometry of the system.

The internal geometry of the potential repository (i.e., drift spacing, number of waste packages, and spacing of waste packages) similarly affects the manner in which dikes will encounter drifts and waste packages. Therefore, if the geometry of the system varies, the number of waste packages damaged will vary, which will impact the release that affects dose to the critical group. There is some difference in the manner in which varied geometries impact releases for the two volcanism scenarios, as discussed in Sections 14.3.3.2.3 and 14.3.3.2.4.

The following discussion will illustrate the effect of uncertainty in these parameters. The discussion will begin by illustrating potential variability in factors necessary to achieve higher- and lower-temperature operating modes and discussing their potential impact on waste release. The latter part of the discussion will present a new analysis of a method to approximate releases when comparing potential thermal operating modes (Section 14.3.3.2.2 through Section 14.3.3.2.4).

Table 14.1-2 summarizes the variation of key thermal operating mode parameters for all of the alternatives to be discussed in this section. Figure 14.1-1 illustrates three alternatives that will be mentioned. The EDA II operating mode includes backfill and results in a relatively higher-temperature repository approach (Figure 14.1-1a) (CRWMS M&O 1999 [DIRS 107292]). Figure 14.1-1b is for the operating mode described in the S&ER (DOE 2001 [DIRS 153849]) that was also considered under the higher-temperature repository approach (CRWMS M&O 2000 [DIRS 146021], Section 6.3, Figure 11). Figure 14.1-1c is for one hypothetical layout for a lower-temperature repository operating mode (BSC 2001 [DIRS 154548], Item 1). While the hypothetical lower-temperature operating mode scenarios have been considered by the Yucca Mountain Site Characterization Project, they are used in this section only as a set of assumed scenarios to assist in this discussion.

All of the operating modes considered are to store 70,000 MTHM, but they have different layouts and footprints (Figure 14.1-1). The higher-temperature repository operating modes generally have a smaller footprint, whereas the lower-temperature repository operating modes such as Scenario 1 in Table 14.1-2, generally have larger footprints that represent extensions of higher-temperature footprints. The northern segment of the diagram in Figure 14.1-1c (drifts 1 through 58) is identical to the footprint and repository area for the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]), as shown in Figure 14.1-1b. The southern segment of the diagram represents the extended footprint and repository area associated with an alternative thermal operating mode concept.

The total repository area parameter of the thermal operating mode impacts:

- Annual frequency of dike intersection of the repository footprint
- Conditional probabilities associated with dike length/azimuth angle pairs intersecting with, and contained within, the repository footprint
- Conditional probabilities associated with the number of eruptive centers (conduits) occurring on a dike within the repository footprint.

The probabilities are discussed in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 151551]) for the operating mode described in the S&ER (DOE 2001 [DIRS 153849]) and the EDA II higher-temperature operating mode alternatives.

For the hypothetical lower-temperature operating mode shown in Figure 14.1-1c (BSC 2001 [DIRS 154548], Item 1), the repository footprint has an approximate north-south length of 8,700 m and an area of 1,600 acres. These values represent an increase in the north-south length of approximately 70 percent and an increase in area of approximately 30 percent as compared to the alternative described in the S&ER (DOE 2001 [DIRS 153849]), shown in Figure 14.1-1b. As a first approximation, it is assumed that the relationship between the frequency of dike intersection with the repository footprint (identified above) and the repository north-south length is linear. The impact of this assumption is discussed further in Section 14.3.3.2.2.

The thermal operating mode parameters of waste package length, waste package spacing, and drift spacing impact the calculation of the number of waste packages contained within the diameter of a conduit in the volcanic eruption scenario (CRWMS M&O 2000 [DIRS 153097], Section 5.2). This calculation assumes two placements of a conduit to calculate the maximum number of waste packages contained within the diameter of a conduit (CRWMS M&O 2000 [DIRS 153097], Section 5.2). The first placement assumes that the conduit is centered on a drift. For this placement, the sum of waste package length and waste package spacing divided by conduit diameter equals the number of waste packages contained within the diameter of a conduit. The second placement assumes that the conduit is centered on a pillar. For this placement, when the conduit diameter is larger than the drift spacing, the conduit will hit two drifts (the maximum number of drifts that can be intersected by a single conduit). Based on the geometric relationship between a circular conduit and parallel drifts (CRWMS M&O 2000 [DIRS 153097], Section 5.2 and Figure I-3c), this placement may result in a larger number of waste packages contained within the conduit diameter.

Table 14.3.3.2-1 summarizes the calculated maximum number of waste packages contained within the diameter of a conduit for the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]) and the six hypothetical alternatives listed in Table 14.1-2. The range of conduit diameters corresponds to the range used to calculate the cumulative distribution function (CDF) for the number of waste packages hit per conduit diameter, as reported in *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560], Figure 3 and Attachment I). Review of Table 14.3.3.2-1 indicates that the maximum number of waste packages contained within a conduit diameter ranges from a high of 51 for the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]) and Scenarios 2 and 6 to a low of 23 for Scenario 4. As a first approximation, it is assumed that there is a linear relationship between the combined length of an individual waste package and waste package spacing and the number of waste packages contained within a conduit diameter for a given drift spacing.

The analysis in the S&ER (DOE 2001 [DIRS 153849], Section 2.3]) is based on a higher-temperature operating mode (CRWMS M&O 2000 [DIRS 146021], Section 6.3). Figure 14.1-1b is a schematic diagram of the repository footprint for this operating mode. The impact of varying thermal operating mode parameters on the results reported in the S&ER is evaluated in Sections 14.3.3.2.2 through 14.3.3.2.4 using, scaling factors. The scaling factors identified in these sections are used to provide a qualitative estimate of the impact of repository thermal operating mode alternatives.

14.3.3.2.2 Scaling Factors for Probabilities

The probabilities associated with dike intersection of the repository include consideration of:

- The frequency of dike intersection with the repository
- The conditional probability distribution associated with dike length/azimuth angle pairs that occur within the repository footprint
- The conditional probability distribution for number of eruptive centers (conduits) that occur on a dike within the repository footprint.

The thermal operating mode parameters that impact these probabilities are the location and size of the repository footprint. Two alternative thermal operating modes are compared in this discussion: the one described in the S&ER (DOE 2001 [DIRS 153849]) and one alternative hypothetical layout for a lower-temperature operating mode (Scenario 1 in Table 14.1-2) (BSC 2001 [DIRS 154548], Item 1).

Figure 14.1-1c is a schematic diagram of one alternative hypothetical 70,000 MTHM layout for a lower-temperature operating mode repository concept. The northern segment of this footprint (drifts 1 through 58) is similar to the footprint and repository area for the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]), as shown in Figure 14.1-1b. The southern segment of the diagram represents the extended footprint and repository area associated with an alternative lower-temperature concept. This extended footprint adds approximately 3,300 m to the length and 475 acres to the area. These values represent an increase in length of approximately 70 percent and an increase in area of approximately 30 percent compared to the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]).

The annual frequency of intersection of the repository footprint by a dike is most sensitive to a change in length of the repository layout; it is less sensitive to a change in area. The relationship between annual frequency of intersection and repository length is not linear, but it was assumed to be linear for a first approximation. Using this assumption, the increased length of the alternative layout for a lower-temperature operating mode (BSC 2001 [DIRS 154548], Item 1) would result in an increase in the annual frequency of intersection of approximately 70 percent as compared to the annual frequency of intersection for the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849], Section 4.4.3). Using this scaling factor, the mean annual frequency of intersection of 1.6×10^{-8} (DOE 2001 [DIRS 153849], Section 4.4.3) may increase for the Scenario 1 hypothetical lower-temperature operating mode (BSC 2001 [DIRS 154548], Item 1) to a qualitatively estimated mean annual frequency of intersection of 2.72×10^{-8}.

The conditional probability distribution of dike intersection lengths within the alternative layout (BSC 2001 [DIRS 154548], Item 1) and the frequency of at least one eruptive center (conduit) within the elongated footprint associated with this alternative layout would both change. The dike intersection lengths would be skewed to longer lengths because of the longer repository length. The tail of the distribution would extend to higher intersection lengths, up to the full length of the alternative layout. The frequency that at least one eruptive center would occur within the repository would probably increase somewhat. Quantifying the change in the conditional probability distribution of dike intersection and the frequency of at least one eruptive center (conduit) occurring within the repository footprint would require a new analysis using the repository footprint for the alternative layout. Finally, it is not clear how an elongated repository footprint would impact the conditional probability distribution of azimuths for an intersecting dike without running a new analysis, but the change would probably be insignificant.

The mean frequency of at least one eruptive center (conduit) within the elongated footprint associated with the alternative layout (BSC 2001 [DIRS 154548], Item 1) is assumed to scale proportionally with an increase in the annual frequency of intersection; therefore it would increase approximately 70 percent. Using this assumption, the increased length of the hypothetical lower-temperature operating mode (BSC 2001 [DIRS 154548], Item 1) would result in the same mean conditional probability (conditioned on the probability that a dike intersects the repository) of at least one conduit (eruptive center) intersecting the repository footprint. The probability is approximately 77 percent (DOE 2001 [DIRS 153849], Section 4.3.2.1.2).

For the thermal operating mode reported in the S&ER (DOE 2001 [DIRS 153849], Section 4.3.2.1.2), the estimate of the number of conduits (eruptive centers) was based on the relative weighting of a number of different distribution models (CRWMS M&O 2000 [DIRS 151551], Section 6.5.2.2) that yielded a maximum of 13 conduits. Using this approach, it is estimated that the maximum number of conduits for the alternative layout for a lower-temperature repository operating mode (BSC 2001 [DIRS 154548], Item 1), which is approximately 3,300 m longer than the one described in the S&ER (DOE 2001 [DIRS 153849]), would be approximately 21.

14.3.3.2.3 Scaling Factors for Releases from Waste Packages Hit in the Volcanic Eruption Scenario

The key repository thermal operating mode parameters that impact the number of waste packages hit in the volcanic eruption scenario include the repository footprint (location, length, and width), drift spacing, and the combined length of the waste package and waste package spacing.

For the hypothetical repository lower-temperature operating mode scenarios identified in Table 14.1-2 with a drift spacing of 81 m, the scaling factor is equal to the average combined waste package length and waste package spacing for the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]) (approximately 5 m) (CRWMS M&O 2000 [DIRS 146021]) divided by the combined waste package length and waste package spacing for an alternative operating mode (Table 14.1-2, Scenarios 1, 2, 4, 5, and 6). This scaling factor is multiplied by the volcanic eruption release reported in the S&ER (DOE 2001 [DIRS 153849], Section 4.4.3.3). For example the scaling factor for Scenario 1 is 0.71 (5 m divided by 7 m). Using this scaling factor, the probability-weighted mean total effective dose equivalent reported in the S&ER as 0.004 mrem/yr roughly 300 years after repository closure would be reduced to approximately 0.003 mrem/yr for the Scenario 1 hypothetical lower-temperature operating mode. For repository thermal operating modes with a drift spacing other than 81 m (e.g., Scenario 3, which has a drift spacing of 120 m), a simple scaling factor cannot be applied to estimate waste package releases for alternative operating modes.

14.3.3.2.4 Scaling Factor for Releases from Waste Packages Hit in the Igneous Intrusion Groundwater Transport Scenario

Conceptually, an approximation of igneous intrusion groundwater transport releases from alternative thermal operating modes could be estimated by multiplying the releases reported in the S&ER by a scaling factor equal to the waste package density (number of waste packages per acre of repository area) for the thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]) divided by the waste package density in the alternative. However, significant revisions to key disruptive events AMRs and calculations were accomplished after the S&ER was finalized. Because of the cumulative impact of these revisions, a simple scaling factor cannot be applied to estimate the approximate magnitude of the release for alternative thermal operating modes.

14.3.3.3 Contribution to Release of Zones 1 and 2 in the Igneous Intrusion Groundwater Transport Model

The new work presented in this section was performed to reduce uncertainty in the impacts of releases from different damage zones associated with the igneous intrusion groundwater transport scenario. Information on the contribution to waste release from different damage zones will support focusing analyses on those areas where uncertainty exists and may be reduced by further analysis. The analysis in this section supports a sensitivity analysis in Volume 2 (McNeish 2001 [DIRS 155023]).

The initial version of *Igneous Consequence Modeling for the TSPA-SR* addressed igneous intrusion groundwater transport consequence modeling for a repository thermal operating mode that included backfill (CRWMS M&O 2000 [DIRS 139563]). An update of this report addresses igneous consequence modeling for an operating mode with no backfill (CRWMS M&O 2000 [DIRS 151560]). The effect that a dike (or dikes) intersecting emplacement drifts has on waste package damage in the igneous intrusion groundwater transport scenario varies with proximity to the dike (CRWMS M&O 2000 [DIRS 151552]). Waste package damage in Zone 1 consists of the area immediately around the dike/drift intersection. Waste package behavior in Zone 1 for the backfill and no-backfill operating modes is bounded by the conservative assumption that three packages on either side of the dike, plus a minimum of one package in the path of the dike (seven total packages minimum, depending on dike width), are sufficiently damaged that they provide no further protection for the waste. For multiple dikes in an event (dike swarm), there are seven waste packages damaged in Zone 1 for each dike.

In an update to *Dike Propagation Near Drifts* (CRWMS M&O 2000 [DIRS 151552]), a Zone 2 region is introduced for the no-backfill thermal operating mode described in the S&ER (DOE 2001 [DIRS 153849]). Zone 2 is defined as the portion of an emplacement drift that has been crossed by a dike and is not included in Zone 1. In the absence of backfill, the waste packages in these drifts are directly exposed to a shock wave and pyroclastic flow resulting from the dike encountering the relatively lower pressure in the repository. Pressure in the emplacement drifts would likely have to rise to lithostatic before the dike could continue to propagate upward. The combination of high temperature (1,040° to 1,170°C) and high pressure (approaching the magmatic lithostatic pressure of 7.5 Mpa at the repository depth) would likely be sufficient to cause some degree of failure of the waste packages in Zone 2. The degree of failure is uncertain, and damage is likely to range from moderate to extensive. In the TSPA-SR model for the repository without backfill (CRWMS M&O 2000 [DIRS 153246]), all Zone 2 packages in all drifts intersected by a dike are assumed to be breached with a hole of uncertain cross-sectional area, and all drip shields and cladding in the intersected drifts are assumed to be destroyed to the extent that they provide no further protection for the waste. Endcap failure is used as a surrogate for all types of Zone 2 damage related to dike/waste package interaction.

The area of the hole created by endcap weld failure represents the cross-sectional area of a crack that might open in a failed weld before gas flow into the failed waste package equalizes internal and external pressures, halting the propagation of the crack. In *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560], Section 6.2), a lognormal distribution is developed to represent the uncertainty in the cross-sectional area of holes in failed endcaps. The minimum value of area in the distribution is 1 cm^2 and the maximum area is 1.9×10^4 cm^2, which is an approximation of the full cross-sectional area of a representative endcap with a radius of 77 cm. The mean value of the distribution is 10 cm^2.

Log-normal distributions are selected when the uncertain distribution of values within a population is reasonably believed to be characterized by a normal distribution of logarithms. The distribution is often used when the range of the population spans several orders of magnitude and the mean value is expected to fall relatively closer to the lower bound. Using a normal or uniform distribution for such parameters (rather than a lognormal) would yield a distribution with a mean value that is orders of magnitude above the lower end of the range. In the case of the endcap weld failures, relatively small aperture failures are considered most likely because they would be sufficient to allow gas pressure to equilibrate quickly between the inside and outside of the package. Larger apertures could not be ruled out, so the log-normal distribution was chosen with a relatively small mean values and a low-probability tail that includes the full cross-sectional area of the endcap as the upper bound.

In addition to the degree of waste package failure in Zone 2, the number of packages damaged in Zone 1 and Zone 2 is represented in the TSPA-SR model (CRWMS M&O 2000 [DIRS 153246]) with stochastic data elements. The CDFs for the number of waste packages intersected are discussed in *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000 [DIRS 153097]). The CDFs for the number of packages hit in Zones 1 and 2 take into account dike orientation, length, width, and the number of dikes in a swarm. Two CDFs are used, one for the number of packages in Zone 1 only and one for the number of packages in the combination of Zones 1 and 2. These CDFs were sampled within the TSPA-SR model to determine how many packages are intersected by the igneous intrusion. The methodology for sampling these CDFs is to first sample from Zone 1 only, then sample from the combined Zones 1 and 2 CDFs. The number of packages affected in Zone 2 is simply the number of packages intersected in the combined Zones 1 and 2 CDF minus the number of packages intersected in Zone 1.

The base case no-backfill igneous intrusion groundwater transport scenario described in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) included both Zones 1 and 2 in the dose calculation. To assess the relative importance of Zones 1 and 2 to the dose to the critical group, a TSPA analysis is described in Volume 2 (McNeish 2001 [DIRS 155023], Section 3) that only considers the damage to waste packages in Zone 1. The results of this additional Zone 1 only case in terms of the mean annual dose rate to the critical group are compared to results from the base case to show the relative contributions of Zone 1 and Zone 2 to releases in the igneous intrusion groundwater transport scenario (McNeish 2001 [DIRS 155023], Section 3).

14.3.3.4 Total System Performance Assessment - Site Recommendation Sensitivity to Waste Particle Size Distribution

The new work reported in this section was performed to evaluate uncertainty in the effect on dose to the critical group from waste particle size distribution. This parameter is associated with the volcanic eruption scenario (CRWMS M&O 2000 [DIRS 151560], Section 6.1 and Table 4). The analysis presented in this section supports a sensitivity analysis in Volume 2 (McNeish 2001 [DIRS 155023], Section 3).

The ASHPLUME code (V1.4LV-dll) calculates the areal density of both volcanic ash and spent nuclear fuel in grams per square centimeter on the surface of the earth as a function of relative location from the volcanic vent. For each parameter realization by the TSPA model (all versions), the ASHPLUME code is executed to determine the SNF areal density at the critical location. For each execution of ASHPLUME, the code makes two internal passes: one for calculation of ash deposition, and one for calculation of fuel deposition. The same mathematical model is used for both calculations. In the pass for the fuel deposition calculation, the code simply modifies the ash particle density to account for the incorporation of a fuel particle and determines what fraction of the combined particle mass consists of fuel. An "incorporation ratio" is used to calculate a "fuel fraction," or the ratio of fuel mass to ash mass. For example, an incorporation ratio of 0.3 would mean that a waste particle one-half the diameter of an ash particle could be incorporated into the ash particle. A detailed description of the mathematical model for the ash and fuel deposition calculation is available in Jarzemba et al. (1997 [DIRS 100987]). The combined ash/waste particle density treatment is further clarified in Section 14.3.3.6.

Within the ASHPLUME code, waste particles are treated as varying in size, with the variation in particle size following a log-triangular distribution (Jarzemba et al. 1997 [DIRS 100987], Section 2.2). The particle size distribution is defined by specifying the minimum, mode, and maximum diameter of the fuel particle size distribution. These three parameters are important in determining the ground-level waste density calculated by ASHPLUME because, along with the incorporation ratio, they are used to determine the total mass of fuel contained in waste packages intersected by the volcanic event that is actually entrained in the ash column and transported downwind. In addition, because of the effect of waste particle mass in altering the density of ash particles, the waste particle size distribution will also affect the dispersion calculation within ASHPLUME.

In *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560], Section 6.1.2.1.12), the minimum, mode, and maximum diameter for waste fuel particle size were specified as 0.0001, 0.002, and 0.05 cm, respectively. *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001 [DIRS 153938], Attachment I) notes that waste forms may have different particle diameters in the eruptive environment, depending both on the initial type of the waste (commercial SNF or high-level radioactive glass waste) and the degree and type of alteration of the waste. This uncertainty in waste particle size distribution was examined by conducting a series of sensitivity runs, which are described in Volume 2 (McNeish 2001 [DIRS 155023], Section 3) with the TSPA model using several different values for the minimum, mode, and maximum waste particle sizes that define the log-triangular distribution. For the sensitivity analysis, the minimum waste particle size was reduced by a factor of one-half and the maximum waste particle size was increased by a factor of two. The mode value for the log-triangular particle size distribution was varied between 0.0002 and 0.02 cm, or a range of one-tenth to ten times the base case mode value. The results of this sensitivity analysis are discussed in Volume 2 (McNeish 2001 [DIRS 155023], Section 3.3.1) in terms of the mean dose rate history to the critical group compared to the TSPA-SR (DOE 2001 [DIRS 153849]) igneous disruption scenario. Table 14.3.3.4-1 shows the assumed minimum, mode, and maximum values of particle sizes used in the sensitivity analysis. The TSPA-SR values are also shown in the table for comparison.

14.3.3.5 New Wind Speed Data for Various Heights of Eruption

The new work reported in this section was performed to evaluate uncertainty in the effect on dose to the critical group from wind speed affecting various heights in an ash column during an eruption. This parameter is associated with the volcanic eruption scenario (CRWMS M&O 2000 [DIRS 151560], Section 6.1 and Table 4).

The TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) analysis using ASHPLUME (V1.4LV-dll) employed a distribution for wind speed that was developed in *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560]). Wind speed, paired with direction, is a parameter with a distribution derived from site data taken at altitudes from approximately 1.5 to 5 km above sea level (CRWMS M&O 2000 [DIRS 151560], Section 6.1.2.2.1). Because it is possible for violent strombolian volcanic eruptions of the type possible in the Yucca Mountain region to produce ash plumes higher than 5 km, the distribution of wind speed was reexamined to include wind speeds taken at higher altitudes than those used in the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]). This section documents the development of a new wind speed parameter distribution based on data taken from the Desert Rock Airstrip (NOAA n.d. [DIRS 154435]) between 1978 and 1995. The new distribution for wind speed was used with the TSPA in a sensitivity modeling run that is documented in Volume 2 (McNeish 2001 [DIRS 155023], Section 3).

Wind speed is treated as a stochastic data element within the TSPA model. It is sampled for each realization of the model and passed to the ASHPLUME (V1.4LV-dll) code. The ASHPLUME (V1.4LV-dll) code uses the wind speed information in the calculation of the areal concentration of ash and waste downwind from a potential volcanic eruption through the repository. The wind speed distribution used in the TSPA model is important in determining the ground-level waste concentration, and, therefore, dose to the critical group (proposed 10 CFR 63.115(b) (64 FR 8640 [DIRS 101680])), at the critical location 20 km south of the potential repository.

Igneous Consequence Modeling for the TSPA-SR (CRWMS M&O 2000 [DIRS 151560]) provides a wind speed distribution based on data reported by Quiring (1968 [DIRS 119317]) for the Yucca Mountain region for a seven-year period (1957 to 1964). All wind speed data obtained from different times of the year, different elevations, and different wind directions were considered together to yield an overall wind speed distribution for the Yucca Mountain region. The data were obtained from elevations of approximately 1,500 to 5,000 m above sea level. The wind speed distribution provided in *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560], Section 6.1.2.2.1; DTN: SN0010T0502900.003 [DIRS 154654]) varies between 0.0 and 2,366 cm/s, with a median value of approximately 650 cm/s. This wind speed distribution was used for the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]).

Wind speed is generally a function of height; however, the ASHPLUME code considers wind speed constant with height for each realization. The code also considers the maximum ash column height to be a function of the eruption magnitude, with ash/waste particles diffusing out of the column along the entire height. In order to better understand the sensitivity of the TSPA-SR dose calculations (CRWMS M&O 2000 [DIRS 153246]) to this limitation of the ASHPLUME code, a different wind speed distribution reflecting generally higher wind speeds was used in an analysis described in Volume 2 (McNeish 2001 [DIRS 155023], Section 3) and results compared to the base case dose calculation.

For the analysis in Volume 2 (McNeish 2001 [DIRS 155023], Section 3), wind speed data taken from the Desert Rock Airstrip (NOAA n.d. [DIRS 154435]) between 1978 and 1995 were used to develop the new wind speed distribution, using the same methodology described in *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560], Section 6.1.2.2.1). Desert Rock 300 millibar wind speed data (taken from an average height of 9,434 m from all wind directions) were combined to create the new distribution. The data were grouped into 2 knot (102.86 cm/s) wind speed intervals in an Excel 97 spreadsheet, and a CDF was developed based on the number of wind speed occurrences within each interval. This new wind speed CDF is shown in Figure 14.3.3.5-1, and the data points are listed in Table 14.3.3.5-1. This wind speed CDF includes wind speeds up to 5,683 cm/s, which is approximately 2.4 times faster than the maximum wind speed given in *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560], Section 6.1.2.2.1). The median value for the new distribution is 1,033 cm/s, or approximately 1.6 times faster than in *Igneous Consequence Modeling for the TSPA-SR*. As in the initial TSPA-SR (CRWMS M&O 2000 [DIRS 143665]) calculations, wind direction for this TSPA model calculation was considered to be toward due south (i.e., directly toward the critical group). The assumption of a wind direction toward due south places the critical group on the centerline of the ash plume, where ash thickness is greatest.

The results of the TSPA model run with the new wind speed CDF are presented in Volume 2 (McNeish 2001 [DIRS 155023], Section 3). Results are compared to the initial TSPA-SR calculation (CRWMS M&O 2000 [DIRS 143665]) in terms of the average annual dose rate to the critical group.

14.3.3.6 ASHPLUME Combined Ash and Waste Particle Density Treatment

The discussion in this section is presented for clarification of the issue of how the ASHPLUME code (all versions) treats the density of waste entrained in ash in the eruptive plume for the volcanic eruption scenario. This discussion does not contribute to the analysis in Volume 2 (McNeish 2001 [DIRS 155023]).

Ash particle density is an important parameter within the mathematical model because of its effect on the calculation of the terminal velocity of a particle as it settles in the atmosphere (Jarzemba et. al. 1997 [DIRS 100987]). The particle terminal velocity affects the settling time, and therefore the degree of dispersion that occurs as the particle settles back to earth after an eruption. Because the density of waste is, in general, different from the density of ash, the density of an ash particle will change when it is combined with a waste particle. The correct treatment of this density change in the combined ash and waste particles is necessary if the terminal velocity calculation is to be accurate. The report on *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 139563]) indicates that the ash density does not change after the incorporation of a waste particle. This erroneous indication was corrected in an update to the report (CRWMS M&O 2000 [DIRS 151560], Section 6.1.1).

Igneous Consequence Modeling for the TSPA-SR (CRWMS M&O 2000 [DIRS 151560], Section 6.1.1) provides a description of how the ASHPLUME code (all versions) uses relative particle sizes when determining how waste mass is to be distributed among ash mass. Waste mass is not divided equally among the ash particles. The input parameter "incorporation ratio" is used to calculate a "fuel fraction," which is the ratio of waste fuel mass to ash mass (Jarzemba et al. 1997 [DIRS 100987], Equation 2-8). The fuel fraction calculation prescribes that a waste particle can only be incorporated into an ash particle of a certain size or larger. Thus, larger ash particles will carry more waste mass and smaller ash particles will carry less waste mass, or maybe even none at all.

The particle terminal velocity, V_0, is calculated according to Jarzemba et al. (1997 [DIRS 100987], Equation 2-3). The particle density ("psi" sub p) used in that equation is modified by the ASHPLUME code to account for fuel mass when making the combined-particle dispersion calculation. The combined-particle density is adjusted by the statement (ashden = ashden × [1 + fuel fraction]) in the ASHPLUME code. In this statement, "ashden" represents the ash particle density and "fuel fraction" represents the mass fraction of fuel in the combined particle. This calculation is located in Function ASHDEN.

The update to *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560]) represents a change only in the discussion of particle density; it does not represent a change in the ASHPLUME code. The ASHPLUME code was not modified in regard to the particle density calculation. ASHPLUME V1.0, V1.3, and V1.4LV-dll all implement the particle density adjustment correctly.

14.3.3.7 Volcanism Inputs Supporting Total System Performance Assessment Analysis

In addition to the new work described in Section 14, other new work not included in the S&ER (DOE 2001 [DIRS 153849] is contained in updates of disruptive events analysis model reports and calculations. For the TSPA reported in Volume 2 (McNeish 2001 [DIRS 155023]), volcanism inputs were taken from *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000 [DIRS 151560]), with the exception of the wind speed distribution. The distribution for wind speed is from Section 14.3.3.5 above. These inputs are summarized in Tables 14.3.3.7-1 and 14.3.3.7-2. While some of these inputs are unchanged from those used for the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]), others have been updated. An asterisk in the "Distribution or Value" column of the tables indicates inputs that have been updated since the TSPA-SR.

14.3.3.8 Potential Impact of New Aeromagnetic Data on Probability of Dike Intrusion

Since completion of the *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* (CRWMS M&O 1996 [DIRS 100116]), the USGS has gathered new aeromagnetic data for the Amargosa Valley/Crater Flat/Yucca Mountain region (Blakely et al. 2000 [DIRS 151881]). These data are being assessed to evaluate the likelihood that magnetic anomalies identified in the survey represent buried volcanoes and, if so, provide information on their properties. These results will then be evaluated within the framework of the PVHA to determine whether additional steps are needed to quantify possible changes in the calculated probability of a dike intersection of the potential repository footprint.

The PVHA experts allowed for the presence of undetected volcanoes in the Yucca Mountain region by assigning a "hidden event" factor (typically 1.1 to 1.5) that was used to increase observed volcano counts, which included buried volcanoes that had been inferred at the time of the PVHA.

It is probable that the presence of any newly identified igneous features would not significantly impact the PVHA results because they would be accounted for by the hidden event factor. However, assessing the impact of the new aeromagnetic survey data will depend on the outcome of a full analysis of these data. Aeromagnetic anomalies, tentatively identified to date, are within or very near the volcano source zones identified by the PVHA experts, which suggests that the spatial distribution of volcanoes in the region would not significantly change.

14.4 SEISMIC EVENTS: TREATMENT OF UNCERTAINTIES, MULTIPLE LINES OF EVIDENCE, AND NEW WORK

Seismic events during the postclosure period have been evaluated to determine their potential to disrupt a geologic repository at Yucca Mountain. To assess this potential, a PSHA was carried out to determine the probability of future fault displacement and vibratory ground motion. The seismic hazard, which is the basis for analyses of the seismic response of the repository system, is based on evaluations of tectonic processes and models developed by an expert elicitation process (Wong and Stepp 1998 [DIRS 103731]). This work is summarized in *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 142321]).

Separate analyses were performed to evaluate the effects of seismic events on natural and engineered barrier systems. Except for damage to commercial SNF cladding, earthquake-initiated events were screened out of the TSPA-SR (CRWMS M&O 2000 [DIRS 153246]) on the basis of low probability or low consequence to dose (CRWMS M&O 2000 [DIRS 151553], Section 6.2).

In the sections that follow, treatment of uncertainty in seismic analyses is summarized and an additional line of evidence pertaining to ground motion hazard at Yucca Mountain is presented. No new work has been carried out to address the disruptive condition of seismic events.

14.4.1 Treatment of Uncertainties

Probabilistic Seismic Hazard Analysis–In the PSHA, uncertainties associated with the probabilistic seismic hazard model were addressed explicitly by employing an expert elicitation process (Wong and Stepp 1998 [DIRS 103731]; CRWMS M&O 2000 [DIRS 142321]). Two types of uncertainty were considered and documented (Wong and Stepp 1998 [DIRS 103731], Sections 7.1.1 and 8.1.3; CRWMS M&O 2000 [DIRS 142321], Sections 6.5.2 and 6.6.2):

1. Aleatory uncertainty, which represents the randomness inherent in the natural phenomena of earthquake generation and seismic wave propagation

2. Epistemic uncertainty, which derives from incomplete scientific knowledge of earthquake generation and ground motion propagation processes and the limited data available for use in selecting between alternative conceptual models and interpretations.

Epistemic uncertainty was documented by having multiple experts evaluate alternative interpretations. This information was captured for the probabilistic seismic hazard computation through the use of a logic tree approach in which the branches of the logic tree represent alternative interpretations. Each expert defined branches of the logic tree, then assigned weights to alternative branches depending on the assessment of the degree to which the available data supported that alternative. These multiple interpretations were propagated through the analysis, resulting in a suite of hazard curves and associated weights.

Aleatory uncertainty is captured in the hazard computation by integrating over all variables of the seismic hazard model and is included in each hazard curve. The complete suite of weighted hazard curves from all the experts was then summarized by mean and median curves and 5^{th}, 15^{th}, 85^{th}, and 95^{th} fractile curves. The mean and median curves reflect the central tendency of the hazard analysis, while the separation of the fractile curves reflects the epistemic uncertainty.

At low annual frequencies of exceedance—lower than about 10^{-6}—the hazard uncertainty distribution is increasingly skewed, causing the mean hazard curve to diverge from the median curve. For example, at a 10^{-6} annual frequency of exceedance, the mean peak horizontal ground acceleration is approximately equivalent to the 85^{th} fractile value (DTN: MO0004MWDRIFM3.002 [DIRS 149092]). For an annual frequency of exceedance of 10^{-8}, the mean peak horizontal ground acceleration has likely exceeded the 90^{th} fractile. The increased skewness results from a broadening of the uncertainty distribution at the higher ground motion levels as some of the alternative input parameter sets begin to produce nearly zero hazard. As a result, at low annual frequencies of exceedance, the extreme upper tails of the uncertainty drive the mean hazard.

This result of the extreme skewing in the uncertainty distribution must be appropriately considered in using the hazard curves for regulatory decision-making. When the annual exceedance frequency of interest is in the range of 10^{-5} to 10^{-6} or higher, the mean hazard is generally consistent with physically realizable values. For annual exceedance frequencies below 10^{-6}, however, the mean seismic hazard for Yucca Mountain is increasingly inconsistent with physically realizable ground motion and fault displacement values. At low annual frequencies of exceedance, the median hazard is considered to represent more appropriately the central tendency of the hazard uncertainty for the purpose of FEPs screening. Further discussion of this issue is found in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000 [DIRS 151553], Section 5, Assumption 5.5).

Effects of Fault Displacement on Emplacement Drifts–*Effects of Fault Displacement on Emplacement Drifts* (CRWMS M&O 2000 [DIRS 151954]) was carried out to examine the stresses and rock movement induced on an emplacement drift by nearby fault displacement associated with an earthquake. Uncertainties in the amount of fault displacement and the spatial relationship between the fault and a drift were addressed by analyzing ranges of values.

Fault displacement values ranging from 0.1 to 100 cm were considered (CRWMS M&O 2000 [DIRS 151954], Section 5.13). The upper portion of this range is on the same order of magnitude as the largest displacements observed from paleoseismic studies of the Solitario Canyon fault (120 to 130 cm) and exceeds those for the Bow Ridge fault (CRWMS M&O 2000 [DIRS 151945], Table 12.3-8b). The Solitario Canyon and Bow Ridge faults are the largest in the immediate vicinity of the potential waste emplacement area. Median values of fault displacement hazard for sites within the potential waste emplacement area are less than 100 cm (DTN: MO0004MWDRIFM3.002 [DIRS 149092]).

Other uncertainties in the analysis are type of faulting, rock mass quality in the vicinity of an emplacement drift, and distance from a fault to an emplacement drift. Uncertainty in type of faulting is addressed by considering both normal and strike-slip faulting cases (CRWMS M&O 2000 [DIRS 151954], Section 6). Uncertainty in rock mass quality is included in the analysis by considering two cases that bound the possible range (RMQ = 1 and RMQ = 5). Finally, the analysis looks at the effects of faulting over a range of distances (0 to 100 m) from the fault (CRWMS M&O 2000 [DIRS 151954], Section 6).

Fault Displacement Effects on Transport in the Unsaturated Zone–In *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000 [DIRS 151953]), uncertainties in defining the effects of faulting on the hydraulic properties of fractures is addressed using a bounding approach. Rather than trying to model the changes for a specific earthquake, values are selected to encompass those changes that would be caused by expected fault displacements. Thus, cases were evaluated in which fracture aperture was increased by a factor of 10 and decreased by a factor of 0.2 (or 0.5 for a wetter climate) (CRWMS M&O 2000 [DIRS 151953], Section 6.2.1.5).

In addition, two bounding cases were considered for the spatial distribution of changes to fracture hydraulic properties. In one case, only properties for fractures in fault zones were altered. In the other case, fracture properties were changed throughout the UZ model domain (CRWMS M&O 2000 [DIRS 151953], Section 6.2.1).

14.4.2 Multiple Lines of Evidence: Implications for Vibratory Ground Motion from Studies of Precarious Rocks at Yucca Mountain

There are some lines of evidence that provide additional confidence that seismic hazard and related effects have been appropriately considered. The existence of precariously balanced rocks in the Yucca Mountain region puts some constraints on the level of vibratory ground motion experienced at the site over the past several tens of thousands of years.

Preliminary information on precariously balanced rocks was available to ground motion experts during the PSHA. At that time, however, they did not consider the information in developing their interpretations because of limited knowledge on the duration and frequency of ground motion needed to topple rocks, possible shadow zone effects, and a lack of information on rocks that had been toppled (Wong and Stepp 1998 [DIRS 103731], p. 5-19). Since the PSHA, additional work has been carried out to better understand the implications of precariously balanced rocks.

Precariously balanced rocks provide evidence that past levels of strong vibratory ground motion have been insufficient to topple them. In areas where strong ground motions are known to have occurred historically, precarious rocks are not observed. For example, based on reconnaissance field surveys in southern California, Brune (1996 [DIRS 154300], p. 43) concluded that no precarious rocks are found within 15 km of zones of high-energy release of historic large earthquakes. Laboratory physical modeling, numerical modeling, and field tests provide confidence that rough estimates of the accelerations required to topple precarious rocks can be made without extensive controlled testing (Brune 2000 [DIRS 154301], p. 1107; Anooshehpoor and Brune 2000 [DIRS 154302], pp. 2 to 4). Brune and Whitney (2000 [DIRS 154573], p. 18) noted that numerous precarious rocks exist along Solitario Canyon and argued that accelerations at Yucca Mountain have not exceeded about 0.3 g at the surface during the past 75,000 to 80,000 years. This inference is consistent with information indicating that the last significant surface offset on the Solitario Canyon fault occurred 15,000 to 30,000 years ago (CRWMS M&O 2000 [DIRS 151945], Table 12.3-8b). Vibratory ground motions at the depth of potential waste emplacement would be less than those at the surface.

Precarious rocks have also been used to test ground motion attenuation relations. Brune (2000 [DIRS 154301], p. 1107) notes that, in contrast to observations in the vicinity of strike-slip faults, precarious and semi-precarious rocks are found nearly to the fault trace on the footwall side of normal faults in Nevada and California. Comparison of estimated toppling accelerations with accelerations predicted by a ground motion attenuation relation based largely on data for strike-slip earthquakes suggests that the attenuation relation may be conservative. The attenuation relation overestimates accelerations on the footwall of normal faults at near distances (Brune 2000 [DIRS 154301], Figure 2). This result is consistent with results from dynamic foam rubber models of strike-slip and normal faulting earthquakes (Brune and Anooshehpoor 1999 [DIRS 154303]). That is, the models indicate that ground motions near the fault trace are less for normal faulting earthquakes than for strike-slip earthquakes. The implication of this observation is that seismic hazard estimates using ground motion attenuation curves based largely on data from strike-slip earthquakes, such as were evaluated in the PSHA, may result in conservative values of hazard for sites such as Yucca Mountain, where normal faulting dominates.

14.4.3 Analyses to Evaluate Seismic Events and Their Effects

No new seismic analyses have been carried out since the completion of the S&ER (DOE 2001 [DIRS 153849]). If the site is recommended, additional analyses will be carried out to support a TSPA for the license application. These analyses would address any enhancements of the repository thermal operating modes and finalize or provide additional confidence in current seismic-related FEPs evaluations.

14.5 SUMMARY OF DISRUPTIVE EVENTS ANALYSES AND PARAMETERS PROVIDED TO TOTAL SYSTEM PERFORMANCE ASSESSMENT

Changes to disruptive events analyses since completion of the work described in the S&ER (DOE 2001 [DIRS 153849]) have included updates to analysis model reports and calculations, as well as additional analyses presented for the first time in Section 14.3.3. Three of these additional analyses provide supplemental information, but are not used in the TSPA sensitivity runs or in the TSPA described in Volume 2 (McNeish 2001 [DIRS 155023]). The analysis described in Section 14.3.3.2 was conducted only to provide an understanding of how changes in repository layouts to achieve lower-temperature operating modes would affect disruptive events analyses. The analysis presented in Section 14.3.3.6 simply clarifies how one aspect of the ASHPLUME code works. Section 14.3.3.8 addresses consideration of new aeromagnetic data in the Yucca Mountain region. The other analyses described in Section 14.3.3 support TSPA analyses described in Volume 2 (McNeish 2001 [DIRS 155023]) as follows:

- Analysis of the probability of intersection of a dike or conduit with a potential repository having a 70,000 MTHM storage capacity and using no backfill in emplacement drifts is used as an input in the supplemental TSPA (Section 14.3.3.1).

- Analysis of the contribution to release of waste packages damaged in Zones 1 and 2 in an igneous intrusion groundwater release model (Section 14.3.3.3) supports a TSPA sensitivity analysis.

- A range of waste particles sizes was developed (Section 14.3.3.4) to support a sensitivity analysis of waste particle size distributions.

- A new distribution of wind speeds was selected (Section 14.3.3.5) and is used in a sensitivity analysis of wind speed and as an input in the TSPA of disruptive events.

- Some volcanism input values contained in analysis model reports and calculations were updated (Section 14.3.3.7) and are used as inputs in the TSPA, as summarized in Tables 14.3.3.7-1 and 14.3.3.7-2.

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Table 14.1-2. Repository Features and Hypothetical Operating Modes that Produce a Range of Temperatures

Feature	EDA-II Higher-Temperature Operating Mode[a]	Higher-Temperature Operating Mode Addressed in the S&ER[b]	Example Operating Mode Parameters for 70,000 MTHM Inventory For Lower Temperature Repository					
			Example 1: Lower Waste Package Temperature through Extended Ventilation and Increase in Emplacement Area			Example 2: Lower Waste Package Temperature through Increased Emplacement Area and Limited Period of Forced Ventilation		Example 3: Lower Drift Wall Temperature and Relative Humidity through Natural Ventilation
			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Number of waste packages	10,039	11,184	~11,000	~16,000	~11,000	~11,000	~11,000	~11,000
Waste package spacing (m)	0.1	0.1	2	0.1	0.1	6	2	0.1
Approximate waste package length (m)	5.1	4.9	~5	~5	~5	~5	~5	~5
Drift center-to-drift center spacing (m)	81	81	81	81	120	81	81	81
Total emplacement drift length (km)	54	56	80	80	60	130	80	60
Required emplacement area (acres)	1,050	1,125	~1,600	~1,600	~1,700	~2,500	~1,600	~1,100
Backfilled	Yes	No	No	No	No	No	No	No

Sources: [a] CRWMS M&O 1999 [DIRS 150421], Item 1; CRWMS M&O 1999 [DIRS 107292], Section 7.1, Tables 6.2 and 6.3; [b] CRWMS M&O 2000 [DIRS 146021], Sections 4.2.1.5 and 6.3.1, Table 28.

NOTE: The example operating mode parameters for a 70,000 MTHM inventory for a lower-temperature repository are assumed. They are used only for sensitivity analyses and do not need to be verified.

Table 14.2-1. Key Documents Supporting the Analysis of Disruptive Processes and Events

Document	Document Identifier Number
Disruptive Events Process Model Report (CRWMS M&O 2000 [DIRS 151968])	TDR-NBS-MD-000002
Features, Events, and Processes: Disruptive Events (CRWMS M&O 2000 [DIRS 151553])	ANL-WIS-MD-000005
Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (CRWMS M&O 2000 [DIRS 151551])	ANL-MGR-GS-000001
Characterize Eruptive Processes at Yucca Mountain, Nevada (CRWMS M&O 2000 [DIRS 142657])	ANL-MGR-GS-000002
Dike Propagation Near Drifts (CRWMS M&O 2000 [DIRS 151552])	ANL-WIS-MD-000015
Igneous Consequence Modeling for TSPA-SR (CRWMS M&O 2000 [DIRS 151560])	ANL-WIS-MD-000017
Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada (CRWMS M&O 2000 [DIRS 142321])	ANL-CRW-GS-000003
Fault Displacement Effects on Transport in the Unsaturated Zone (CRWMS M&O 2000 [DIRS 151953])	ANL-NBS-HS-000020
Effects of Fault Displacement on Emplacement Drifts (CRWMS M&O 2000 [DIRS 151954])	ANL-EBS-GE-000004
Number of Waste Packages Hit by Igneous Intrusion (CRWMS M&O 2000 [DIRS 153097])	CAL-WIS-PA-000001
Comparison of ASHPLUME Model Results to Representative Tephra Fall Deposits (CRWMS M&O 2000 [DIRS 152998])	CAL-WIS-MD-000011

Table 14.3.3.2-1. Summary of the Number of Waste Packages Contained within a Conduit Diameter for the Operating Modes Presented in Table 14.1-2

Conduit Diameter (m)	Number of Waste Packages Contained Within a Conduit Diameter			
	Scenarios 2 and 6	Scenarios 1 and 5	Scenario 4	Scenario 3
4.5	1	1	1	1
10	2	2	1	2
15	3	3	2	3
20	4	3	2	4
25	5	4	3	5
30	6	5	3	6
35	7	5	4	7
40	8	6	4	8
45	9	7	5	9
50	10	8	5	10
55	11	8	5	11
60	12	9	6	12
65	13	10	6	13
70	14	10	7	14
75	15	11	7	15
80	16	12	8	16
85	17	13	8	17

Table 14.3.3.2-1. Summary of the Number of Waste Packages Contained within a Conduit Diameter for the Operating Modes Presented in Table 14.1-2 (Continued)

Conduit Diameter (m)	Number of Waste Packages Contained Within a Conduit Diameter			
	Scenarios 2 and 6	Scenarios 1 and 5	Scenario 4	Scenario 3
90	18	13	9	18
95	20	15	10	19
100	24	17	11	20
105	27	20	13	21
110	30	22	14	22
115	33	24	15	23
120	36	26	17	24
125	38	28	18	25
130	41	30	19	26
135	43	31	20	27
140	46	33	21	29
145	48	35	22	33
150	51	37	23	36

Source: BSC 2001 [DIRS 154933].

Table 14.3.3.4-1. Waste Particle Sizes Used in Total System Performance Assessment and in the Sensitivity Analysis for Volume 2 Using New Distributions

	Minimum (cm)	Mode (cm)	Maximum (cm)
Base case	0.0001	0.002	0.05
Assumed values	0.00005	0.0002	0.005
	0.00005	0.002	0.1
	0.00005	0.02	0.05
	0.0001	0.0002	0.1
	0.0001	0.0002	0.005
	0.0001	0.02	0.1
	0.0001	0.02	0.05

Sources: DOE 2001 [DIRS 153849]; McNeish 2001 [DIRS 155023].

Table 14.3.3.5-1. Desert Rock Wind Speed Cumulative Probability Distribution

Wind Speed (cm/s)	Cumulative Probability
0.00	0.0000
25.72	0.0003
128.58	0.0113
231.44	0.0365
334.30	0.0761
437.16	0.1241
540.02	0.1823
642.88	0.2474
745.74	0.3183
848.60	0.3814
951.46	0.4442
1054.32	0.5143
1157.18	0.5763
1260.04	0.6305
1362.90	0.6864
1465.76	0.7357
1568.62	0.7798
1671.48	0.8217
1774.34	0.8504
1877.20	0.8771
1980.06	0.9016
2082.92	0.9250
2185.78	0.9422
2288.64	0.9566
2391.50	0.9667
2494.36	0.9754
2597.22	0.9827
2700.08	0.9874
2802.94	0.9915
2905.80	0.9931
3008.66	0.9951
3111.52	0.9966
3214.38	0.9980
3317.24	0.9987
3471.53	0.9992
3677.25	0.9994
3934.40	0.9997
4705.85	0.9998
5683.02	1.0000

Source: Statham 2001 [DIRS 154932].

NOTE: Data obtained from an average height of 9,434 m.

Table 14.3.3.7-1. Volcanic Eruption Event Input Parameters for Total System Performance Assessment Supplemental Model

Input Parameter	Input Parameter Format	Distribution or Value
ASHPLUME – min grid location on x-axis	Point Value	0
ASHPLUME – max grid location on x-axis	Point Value	0
ASHPLUME – min grid location on y-axis	Point Value	-20
ASHPLUME – max grid location on y-axis	Point Value	0
ASHPLUME – # of grid locations on x-axis	Point Value	1
ASHPLUME – # of grid locations on y-axis	Point Value	1
ASHPLUME – max particle diameter for transport	Point Value	10 cm
ASHPLUME – min height of eruption column	Point Value	1 m
ASHPLUME – threshold limit on ash accumulation	Point Value	1e-10
ASHPLUME – run type: deterministic or stochastic	Point Value	deterministic
ASHPLUME – option to save particle size info at dose point	Point Value	Not saved
ASHPLUME – particle shape factor	Point Value	0.5
ASHPLUME – air density	Point Value	0.001117 g/cm^3
ASHPLUME – air viscosity	Point Value	0.0001758 g/m-s
ASHPLUME – constant [C] relating to eddy diffusivity and particle fall time	Point Value	400 cm^2 /$sec^{5/2}$
ASHPLUME – incorporation ratio	Point Value	0.3
ASHPLUME – ash settled density	Point Value	1.0 g/cm^3
ASHPLUME – ash particle densities at min/max particle sizes	Point Value	2.08 g/cm^3 (for 0.001 cm ash particle) 1.04 g/cm^3 (for 1.0 cm ash particle)
ASHPLUME – ash min/max log-diameter particle sizes for densities	Point Value	-3 (density 2.08 g/cm^3) 0 (density 1.04 g/cm^3)
ASHPLUME – waste particle diameter: minimum mode maximum	 Point Value Point Value Point Value	 0.0001 cm; 0.002 cm; and 0.05 cm
ASHPLUME – event eruptive volume	CDF	0.002 km^3 – 0.44 km^3
ASHPLUME – mean ash particle diameter	CDF	0.001 cm – 0.1 cm
ASHPLUME – mean ash particle diameter standard deviation	CDF	1 – 3 phi units (phi unit is defined to be the negative logarithm in base 2 of the particle diameter in millimeters)
ASHPLUME – event power	CDF	1.0e09 W – 6.31e13 W
ASHPLUME – ash dispersion controlling constant	CDF	0.01 – 0.5
ASHPLUME – conduit diameter	CDF	4.5 m – 150 m [a]
ASHPLUME – initial eruption velocity	CDF	633 cm/sec – 22,294 cm/sec [a]
ASHPLUME – wind speed	CDF	0 cm/sec – 5,683 cm/sec [a]
ASHPLUME – wind direction	Point Value	-90° (toward due south)

Table 14.3.3.7-1. Volcanic Eruption Event Input Parameters for Total System Performance Assessment Supplemental Model (Continued)

Input Parameter	Input Parameter Format	Distribution or Value
Number of packages hit per conduit (volcanic eruption)	CDF	1 – 51 [a]
Number of conduits intersecting waste packages	PDF	1 – 13 [a]
Probability of > 0 conduits occurring within the repository	Point value	.77 [a]
Percent of hit packages that fail	Point value	100%
Event probability (frequency that an igneous event intersects the repository footprint)	CDF	1.380E-11 to 4.28E-07 [a]

Source: CRWMS M&O 2000 [DIRS 151560], Sections 6.1.2, 6.1.3, and Attachment I.

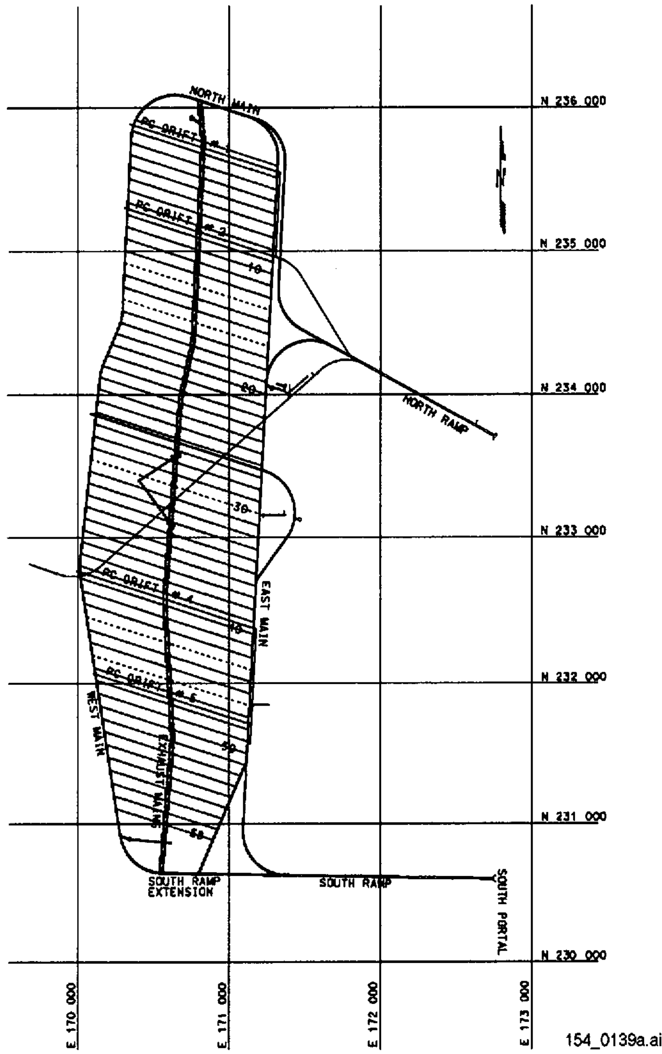
NOTES: [a] Information updated from analyses reported in the S&ER (DOE 2001[DIRS 153849]).
All references to ASHPLUME in this table refer to Version 1.4LV-dll.
PDF = probability density function

Table 14.3.3.7-2. Igneous Intrusion Groundwater Transport Event Input Parameters for Total System Performance Assessment Supplemental Model

Input Parameter	Input Parameter Format	Distribution or Value
Event probability (frequency that an igneous event intersects the repository footprint)	CDF	1.380e-11 – 4.283e-07 [a]
Number of Zone 1 packages intersected (igneous intrusion)	CDF	98 – 1,785 [a]
Number of combined Zone 1 and 2 packages intersected (igneous intrusion)	CDF	0 – 11,184 [a]
Damage to packages in Zone 1	Point value	100%
Damage to packages In Zone 2	Truncated log-normal distribution	Minimum - 1.0 cm^2 Mean - 10 cm^2 Maximum - 1.9E4 cm^2 (size of hole created by end cap weld failure) Standard deviation = 1

Source: CRWMS M&O 2000 [DIRS 151560], Sections 6.1.2, 6.1.3, and Attachment I.

NOTE: [a] Information updated from analyses reported in the S&ER (DOE 2001[DIRS 153849]).

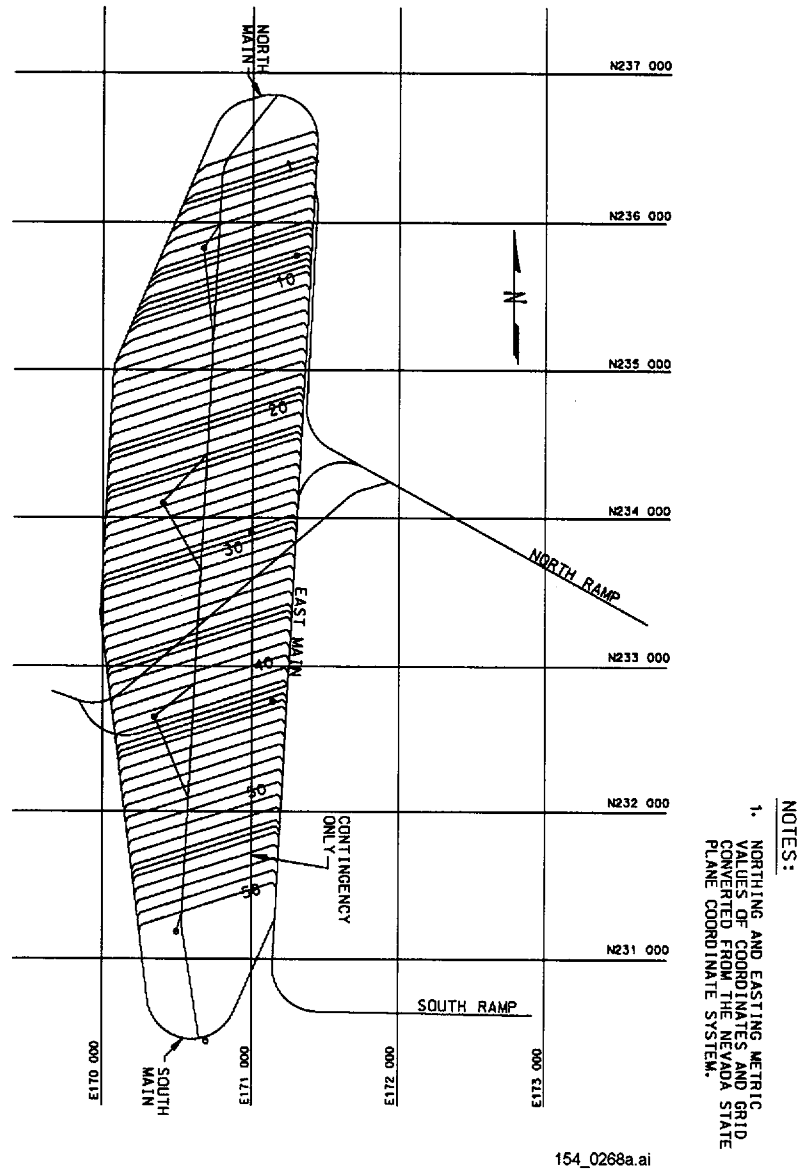


154_0139a.ai

Source: CRWMS M&O 1999 [DIRS 107292].

NOTE: PC Drift = Performance confirmation drift. Dimensions and coordinates are in m. Northing and easting values are from the Nevada State Plane Coordinate System, NAD 27.

Figure 14.1-1a. Repository Layout Used in Disruptive Events Analyses: Enhanced Design Alternative II Higher-Temperature Operating Mode

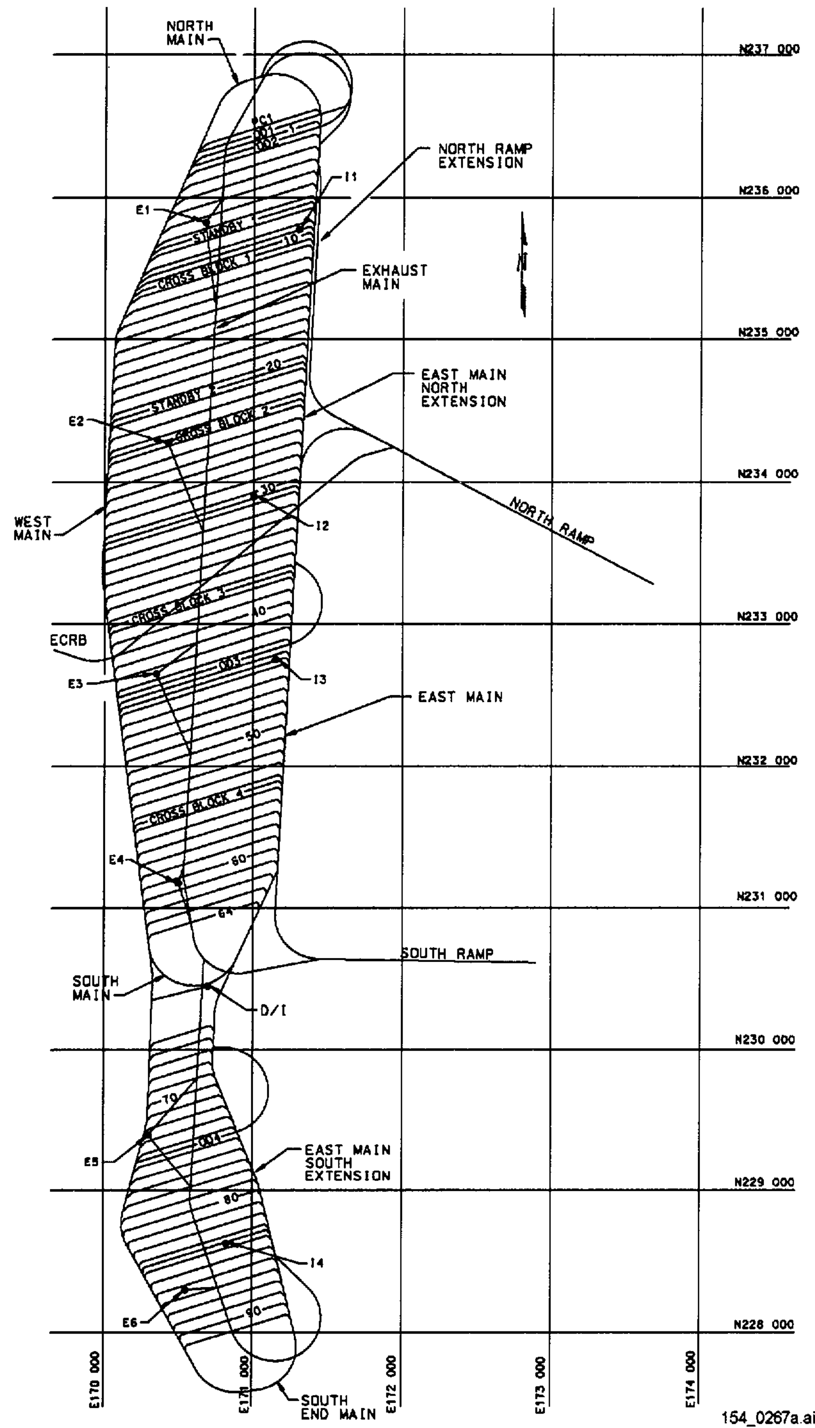


154_0268a.ai

Source: CRWMS M&O 2000 [DIRS 146021].

NOTE: Dimensions and coordinates are in m. Northing and easting values are from the Nevada State Plane Coordinate System, NAD 27. *Yucca Mountain Science and Engineering Report* (DOE 2001 [DIRS 153849]).

Figure 14.1-1b. Repository Layout Used in Disruptive Events Analyses: Higher-Temperature Operating Mode Addressed in the Yucca Mountain Science and Engineering Report

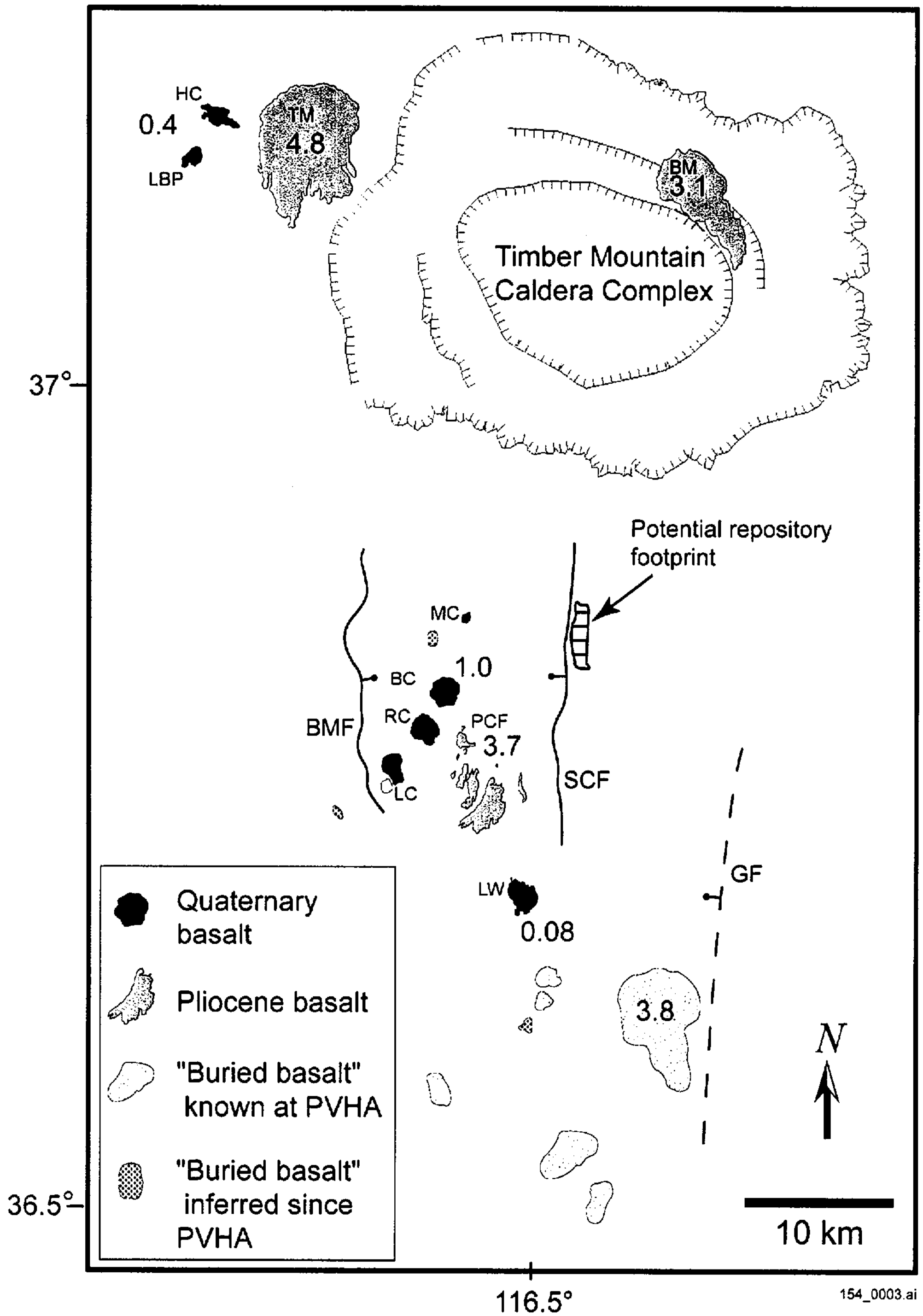


154_0267a.ai

Source: BSC 2001 [DIRS 154548].

NOTES: This repository layout relates to Scenario 1 in Table 14.1-2. Dimensions and coordinates are in m. Northing and easting values are from the Nevada State Plane Coordinate System, NAD 27. PC = Performance confirmation drift. OD = Observation drift. I1 = Intake shaft. E1 = Exhaust shaft. D/I = Development/Intake shaft. ECRB = Enhanced Characterization of the Repository Block.

Figure 14.1-1c. Repository Layout Used in Disruptive Events Analyses: Lower-Temperature Operating Mode

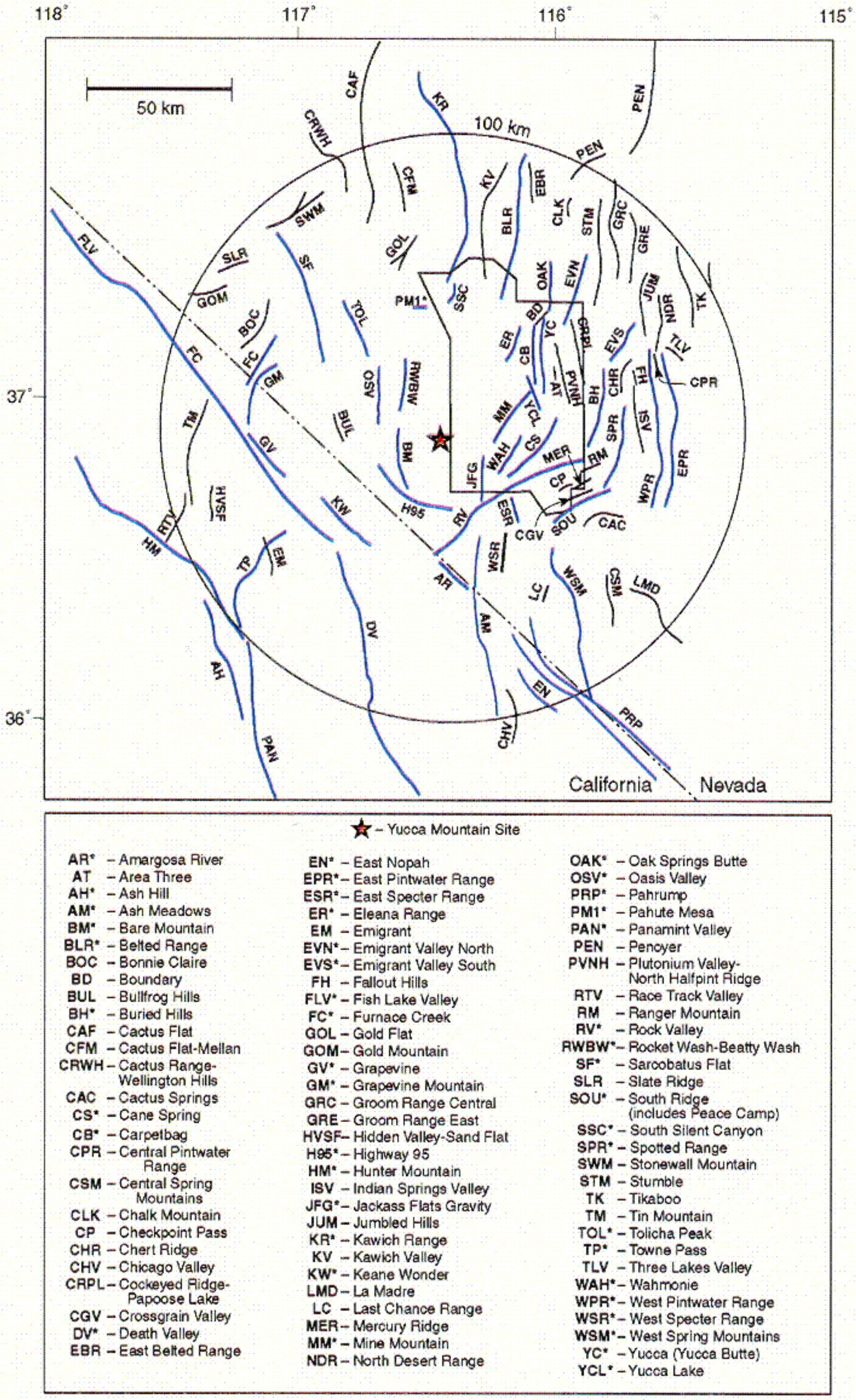


154_0003.ai

Source: CRWMS M&O 2000 [DIRS 151551], Figure 3.

NOTES: Post-Miocene ages are less than 5.3 my. Clusters are shown where multiple volcanoes have indistinguishable ages. Numbers by each volcano indicate approximate age in millions of years. BC = Black Cone; BM = Buckboard Mesa; BMF = Bare Mountain Fault; GF = Gravity Fault; HC = Hidden Cone; LBP = Little Black Peak; LC = Little Cones; LW = Lathrop Wells; MC = Makani Cone; PCF = Pliocene Crater Flat; RC = Red Cone; SCF = Solitario Canyon Fault; TM = Thirsty Mesa; PVHA = Probabilistic Volcanic Hazard Analysis.

Figure 14.2-1. Location and Age of Post-Miocene Volcanoes in the Yucca Mountain Region



154_0457.ai

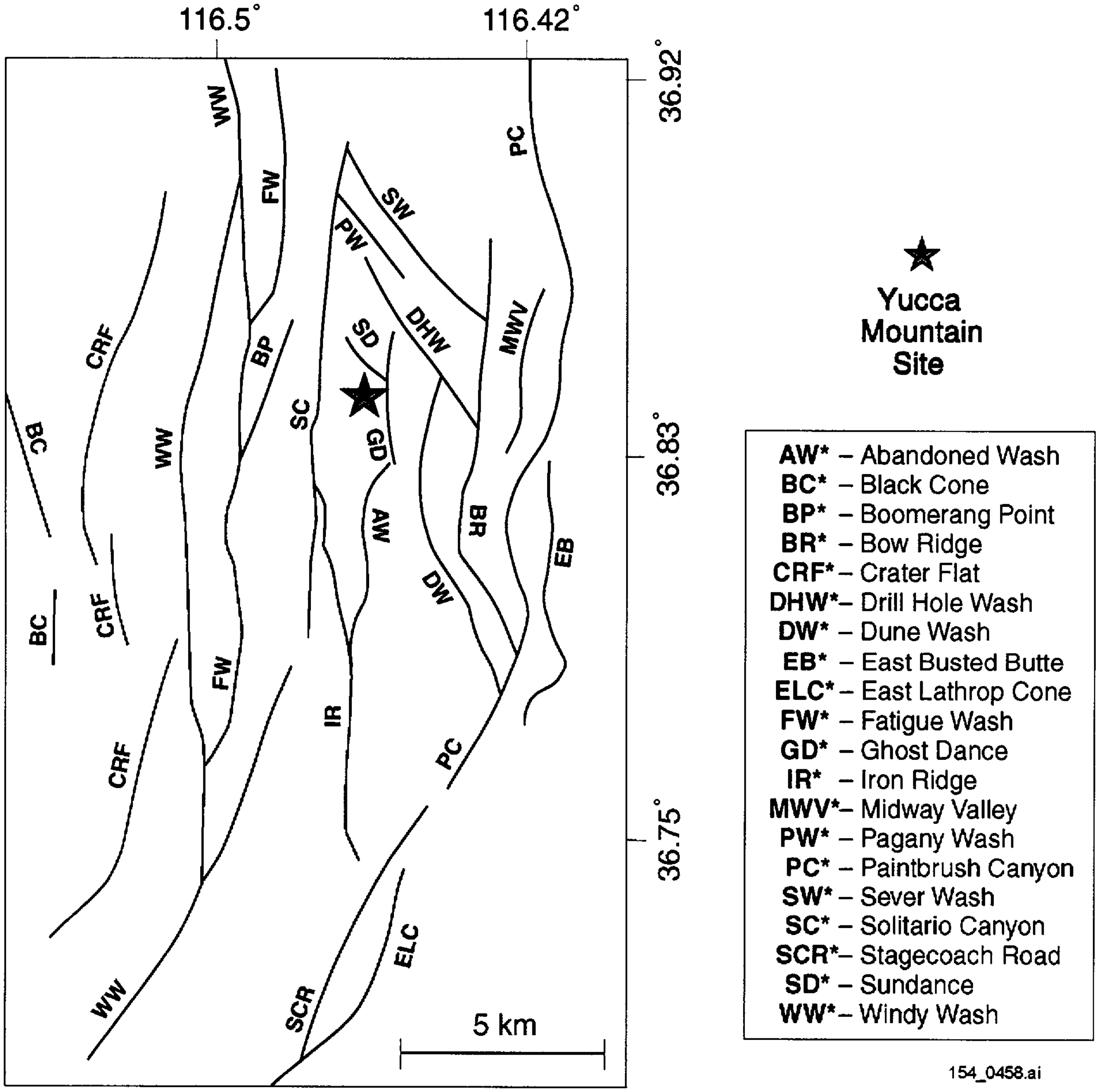
154_0457.ai

Source: Modified from CRWMS M&O 2000 [DIRS 142321].

NOTE: Faults included in the PSHA (Wong and Stepp 1998 [DIRS 103731]) are shown as bold lines on the map and asterisks in the legend.

Figure 14.2-2a. Known or Suspected Quaternary Faults and Potentially Important Local Faults within 100 km of Yucca Mountain

C03

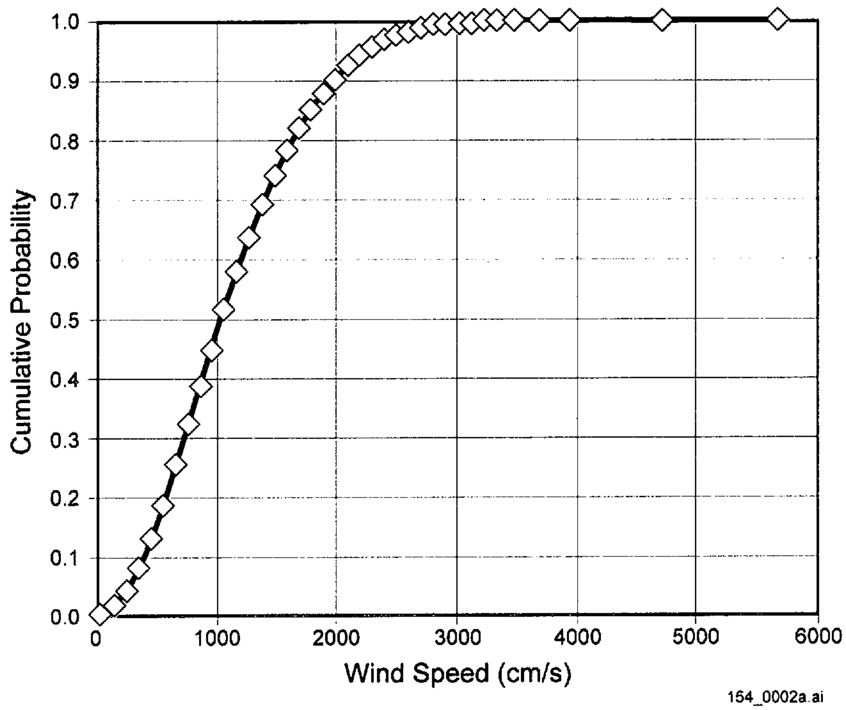


154_0458.ai

Source: CRWMS M&O 2000 [DIRS 142321].

NOTE: These faults are included in the PSHA (Wong and Stepp 1998 [DIRS 103731]).

Figure 14.2-2b. Known or Suspected Quaternary Faults and Potentially Important Local Faults in the Vicinity of the Yucca Mountain Site



154_0002a.ai

Source: Statham 2001 [DIRS 154932].

NOTES: Data points listed in Table 14.3.3.5-1. Average height = 9,434 m.

Figure 14.3.3.5-1. Desert Rock Airstrip Wind Speed Cumulative Probability Distribution

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