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Civilian Radioactive Waste Management System
Management & Operating Contractor

Biosphere Process Model Report

TDR-MGR-MD-000002 REV 00 ICN 01

May 2000

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Civilian Radioactive Waste Management System
Management & Operating Contractor

Biosphere Process Model Report

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May 2000

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EXECUTIVE SUMMARY

The Biosphere Process Model Report (PMR) and supporting Analysis/Model Reports (AMRs) provide information for the evaluation of performance of a potential monitored geologic repository at Yucca Mountain, Nevada. The biosphere work was undertaken to provide the technical basis for this aspect of the Total System Performance Assessment (TSPA). The biosphere work reported here is for a "reference biosphere", that is, one defined to meet regulatory guidance specific to the potential repository.

The biosphere model summarized in this report describes aspects of the biosphere in the general vicinity of Yucca Mountain. The model concentrates on environmental mechanisms through which radioactive material released from a potential repository into the biosphere could reach a human receptor, and personal behaviors important to determining degree of exposure to that material. To be pertinent for Yucca Mountain, these behaviors and environmental mechanisms must be consistent to the surroundings of the mountain.

The biosphere model consists of a conceptual model coupled to a mathematical representation of that concept. The conceptual model includes definitions that were developed for the human receptors around which the model is designed, and selection of the features, events, and processes (FEPs) important to modeling this biosphere. There are two receptors of interest, an average member of the critical group, which is constructed based on DOE guidance that is consistent with the Nuclear Regulatory Commission's proposed rule for the potential repository, and the reasonably maximally exposed individual (RMEI) based on the Environmental Protection Agency's proposed regulation. The RMEI is presumed to have characteristics similar to an average member of the critical group; that group is expected to experience the highest potential exposures to radiation.

The mathematical representation is used to calculate values describing the results of exposure to radioactive material via hypothesized scenarios. Consideration of model needs and comparison of available model mathematical representations concluded that an existing computer code, GENII-S, provides an appropriate representation. It is capable of addressing the FEPs applicable to the Yucca Mountain biosphere, and has been used by the principal regulatory agencies involved in waste isolation.

Model validation work concluded that the combination of the conceptual model, appropriately selected input parameters, and the mathematical expression of the model are valid for use in evaluating the reference biosphere. The report provides the criteria used and judgments made that conclude confidence exists that the model is appropriate and adequate for the intended purpose.

Calculations were performed for two scenarios under which radioactive material could be introduced into the reference biosphere. One of these is a groundwater contamination scenario for undisturbed performance of the potential repository and for some disruptive events, such as seismic events and human intrusion. The second scenario addresses contamination of soil with volcanic ash and is referred to as the disruptive volcanic event scenario.

The results of this work are expressed as reasonably conservative Biosphere Dose Conversion Factors (BDCFs). These conversion factors are used as multipliers to convert any concentration of a specific radionuclide at a source to an annual radiation dose to a human receptor. They are the final link between the geosphere and receptors. This biosphere work does not proceed to calculate those doses. Dose calculations are performed in the TSPA once the radionuclide concentrations are estimated.

Results of the sensitivity analysis for the groundwater contamination scenario support the conclusion that the inhalation and external exposure pathways are not significant, and the ingestion pathway accounts for essentially all of the dose contribution to the BDCF. Conclusions for the disruptive volcanic event scenario are variable among the radionuclides of interest, however, the inhalation and soil ingestion pathways are important.

The sensitivity analysis for the disruptive volcanic event scenario also investigated possible variations in the amount of dust in the breathing air to ensure understanding of the effect of, for example, thicker volcanic ash deposits, and assumptions about surface-disturbing activities. Two higher levels of mass loading were hypothesized based on reported measurements following the eruption of Mount St. Helens. The conclusion for levels associated with non-occupational settings is that the originally calculated BDCFs would need to be multiplied by a factor of approximately 2 to 4, depending on the radionuclide selected. For levels associated with occupational settings, the multiplier is about 13 to 38 depending on the radionuclide.

The Biosphere effort estimated that the annual volume of water used is approximately 97 acre-feet per year for each farm. The specific number of farms on which to base annual groundwater withdrawal is uncertain, but the expected water usage is in the range of 1454 to 2423 acre-feet per year. Additionally, water usage for domestic purposes was found to be less than a half percent of the agricultural usage.

The biosphere work undertaken and reported in this PMR and the values it has produced will facilitate TSPA calculations to assess performance of a potential repository. This will support preparation of the Site Recommendation. Pertinent BDCFs and the associated information that could be used to support National Environmental Policy Act analysis were also reported in this PMR.

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TABLES

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ACRONYMS AND ABBREVIATIONS

ACNW	Advisory Committee on Nuclear Waste
AMCG	average member of the critical group
AMR	Analysis/Model Report
BDCF	biosphere dose conversion factors
Bq	Becquerel
CEDE	committed effective dose equivalent
CFR	Code of Federal Regulation
CNWRA	Center for Nuclear Waste Regulatory Analyses
CRWMS	Civilian Radioactive Waste Management System
DCF	dose conversion factor
DOE	U.S. Department of Energy
EDE	effective dose equivalent
EPA	U.S. Environmental Protection Agency
ESTSC	Energy Science and Technology Software Center
FEP	features, events, and processes
FGR	Federal Guidance Report
FR	Federal Register
GSD	geometric standard deviation
IA	igneous activity
ICRP	International Commission on Radiological Protection
IRSRs	Issue Resolution Status Reports
KTI	Key Technical Issues
M&O	Management and Operating Contractor
NEPA	National Environmental Policy Act
NRC	U.S. Nuclear Regulatory Commission
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
ORNL	Oak Ridge National Laboratory
OSTI	Office of Scientific and Technical Information
PMR	Process Model Report
PNL	Pacific Northwest Laboratory
QA	quality assurance
QARD	Quality Assurance Requirements and Description
RSICC	Radiation Safety Information Computational Center
RME	reasonable maximum exposure
RMEI	reasonably maximally exposed individual
RSS	repository safety strategy
SR	Site Recommendation
TEDE	total effective dose equivalent
TSPA	Total System Performance Assessment
TSPAI	Total System Performance Assessment and Integration
TSPA–SR	Total System Performance Assessment–Site Recommendation
TSPA-VA	Total System Performance Assessment-Viability Assessment
USFIC	Unsaturated Zone and Saturated Zone Flow Under Isothermal Conditions
YMP	Yucca Mountain Site Characterization Project

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1. INTRODUCTION

To evaluate the postclosure performance of a potential monitored geologic repository at Yucca Mountain, a Total System Performance Assessment (TSPA) will be conducted. Nine Process Model Reports (PMRs), including this document, are being developed to summarize the technical basis for each of the process models supporting the TSPA model. These reports cover the following areas:

- Integrated Site Model
- Unsaturated Zone Flow and Transport
- Near Field Environment
- Engineered Barrier System Degradation, Flow, and Transport
- Waste Package Degradation
- Waste Form Degradation
- Saturated Zone Flow and Transport
- Biosphere
- Disruptive Events

Analysis/Model Reports (AMRs) contain the more detailed technical information used to support TSPA and the PMRs. The AMRs consists of data, analyses, models, software, and supporting documentation that will be used to defend the applicability of each process model for evaluating the postclosure performance of the potential Yucca Mountain repository system. This documentation will ensure the traceability of information from its source through its ultimate use in the TSPA-Site Recommendation (SR) and in the National Environmental Policy Act (NEPA) analysis processes.

1.1 OBJECTIVE

The objective of the Biosphere PMR is to summarize (1) the development of the biosphere model, and (2) the Biosphere Dose Conversion Factors (BDCFs) developed for use in TSPA. The Biosphere PMR does not present or summarize estimates of potential radiation doses to human receptors. Dose calculations are performed as part of TSPA and will be presented in the TSPA documentation. The biosphere model is a component of the process to evaluate postclosure repository performance and regulatory compliance for a potential monitored geologic repository at Yucca Mountain, Nevada. The biosphere model describes those exposure pathways in the biosphere by which radionuclides released from a potential repository could reach a human receptor. Collectively, the potential human receptor and exposure pathways form the biosphere model. More detailed technical information and data about potential human receptor groups and the characteristics of exposure pathways have been developed in a series of AMRs and Calculation Reports.

1.2 SCOPE

The Biosphere PMR provides a summary of the technical information that describes the biosphere model. Therefore, no new analyses or data are presented in the PMR. The technical information and data are contained in the following sixteen AMRs and Calculation Reports:

- *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEPs)* (Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) 2000a)

- *Environmental Transport Parameter Analysis* (CRWMS M&O 1999a)

- *Transfer Coefficient Analysis* (CRWMS M&O 2000s)

- *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000b)

- *Identification of Ingestion Exposure Parameters* (CRWMS M&O 2000c)

- *Input Parameter Values for External and Inhalation Radiation Exposure Analysis* (CRWMS M&O 2000t)

- *Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods* (CRWMS M&O 1999d)

- *Evaluate of Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000d)

- *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e)

- *Non-Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis* (CRWMS M&O 2000f)

- *Distribution Fitting to the Stochastic BDCF Data* (CRWMS M&O 2000g)

- *Abstraction of BDCF Distributions for Irrigation Periods* (CRWMS M&O 2000h)

- *Biosphere Dose Conversion Factor for Reasonably Maximally Exposed Individual and Average Member of Critical Group* (CRWMS M&O 2000i)

- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j)

- *Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis* (CRWMS M&O 2000k)

- *Groundwater Usage by the Proposed Farming Community* (CRWMS M&O 2000l)

The primary product of the biosphere modeling effort is radionuclide-, scenario-, and receptor-specific BDCFs. A BDCF is a multiplier that converts a unit concentration of a radionuclide in a source (e.g., pumping and using contaminated groundwater) to an annual radiation dose received by a human from that unit concentration. The BDCF includes the effects of the various pathways through the biosphere (e.g., irrigation and uptake of a radionuclide by plants, and then ingestion by a human) on that radionuclide, as well as the effect of various pathways through a human (e.g., fraction consumed by a human, where it is accumulated in the body, and its retention time). The Biosphere PMR focuses on summarizing information on potential human receptor groups, potential exposure scenarios, characteristics of exposure pathways in those scenarios, and BDCFs. The report is organized into five primary chapters including the Introduction. Chapters are summarized in Section 1.5.

1.3 QUALITY ASSURANCE

The development of the biosphere process model was evaluated in accordance with QAP-2-0, *Conduct of Activities* and was determined to be quality affecting and subject to the requirements of the *Quality Assurance Requirements and Description* (QARD) (U.S. Department of Energy (DOE) 2000). Therefore, preparation of the Biosphere PMR was conducted in accordance with the QARD under the Office of Civilian Radioactive Waste Management (OCRWM) quality assurance (QA) program and applicable QA procedures.

Personnel preparing this report were trained and qualified according to OCRWM procedures AP-2.1Q, *Indoctrination and Training of Personnel* and AP-2.2Q, *Establishment and Verification of Required Education and Experience of Personnel.* Classification of items in accordance with CRWMS M&O procedure QAP-2-3, *Classification of Permanent Items* was not required due to the subject of this document.

Approximately 40 qualified, accepted, or unqualified data sets were used as inputs in AMRs supporting the Biosphere PMR. These data sets are listed in the Document Input Reference System database for each AMR. The data reside in the Technical Data Management System and are tracked by data tracking numbers. Because biosphere transport and uptake is not considered a principal factor, qualified data sets used as inputs were reclassified as Qualified-Verification Level 2, and no further confirmation of qualification status was required per AP-3.15Q, *Managing Technical Product Inputs.* Accepted data were approved for use in quality-affecting work in accordance with AP-SIII.2Q, *Qualification of Unqualified Data and the Documentation of Rationale for Accepted Data.* Qualification plans are being developed and implemented to evaluate all unqualified data inputs.

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

The GENII-S computer code was used to calculate BDCFs (Leigh et al. 1993). GENII-S is a stochastic environmental dose assessment software code that can use both groundwater and atmospheric releases as sources of radionuclides and calculate radiation doses to man based on user defined parameters and pathways. GENII-S is acquired software and was qualified under the OCRWM QA program for use on the YMP (CRWMS M&O 1998d). The software code is maintained under Configuration Management (CSCI: 30034 V1.4.8.5).

1.4 RELATIONSHIP TO OTHER PROCESS MODEL REPORTS AND KEY PROJECT DOCUMENTS

The results of the biosphere evaluations are for use in the TSPA model to support SR. Pertinent information that could be used in the NEPA analysis may also be found in the text. This section addresses the relationships between this document, other PMRs, and other key project documents.

1.4.1 Relationship to Other Process Model Reports

The Biosphere PMR develops the probability distributions of BDCFs for a list of radionuclides of interest (detailed in 3.3). The Biosphere PMR interfaces with the *Waste Form Degradation PMR*, the *Saturated Zone Flow and Transport PMR*, and the *Disruptive Events PMR* in the TSPA model.

The *Waste Form Degradation PMR* provides information for the potential source term for the specific time frame of postclosure. The list of radionuclides of interest that BDCFs were developed for in this PMR was based on input from the waste form degradation area (CRWMS M&O 2000m).

The *Disruptive Events PMR* (CRWMS M&O 2000q) outlines seismic as well as volcanic activity for consideration in TSPA-SR (CRWMS M&O 2000n). The BDCFs for soil contaminated by radioactivity in volcanic ash are used in the disruptive volcanic event scenario calculations. The TSPA model couples these BDCFs and the information provided in the *Disruptive Events PMR* to address the consequences to the human receptor.

The *Saturated Zone Flow and Transport PMR* (CRWMS M&O 2000r) addresses the masses of each radionuclide migrating into the Amargosa Valley annually for the subsequent TSPA model use. The BDCFs for the undisturbed performance scenario (see Section 3.1.5) are used in the TSPA model to calculate annual doses to human receptors. The annual volume of water used by the farming community where the critical group (detailed in 3.1) resides is reported in this PMR. The TSPA model uses this information to derive the annual expected dose to the human receptor.

1.4.2 Relationship to Key Project Documents

The *Biosphere PMR* provides input to the TSPA model and supports the development of the planned TSPA-SR document. Biosphere is discussed as one of the system and subsystem models that define the repository system described in the planned Site Recommendation Consideration Report.

The magnitude of the Yucca Mountain Site Characterization Project (YMP) and the complexities associated with both the natural and engineered barrier systems, dictate that the Project prioritize its activities and focus on the factors most important to performance. The *Repository Safety Strategy (RSS)* (CRWMS M&O 2000o) determines the most important factors (Principal Factors) that affects performance of the potential repository. Though Biosphere Transport and Uptake is not a Principal Factor, it is addressed in the RSS postclosure safety case as a factor with potential to delay and dilute radionuclide concentrations. The information for Biosphere Transport and Uptake is provided by the current PMR.

1.5 OVERVIEW

This PMR synthesizes and summarizes the technical information describing the biosphere model. The report organizes material developed in the supporting AMRs in a sequence selected to aid communication of this information as described below. This section provides an overview of this report.

An introduction is provided in Chapter 1. Evolution of the biosphere model through several previous applications at Yucca Mountain to the current model is described in Chapter 2. The technical material is presented in Chapter 3. This chapter discusses development of the model and the results produced by the model. The biosphere model is a description of the processes required to evaluate the movement of radioactive material through the environment and uptake by humans. It consists of a conceptual model coupled to a mathematical representation of that concept. This mathematical tool is used to calculate factors for estimating radiation doses to people if they were exposed to a selected type and concentration of radioactive material. The biosphere work doesn't calculate doses. These calculations are performed in TSPA.

In Chapter 3, the conceptual model is discussed first. This includes defining the human receptors around which the model is designed. The selection of features and processes potentially important to modeling the biosphere is then discussed, followed by describing the two hypothesized exposure scenarios. One scenario is that the potential repository remains undisturbed after the period of waste emplacement, referred to as groundwater contamination scenario. The second scenario involves a hypothesized disruption of the potential repository by a volcano, referred to as disruptive volcanic event scenario.

Chapter 3 next presents the mathematical representation of the biosphere model. This includes selection of the computer code, qualification of that code, validation of the model, and discussion of the inputs describing the biosphere that are needed to perform calculations. Also presented are two important analyses: one developing water use estimates for the population in the area of interest; and the second investigating buildup and removal of radioactive material in soil.

The chapter also presents results of using the computer program to calculate BDCFs for the selected human receptors and exposure scenarios. Statistical treatment of the results is presented. This includes discussion of uncertainty in the calculated values, and the sensitivity of the values to various input parameters.

In Chapter 4, biosphere related expectations of the potential repository's licensing agency, the U.S. Nuclear Regulatory Commission (NRC), are discussed along with how these expectations are addressed by the biosphere work performed. Other views and alternatives to the approaches selected are also addressed.

The work is summarized and conclusions are provided in Chapter 5. To aid the reader, the many references used in developing this summary report are listed in Chapter 6. An appendix includes a glossary of terms for the special vocabulary essential to presentation of this material.

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2. EVOLUTION OF THE BIOSPHERE PROCESS MODEL

The biosphere system is an integral component of the TSPA for the potential repository and it is represented by a model that allows the calculation of postclosure BDCFs calculated for TSPA use. Since the identification of Yucca Mountain as the site for a potential repository, the DOE has commissioned several TSPA studies as part of the ongoing site evaluation process. These performance assessments used different models, which are described in this section.

2.1 PREVIOUS BIOSPHERE MODELS

There were no recognized criteria that call for a biosphere model until the publication of the *Technical Bases for Yucca Mountain Standards* (National Research Council 1995, Part I). Two sets of total system analyses were performed in 1991 by Pacific Northwest Laboratory (PNL) (Eslinger et al. 1993) and Sandia National Laboratory (SNL) (Barnard et al. 1992). Only the analysis performed by the PNL included dose modeling. Three TSPA iterations were subsequently issued as TSPA-93 (CRWMS M&O 1994; Wilson et al. 1994), TSPA-95 (CRWMS M&O 1995), and Total System Performance Assessment-Viability Assessment (TSPA-VA) (DOE 1998). TSPA-VA reported results from the first biosphere modeling effort for YMP.

2.1.1 1991 Total System Performance Analyses

The analysis performed by PNL in 1991 included dose modeling (Eslinger et al. 1993, Section 10.3). Though it was very comprehensive, it did not use site-specific information for Yucca Mountain nor did it include a biosphere model study. The scenarios evaluated in the analysis fell into two classes: Undisturbed Performance and Disruptive Scenarios. For each Scenario, Waterborne and Surface Contamination Exposures were evaluated. Under the Waterborne Exposure, cases for Farm Exposure and Drinking Water-only Exposure were analyzed. While under the Surface Contamination Exposure, cases for Driller, Garden and External-only exposures were analyzed. The Waterborne Exposure placed a receptor well 5 km down-gradient from the repository, while the receptor is assumed to be located directly above the repository for Surface Contamination Exposure.

The findings of the analysis were that the Surface Contamination Exposure produced the highest annual doses (Eslinger et al. 1993, Chapter 10). However, the analysis did not include any pathway analyses in terms of biosphere transport and uptake.

2.1.2 Total System Performance Assessments 93 and 95

Building on the initial dose modeling, the following two TSPA evaluations focused on the Engineered Barrier and Geosphere process models. These areas were believed to be major contributors to the uncertainties in the overall TSPA predictions. Only limited attention was focused on the radiation dose to humans. Dose was assessed using the assumption of ingesting two liters of contaminated water per day. No biosphere transport and uptake model was considered. This simplified assessment allowed the use of deterministic dose conversion factors (DCF) taken from Federal Guidance Report (FGR) Number 11 (Eckerman et al. 1988, Table 2-2). Because of the its elementary nature, the assessment was readily incorporated into the TSPA capability and permitted the evaluation of the relative importance of various ingested radionuclides as a function of time. Although it did not elucidate the biosphere processes, the later TSPA-VA study and the work being reported in TSPA-SR (CRWMS M&O 2000n) confirmed that drinking water was at least one of, if not the, major contributor to radiation dose.

2.1.3 Total System Performance Assessment -Viability Assessment

TSPA-VA (DOE 1998) was the first effort to incorporate an all-pathway biosphere model. To allow the biosphere model to be developed and incorporated into the TSPA model, use was made of BDCFs. For a given radionuclide, the BDCF for that radionuclide is the all-pathway annual dose that would be received by the defined human receptor if there were unit concentration of the radionuclide present in the source term. It should be noted that at the time of defining the analysis for VA, there was no regulatory guidance for either the reference biosphere or the receptor group(s) of interest.

The biosphere modeling efforts undertaken for TSPA-VA included:

- Identified Features, Events, and Processes (FEPs) considered important for the Amargosa Valley region to formulate the biosphere model.

- Reviewed available computer codes that have a record of regulatory acceptance to determine which existing code provided the best match to the Yucca Mountain biosphere. GENII-S code (Leigh et al. 1993), with its predecessor code GENII, was selected as it provided the most comprehensive modeling capability for the region under study while providing a stochastic capability to propagate uncertainties into the TSPA model.

- Conducted a regional demographic survey and analysis to establish the eating (of locally grown food) and drinking habits of the local population (DOE 1997, CRWMS M&O 1999f).

- Considered three receptor groups, namely, (1) the present Amargosa Valley population, (2) a resident farmer, and (3) a subsistence farmer. The eating and drinking habits of the Amargosa Valley population was based on the actual survey data. The subsistence farmer grew/raised all the food he/she used locally using contaminated water and drank only the contaminated water. The resident farmer drank only local water, but only 50 percent of his/her food were grown locally.

- Applied uncertainty analysis methods to address uncertainties in eating/drinking habits and biosphere pathway parameters and to generate expected statistical distributions for the BDCFs for use in TSPA model.

- Generated BDCFs for the 39 radionuclides identified by previous TSPA evaluations to be of potential importance to determination of dose over the million-year period of interest.

- Conducted limited sensitivity analysis. The biosphere pathways were evaluated in relative importance to their contribution to dose for the three radionuclides considered most important to determination of dose (Technetium-99, Iodine-129, and Neptunium-237).

A conceptual model was defined and presented by mathematical models, which analyzed pathways for radionuclides of interest throughout the system. BDCFs were calculated for each specific radionuclide. These BDCFs were incorporated into TSPA model. The biosphere model studies conducted for the TSPA-VA provided pertinent information to the TSPA model. Those studies represented a solid foundation for the current biosphere model efforts.

2.2 CURRENT BIOSPHERE MODEL

The current biosphere model was developed in support of TSPA-SR and NEPA processes. It was built upon the model used for TSPA-VA but includes a number of modifications. Changes introduced since TSPA-VA are identified below:

- All analyses and models were developed under the OCRWM QA program (DOE 2000).
- A set of FEPs that conforms to the proposed rules was used to identify the attributes of the conceptual biosphere model (64 FR 8640).
- The receptors of interest concepts, as specified by the regulatory agencies, were used in calculations (64 FR 8640, 64 FR 46976).
- The reference biosphere, as defined by the NRC, was used to define the extent of calculations (64 FR 8640).
- Radionuclide build up in soils due to continuing periods of irrigation with contaminated water was included in the analyses.
- Enhanced sensitivity and pathway analyses were conducted for all radionuclides of interest.
- The model no longer considered future climate change over a period of one million years (Dyer 1999).
- Soil and radionuclide removal by wind erosion was considered and incorporated into the BDCF sampling algorithm.
- An assessment of the annual water usage by a proposed farming community was conducted.

A detailed description for the current biosphere model is presented in Chapter 3 of this report.

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3. BIOSPHERE MODEL

The biosphere system is the link between the geosphere system and the receptor and it is represented by the biosphere conceptual model. The setting of the biosphere in the context of the overall repository system is shown in Figure 3-1. Typical scope of biosphere modeling includes the migration and accumulation of radionuclides in the biosphere and the evaluation of the potential radiological impacts on a human receptor. The specific case of the biosphere modeling for the potential repository at Yucca Mountain, described in this PMR, differs from the conventional approach. The biosphere conceptual model in this case is limited to consideration of biosphere transport, and human intake and exposure, resulting from a unit of activity concentration present at the contamination source, such as groundwater or volcanic ash. The model does not include evaluation of radiological impact or assessment of doses; it provides dose factors, called BDCFs, that enable such evaluations or assessments that are carried out in the TSPA model.

The biosphere system can be conceived as a set of specific biotic and abiotic components of the accessible environment and the relationships between these components. Typically, construction of the conceptual model of the biosphere is based on developing assumptions and hypotheses regarding these characteristics. This is followed by constructing a logical and comprehensive framework that combines those assumptions and hypotheses with relevant scientific understanding to enable calculations of radiological impact. The attention, therefore, is focused on the characteristics of the environment that are important from the perspective of contributing to BDCFs for exposure scenarios under consideration. The biosphere conceptual model constructed for the potential repository is representative of a reference biosphere system delineated by the proposed rules and the interim guidance (64 FR 46976, Section III.B.6; 64 FR 8640, 63.115; Dyer 1999, Section 115). This conceptual model and its range of application are described in Section 3.1.

Following the construction of the biosphere conceptual model, the next step is usually the development of an assessment tool based on the mathematical representation of the model components and processes. The assessment tool consists of the mathematical description of the processes and relationships among variables, the representation of the mathematical algorithms in a computer code (i.e., software), and databases that contain generic and site-specific values for model parameters. For the conceptual model of the Yucca Mountain biosphere, existing mathematical representations of biosphere processes and associated computer codes were evaluated to determine their relevance to the performance of the Yucca Mountain system and the reference biosphere system. The description of the assessment tool selected to be used for YMP biosphere modeling, the GENII-S code, is presented in Section 3.2.

Section 3.3 contains the summary of the BDCF calculations, abstractions, as well as sensitivity and uncertainty analysis. Section 3.4 presents the model of water usage by the hypothetical farming community for the reference biosphere and Section 3.5 presents a summary of alternative views regarding biosphere modeling.

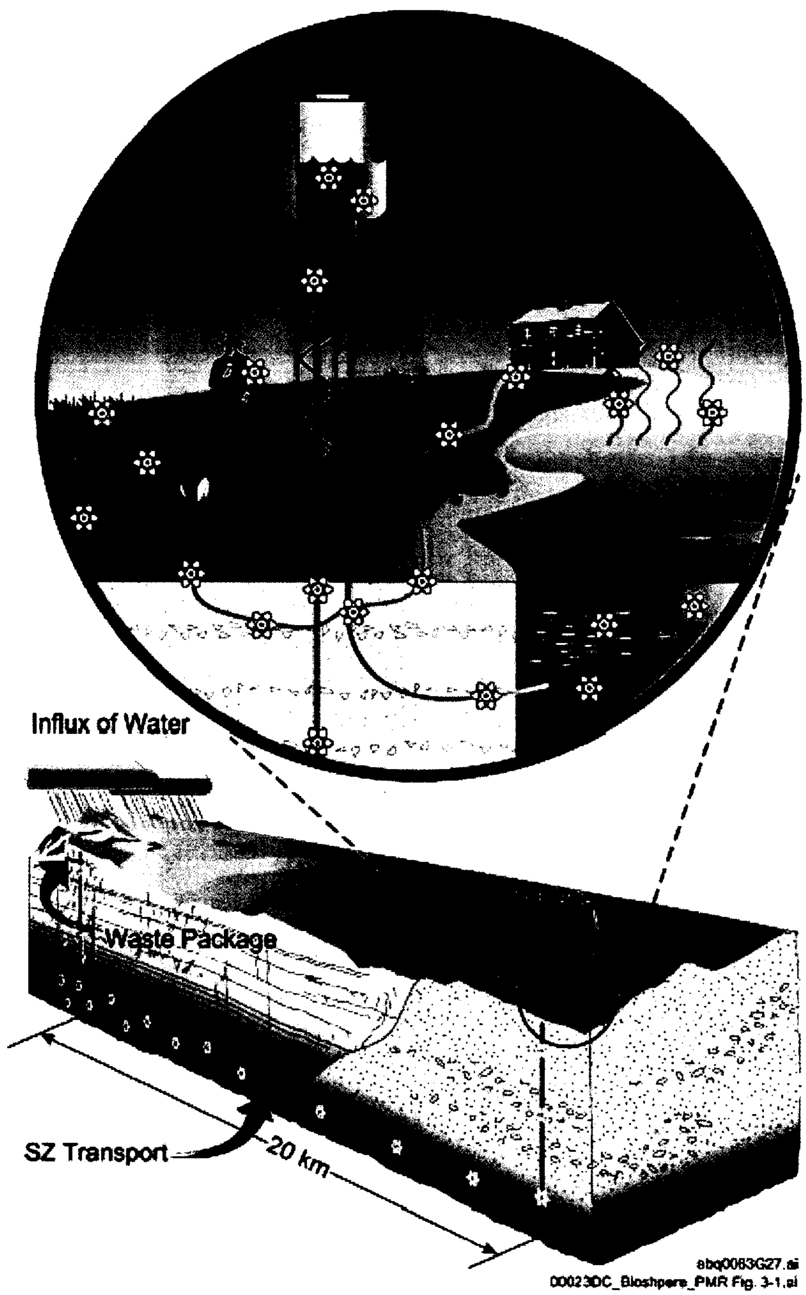


Figure 3-1. Illustration of the Biosphere in Relationship to the Potential Repository System

3.1 CONCEPTUAL MODEL OF BIOSPHERE

The conceptual model of the biosphere is based on the characteristics of the reference biosphere, which are bounded by the criteria identified in the proposed rules (64 FR 8640, Section 63.115, 64 FR 46976, Section III.B.6) and, where applicable, in the interim guidance (Dyer 1999, Section 115). To complete formulation of the conceptual biosphere model, basic assumptions regarding the receptor of interest, including the type of society and characteristics of human behavior, need to be made. In construction of the conceptual biosphere model for the YMP, two types of human receptor were considered: an average member of the critical group and the reasonably maximally exposed individual (RMEI). Section 3.1.2 outlines strategies for identifying and describing human receptors.

The biosphere system and associated chemical, physical, and biological processes can be characterized by the selection of appropriate FEPs. Biosphere model conceptualization is accomplished by the progressive screening of the list of potentially relevant FEPs to determine those that are appropriate for incorporation in an assessment tool given the overall context of the assessment and reference biosphere system of interest. This process is described in Section 3.1.3. Identification of the applicable FEPs helped develop the biosphere conceptual model, which is described in Section 3.1.4. Scenarios of human exposure are addressed in Section 3.1.5.

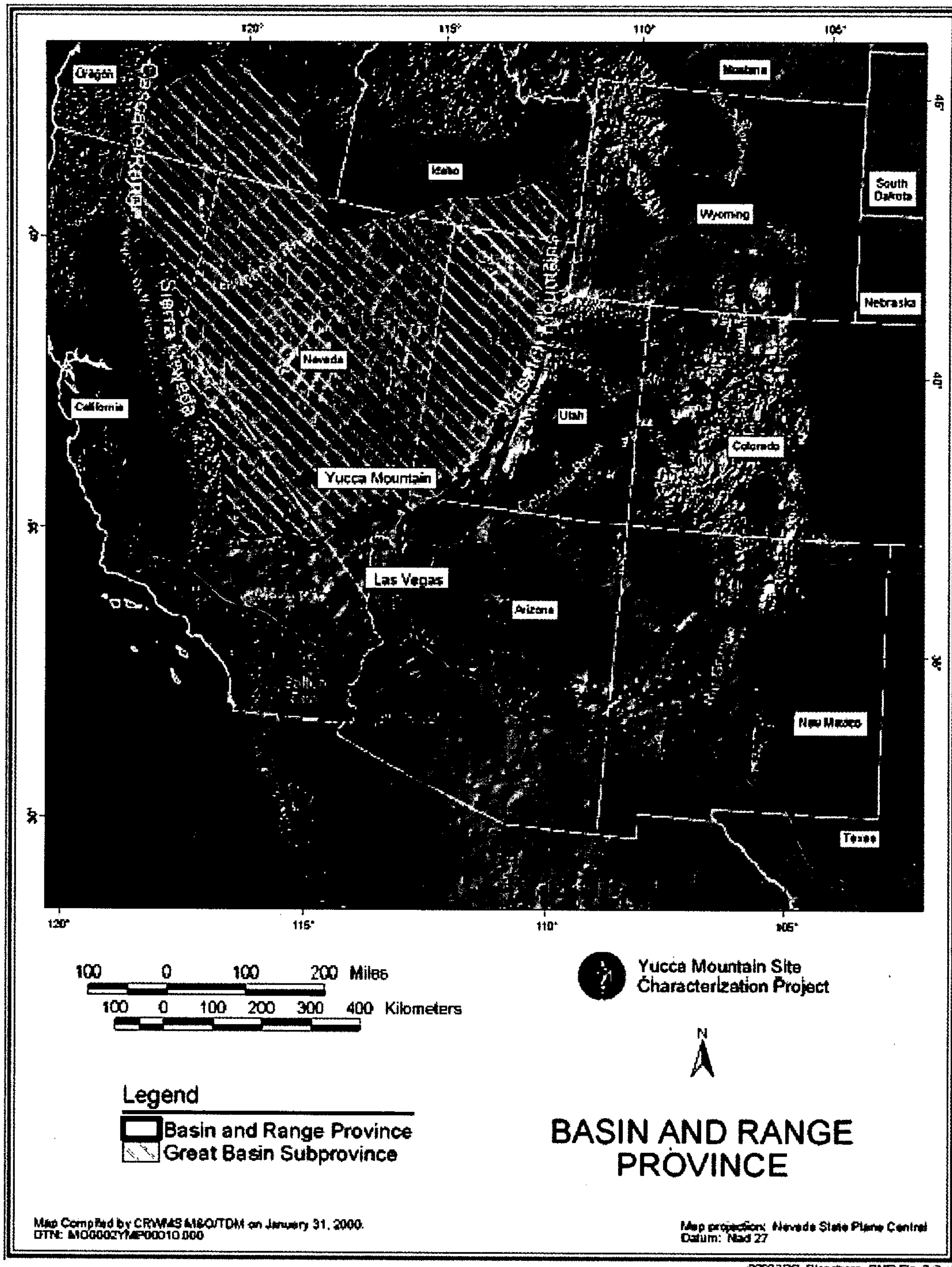
3.1.1 Reference Biosphere

In the context of the potential Yucca Mountain repository, the reference biosphere system is bounded by the proposed rules and the interim guidance (64 FR 46976, 64 FR 8640, Dyer 1999), which requires that the biosphere system be consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain site. Work in progress is evaluating the potential future climate change, based on geologic data and will be reported in the subsequent revision of this report. Description of the reference biosphere systems involves identification of the system components, which form the foundation for long-term representation of the biosphere. These components include the biosphere environmental setting such as geography, climate, and relevant geology, as well as ecosystems, including human communities.

3.1.1.1 Geography, Geology, and Physiography

Yucca Mountain is located in Nye County in southern Nevada, approximately 160 km northwest of Las Vegas, in a semi-arid, sparsely populated region in the transition zone between the Great Basin and the Mojave deserts. Yucca Mountain and surrounding areas are in the southern part of the Great Basin, the northern-most subprovince of the Basin and Range Physiographic Province (Figure 3-2). The topography is typical of the Great Basin, which is characterized by more or less regularly spaced, north-south trending mountain ranges and intervening alluvial basins that were formed by faulting.

The area surrounding Yucca Mountain can be subdivided into eight clearly defined physiographic landforms (CRWMS M&O 1998a). The four landforms most relevant to the biosphere conceptual model are Yucca Mountain, Fortymile Wash, Jackass Flats, and the Amargosa Desert (Figure 3-3). Yucca Mountain is an irregularly shaped upland, 6 to 10 km wide and about 40 km long. The crest of the mountain reaches elevations of 1,500 to 1,930 m,



NOTE: Names of specific geographical points are not necessary to the technical content of this document.

Figure 3-2. Location of Yucca Mountain in Relation to the Subprovinces of the Basin and Range Physiographic Province

NOTE: Names of specific geographical points are not necessary to the technical content of this document.

Figure 3.3. Regional Map of Yucca Mountain and the Amargosa Valley

about 650 m higher than the floors of adjacent washes in Crater and Jackass Flats. Yucca Mountain is composed of fine-grained volcanic rocks and was formed by fault blocks that are tilted eastward, so that the fault-bounded west-facing slopes are generally high, steep, and straight in contrast to the gentler and commonly deeply dissected east-facing slopes. Drainage from the west flank of the mountain flows southward down narrow fault-controlled canyons and out into Crater Flat. Drainage from the east flank flows southeastward down Yucca, Drill Hole, and Dune Washes into Fortymile Wash.

Fortymile Wash is a large ephemeral wash that drains an area of approximately 620 km^2 east and northeast of Yucca Mountain. From its headwaters northeast of Yucca Mountain, it flows southward through Fortymile Canyon and continues down the south-sloping piedmont that forms the west end of Jackass Flat. Along this latter reach, the wash has cut a nearly linear trench, 150 to 600 m wide and as much as 25 m deep in alluvial deposits. This trench gradually decreases downslope until the wash merges with the Amargosa Desert basin.

Jackass Flats is an asymmetric alluvial basin, 8 to 10 km wide and nearly 20 km long, that lies east of Yucca Mountain and Fortymile Wash. It is formed principally by piedmonts that slope away from highlands to the north, east, and south, merge in the central basin area, and descend gradually westward and southwestward toward Fortymile Wash.

The Amargosa Desert is a broad northwest-trending basin approximately 80 km long and as much as 30 km wide. The basin is one of the largest in the southern Great Basin. The basin floor slopes gently southeastward from elevations of about 975 m at the north end, near Beatty, Nevada, to about 600 m toward the south end. The Amargosa River, which catches runoff from the Yucca Mountain area streams, extends southeastward along the basin axis, and eventually ends in Death Valley.

3.1.1.2 Climate

Low precipitation, hot summers, cool winters, and low relative humidity characterize the regional climate (CRWMS M&O 1998b). A dominant feature of the region is the Sierra Nevada Mountains that lie to the west. The mountains are a major barrier to moist air masses moving from the Pacific Ocean and create a rain shadow. Annual average precipitation in the region typically ranges from 100 to 200 mm (4 to 8 inches). Average precipitation decreases from the higher to lower elevations. About 50 percent of the annual precipitation falls from November through April from large-frontal storms. Precipitation during the drier summer months often occurs as localized thunderstorms that may create flooding and runoff. Precipitation often varies between years by a factor of 2. Temperatures vary greatly through the year. The average maximum daytime temperature in July is about 35°C (95°F) and 11°C (52°F) in January. Although average nighttime temperatures in January (2°C [36°F]) are above freezing, freezing temperatures do occur. Low precipitation and warm temperatures keeps atmospheric humidity low. Average annual relative humidity is less than 20 percent.

The combination of low precipitation, warm temperatures, and low humidity result in high rates of evaporation and loss of moisture by plants via transpiration. Shrubs adapted to periodic drought and extremes in temperatures dominate the native vegetation in the region (CRWMS M&O 1996). Vegetation covers 20 to 30 percent of the ground depending on precipitation.

3.1.1.3 Groundwater, Human Activities, and Water Use

Groundwater in aquifers beneath Yucca Mountain flows north to south (D'Agnese et al. 1997). Therefore the groundwater flow is from Yucca Mountain into the Amargosa Desert region immediately to the south (Figure 3-3). The nearest human residents to Yucca Mountain in the direction of groundwater flow live in the community of Amargosa Valley. Amargosa Valley is an area of approximately 1300 km^2 defined as a tax district by the Nye County commissioners in the early 1980s. Within this district the closest inhabitants to Yucca Mountain are approximately 20 km south at the intersection of U.S. 95 and Nevada State Route 373 (Figure 3-3). There are eight inhabitants at this location. If radionuclides were to be released into the groundwater or the air at Yucca Mountain, groundwater flow and wind patterns suggest that some could spread south and east into this region with time. The groundwater flow in the vicinity of Yucca Mountain is described in more detail in the *Saturated Zone Flow and Transport PMR* (CRWMS M&O 2000r).

Although sparsely populated, the Amargosa Valley region does support a population of about 1,270 in approximately 450 households (DOE 1997, Section 2.4, CRWMS M&O 1999f). The community has a general store, community center, senior center, library, medical clinic, elementary school, restaurant, hotel-casino, and a motel. The Amargosa Valley region is primarily rural agrarian in nature. Agriculture is mainly directed toward growing livestock feed (e.g., alfalfa), however, gardening and animal husbandry are common. All of the agriculture and the majority of the people live in the Amargosa Farms area approximately 30 km south of Yucca Mountain. The Amargosa Farms area is a triangle of land bounded by the Amargosa Farm Road to the north, Nevada State Route 373 to the east, and the California border running from the northwest to the southeast (Figure 3-3). Commercial agriculture in the Amargosa Valley farming triangle area includes a large dairy with approximately 4,500 dairy cows, a garlic farm that produces about 900 kg of garlic per year, and a catfish farm that sustains approximately 15,000 catfish. The area contains approximately 1,800 acres planted in alfalfa, 30 acres in oats, 80 acres in pistachios, and 10 acres in grapes.

Because of the semi-arid environment, agricultural crops and gardens depend entirely on irrigation for water. Water for household uses, agriculture, horticulture, and animal husbandry is primarily acquired from local wells. There is no naturally occurring surface water (i.e., perennial lakes and streams).

3.1.2 Human Receptor

Two human receptors of interest are addressed in the *Biosphere PMR*: (1) an average member of the critical group, and (2) the RMEI. The critical group represents those individuals in the expected population at risk who, based upon cautious, but reasonable, assumptions, are expected to receive the greatest potential doses due to possible releases from the potential repository. Human exposure to radiation is evaluated in terms of radiation dose. The basic dosimetry concepts are introduced in Section 3.1.2.1. It is noted that although guidance and criteria are often stated in terms of dose, this biosphere work does not evaluate dose. Dose calculation is a part of the TSPA model. The critical group and its average member are discussed in Section 3.1.2.2. The RMEI is a hypothetical individual whose expected dose is well above the expected average dose in the exposed population at risk. The characteristics and the development of the RMEI are discussed in Section 3.1.2.3. The assumed habits and characteristics of the receptors of interest for the biosphere are consistent with the present conditions of the Yucca Mountain region. The receptor of interest is an adult, whose habits and characteristics are based on present day population in the vicinity of Yucca Mountain. The DOE guidance (Dyer 1999, Section 115(b)) as well as the proposed NRC rule (64 FR 8640, Section 63.115(b)) specifically require that the receptor of interest is an adult.

3.1.2.1 Human Exposure to Radiation

The major goal of repository performance assessment is to assure that the doses from radionuclide release from the repository for the compliance period satisfy performance objectives of the proposed 10 CFR 63 (64 FR 8640, Section 63.113). One of these objectives requires that the mean annual dose to the receptor be calculated. The dose assessment is performed as a part of TSPA. Biosphere model itself does not result in dose assessment. Its function is to provide radionuclide-specific dose factors, BDCFs, which are used in the TSPA to calculate annual doses from individual radionuclides. The sum of annual doses for important radionuclides may then be compared with the proposed requirements of the proposed 10 CFR 63. Although dose assessment is not performed by the Biosphere model, this section discusses the radiation exposure concepts used in the Biosphere model to produce BDCFs.

Technically, dose is the amount of energy (in the form of ionizing radiation) absorbed by the body per unit of its mass. However, in order to evaluate effects of radiation, consideration must be given to the type of radiation that delivered this energy, the part of the human body in which the energy was deposited. In addition, although the dimensions of dose are energy per unit mass, the dose is usually expressed in special units, rather than in units of energy per mass. In this document, in common with many radiological assessments, the term dose is used to express total effective dose equivalent (TEDE) (10 CFR 20, Section 20.1003) or committed effective dose equivalent (CEDE) (10 CFR 20, Section 20.1003), in units of rems or millirems (a one thousandth part of a rem). Effective dose equivalent expresses radiation doses that account for the type of radiation and the part of the body receiving the radiation.

Effective dose equivalent is most easily understood when broken down into its constituent parts. Dose equivalent refers to the radiation dose absorbed by a tissue or organ, multiplied by a quality factor that accounts for the different biological impacts of different types of radiation (i.e., gamma rays, beta and alpha particles) (ICRP 1977). The effectiveness of dose equivalent relates to the non-uniform or partial body irradiation that often occurs following an intake of radioactive material or exposures to radionuclide external to the body. This factor accounts for the different sensitivities of tissues to radiation (ICRP 1977). For example, the alpha particles emitted by plutonium cannot penetrate the skin, however, if plutonium is ingested or inhaled, the alpha particles can damage internal body tissues. Accounting for the effectiveness of radiation is accomplished by defining a system of tissue weighting factors such that the sum of the products of the dose equivalent to each organ and its associated tissue weighting factor yield an "effective" dose equivalent. Use of tissue weighting factors allows non-uniform exposures to be treated as if they were whole body exposures.

In this study, two types of radiation exposure were considered when determining the BDCFs: internal and external. Internal exposures result from ingestion or inhalation of radioactive materials, such that the parts of individual's body are exposed to radiation internally (e.g., the lungs or some other organ). External exposures result from the individual being in close proximity to a radiation source, which exists outside of the body.

Internal doses are expressed in terms of CEDE (10 CFR 20, Section 20.1003). When radionuclides are taken into the body, they can become distributed in various tissues and organs and continue to irradiate the body after the time of intake, such that the receptor is committed to receiving the dose over an extended period. The factors used to calculate CEDE integrate the dose that will be received by an individual during the 50-year period following intake.

A dose resulting from an external exposure to radiation can be easily expressed as the total dose the receptor would receive in a given year (i.e., annual effective dose equivalent) from all exposures to sources of radioactivity external to the receptor's body. In contrast, internal doses from radionuclide intakes during one-year period are expressed as committed doses, such that the receptor may not incur this entire dose during the year of exposure or intake. The following hypothetical examples are provided to help explain the CEDE.

Consider that all of the committed dose for a given year of exposure (say 5 mrem) was due to tritiated water (Hydrogen-3). It would be straightforward to report this as an annual dose of 5 mrem/yr. This is because the tritiated water has a biological half-life of approximately 10 days, and therefore the tritium would deliver its entire CEDE within the year of exposure. In contrast, consider that all of the committed dose for a given year of exposure (say 5 mrem) was due to plutonium-239, which has long biological (>40 yr.) and radiological (24,000 yr.) half-lives. The 5 mrem CEDE would actually be spread out over the 50-yr period for which the CEDE is calculated (i.e., an average of 0.1 mrem/yr. for 50 years).

The most accurate way to interpret the "annual dose" is to think of it as "dose associated with a single year of exposure". For example, an "annual dose" of 5 mrem/yr. means that for that year of exposure, the receptor will receive a dose of 5 mrem (which for some radionuclides may actually be spread out over a number of years subsequent to the year of exposure). Such an approach allows doses from internal and external exposures to be combined. This is referred to as TEDE (10 CFR 20, Section 20.1003), which includes both effective dose equivalent (from external exposures) and committed effective dose equivalent (from internal exposures). In the TSPA-SR, results are to be presented as annual doses in terms of TEDE.

3.1.2.2 Average Member of the Critical Group

DOE has issued guidance (Dyer 1999) to be used within the YMP for planning for the SR and draft License Application until such time as the NRC issues its final regulations. The proposed NRC regulations are at 10 CFR 63 (64 FR 8640). The DOE guidance for identification of the critical group (Dyer 1999, enclosure, Section 115(b)) is consistent with the NRC's proposed rule at 10 CFR 63.115(b) (64 FR 8640) and states the following:

"(b) Critical group.

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

(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 consideration shall be consistent with present knowledge of adults."

The critical group constructed using the above guidance and criteria should be a relatively homogeneous group of people whose location and habits are such that they represent those individuals that are expected to receive the highest doses as the result of the discharge of radionuclides from Yucca Mountain.

In order to select a critical group, individuals likely to be at the highest risk from among the exposed population must be specified. In the process, assumptions are made about the diet, nature of human activities, lifestyles and pathways that affect the level of exposure. In the case of the potential repository at Yucca Mountain, the exposed population is identified by the guidance, as stated in the beginning of this section. The primary factor that designates these individuals as the population at risk is the location relative to the potential repository (64 FR 8640, VI).

Conceptually, the process to identify the critical group is composed of three steps. The first step is to logically identify screening groups based on the framework of DOE interim guidance and criteria identified by the NRC and EPA in the proposed rules. The second step is to use data regarding dietary characteristics and behaviors of the population in the Yucca Mountain region to select a preliminary critical group that exhibits behaviors and characteristics that will result in the highest expected annual doses (Dyer 1999, Section 115). Finally, the analysis examines additional lifestyle and land use data to complete the identification of the critical group and its characteristics and attributes.

An analysis constructed four screening groups that encompass the range of diet, lifestyle, and land use characteristics expected to be found in the region surrounding Yucca Mountain. This construct of the screening groups is based on logic and the regulatory framework, including DOE guidance for the behaviors and characteristics of the critical group, and background information from NRC and EPA documents. For example, there is an NRC analogous situation whereby

NRC identifies a "Resident farmer" for contaminated soil sites (NRC 1998, p. A-2). The resident farmer is "a person who lives on the site following license termination, grows some portion of their diet on the site, and drinks water from an on-site well."

Dietary attributes included consumption of locally produced food and tap water. For the lifestyle characteristic, the identification of the screening groups included employment, recreational activities, and type of residence. The employment attribute is considered in terms of Standard Industrial Classifications in the Amargosa Valley as identified in the 1990 Census (U.S. Census Bureau 1999). The residence type attribute is also based on 1990 Census information for Amargosa Valley. Recreational attributes assessed are those common to rural areas in the western United States. Similarly, the land use characteristic attributes are common to the Yucca Mountain region (CRWMS M&O 1998c). An assessment of the characteristics of the representative farming community populations residing near Yucca Mountain, consistent with the guidance discussed above, resulted in the selection of four screening groups representing potential different types of behavior. These four screening groups and their associated attributes are discussed below.

Subsistence farmers – A group of adults who raise all of their food locally on contaminated soil, eat nothing but locally produced food, and obtain all their drinking water and irrigation water from a contaminated groundwater supply. Subsistence farmers are assumed to be employed in agriculture and engaged in outdoors recreational activities on contaminated land, including growing their own garden. Because of the nature of their activities, subsistence farmers' exposure to radionuclides present in the environment is considered high. They live in a mobile/manufactured home, the predominant housing type for the area. Their land use is agricultural on irrigated (contaminated) land.

Residential farmers – A group of adults who locally grow some of their own food on contaminated soil, eat a substantial amount of locally produced food, and obtain most of their drinking water and irrigation water from a contaminated groundwater supply. Residential farmers are assumed to be employed in outdoor occupations such as agriculture or construction on contaminated land. They are assumed to have outdoors recreational activities on contaminated land, including growing their own garden. They live in a mobile/manufactured home, the predominant housing type for the area. Their land use is assumed to be primarily agricultural or residential on irrigated (contaminated) land.

Residents – A group of adults who raise none of their own food, eat some locally produced food, and obtain some of their drinking water from a contaminated groundwater supply. Residents are assumed to be employed in either indoor or outdoor occupations, although it is less likely they are employed in agriculture. They are assumed to participate in some outdoor activities on contaminated land, although not growing their own garden. They live in a mobile/manufactured home, the predominant housing type for the area. Their land use is assumed to not be agricultural, although they have a residential use which may be on irrigated (contaminated) land.

Inhabitants – A group of adults who raise none of their own food, eat no locally produced foods, and obtain none of their drinking water from a contaminated groundwater supply. Inhabitants are assumed to be employed in either indoor or outdoor occupations, although it is less likely they are employed in agriculture. They are assumed to participate in some outdoor activities on contaminated land, although not growing their own garden. They live in a mobile/manufactured home, the predominant housing type for the area. Their land use is assumed to not be agricultural, although they have a residential use which may be on irrigated (contaminated) land.

The potential exposure of the screening groups was evaluated (CRWMS M&O 2000f) for the postulated exposure pathways associated with the dietary characteristics, lifestyle characteristics (employment, recreation, and residence type attributes), and the land use characteristics. The exposure potential determined for the screening groups is based on their dietary, lifestyle and land use characteristics and is summarized in Table 3.1. It is noted that the rankings, high to low (or none) are a measure of potential exposure level to a specific pathways among the screening groups. They are not meant to compare exposure potentials between the pathways. Exposure potential for each pathway is determined independently of other pathways. A "high" ranking in one pathway is not necessarily equivalent to a "high" ranking for another pathway.

Based on the results of exposure potential for the screening groups, the relative ranking, by exposure potential, of essential characteristics and attributes (such as diet, lifestyle, and land use) of the screening groups was determined. The ranking is the result of the sensitivity analysis (CRWMS M&O 2000f). This concept is depicted in Figure 3-4.

The screening groups were analyzed against known data. First, dietary attributes of the four screening groups were examined against data collected through the 1997 Food Consumption Survey (DOE 1997, CRWMS M&O 1999f). The 1997 survey was conducted to collect dietary and lifestyle information on adults residing within the 50-mile radiological monitoring grid centered on Yucca Mountain (DOE 1997, CRWMS M&O 1999f). The purpose of this DOE-commissioned study was to gather empirical information on the consumption of locally produced food and water within the area, including the communities of Amargosa Valley, Beatty, Indian Springs, and Pahrump. The results of the study showed variations in (1) the proportion of respondents eating locally produced food and tap water and (2) the amounts of locally produced food eaten by those who do consume locally produced food and tap water. The methods and confidence levels of the survey and the resultant data are discussed in the Food Consumption Survey report (DOE 1997, CRWMS M&O 1999f).

An examination of the dietary attributes of the screening groups showed that the subsistence farmer group does not exist in the Yucca Mountain region. Thus, the "Subsistence Farmer" column in Table 3-1 can be eliminated from further consideration. The inhabitant group, as defined, consumes no locally produced food or tap water. In addition, this group does not grow a garden and thus may be expected to spend no more time outdoors on contaminated soil than do

Table 3-1. Exposure Potential of the Screening Groups for the Postulated Pathways

Screening Group/Pathway	Subsistence Farmers	Residential Farmers	Residents	Inhabitants
External exposure to penetrating radiation from soil sources while outdoors	High	Moderate	Moderate to low	Low
External exposure to penetrating radiation from soil sources while indoors	High to moderate	Moderate	Moderate to low	Low
Inhalation exposure to resuspended soil while outdoors	High	Moderate	Moderate to low	Low
Inhalation exposure to resuspended soil while indoors	Moderate	Moderate	Low	Low
Purposeful (geophagic) ingestion of soil	Low	Low	Low	Low
Inadvertent ingestion of soil	High	Moderate	Low	Low
Ingestion of drinking water from a contaminated groundwater source	High	High	Moderate	None
Ingestion of contaminated plant products	High	Moderate to high	Moderate to low	None
Ingestion of contaminated animal products	High	Moderate to high	Moderate to low	None

members of the residential farmer or resident groups. Because this inhabitant group will receive less potential exposure through the ingestion pathway (than the residential farmer or resident groups), and will not be expected to receive more inhalation or external exposure while outdoors (than the residential farmer or resident groups), a decision was made that the inhabitant group should be eliminated from consideration as not being a group that "exhibits behaviors or characteristics that will result in the highest expected annual doses" (Dyer 1999, Section 115). Finally, the dietary attributes of the residential farmer were compared with those of residents. The residential farmer is operationally defined as having a food garden, while the residents do not have a food garden. Data from the 1997 survey (DOE 1997, CRWMS M&O 1999f) indicate that 77 survey respondents exhibit residential farmer attributes and 52 demonstrate attributes of residents. The data show that, on average, the residential farmer consumes more tap water and locally produced food across all food types (except meat and milk) than does the resident. Based on the screening of the dietary attributes, it was concluded that the residential farmer group is the preliminary critical group.

Additional data were examined to identify other characteristics of the critical group. Related to the lifestyle characteristic, for the employment attribute, 1990 Census Data (U.S. Census Bureau 1999) were examined. Based on existing employment classifications in the Amargosa Valley, the highest exposure potential due to outdoor employment would be for agricultural or

Potential Exposure: Relative Ranking	Diet: Locally Produced Food & Water	Lifestyle	Land Use
High	Subsistence Farmers	Outdoor on Contaminated Land	Irrigated
	Resident Farmers		
	Residents	Outdoor on Non-Contaminated Land	
Low	Inhabitants	Indoor	Not Irrigated

00023DC_Biosphere_PMR Fig. 3-4.cdr

Figure 3-4. Relative Ranking of the Screening Groups by Exposure Potential construction workers. For the recreational attribute, outdoor activities on contaminated land have the highest potential for exposure. These data were consistent with the description of the residential farmer group. While the data could also be relevant for the resident group and inhabitant groups, these groups would not be expected to receive more inhalation or external exposure while outdoors than the residential farmer group.

These comparisons suggest that the critical group is likely to be comprised of individuals represented by the Amargosa Valley adults who exhibit the dietary characteristics and behaviors of the residential farmer screening group. Specifically, they consume some locally produced food and tap water and they have a garden. The other characteristics of the residential farmer screening group also are assumed to be accurate as they are reasonably conservative and consistent with Census data for Amargosa Valley. Thus, the residential farmer group is selected to be the critical group. The average member of the critical group has the dietary attributes (tap water and locally produced food consumption rates) shown in Table 3-16.

Food consumption information for the group of 77 respondents classified as the residential farmer group was used to develop consumption rates for locally produced food by type and for tap water. These were used to calculate BDCFs for the critical group. The sensitivity and pathway analyses for the critical group BDCFs indicated that ingestion is the most important pathway and that a small subset of parameters related to ingestion explains most of the variation in the radionuclide-specific BDCFs (CRWMS M&O 2000f). Therefore the critical group is predominantly defined by the dietary characteristics of its members. Results from TSPA and changes in the regulatory requirements and guidance will be examined to ensure this assessment and identification of the critical group remains appropriate for its intended use. As necessary, this assessment will be revised to incorporate these changes and other required refinements.

3.1.2.3 Reasonably Maximally Exposed Individual

The EPA-proposed human receptor is defined differently from the NRC's critical group and its average member discussed in the previous section. The EPA uses the high-end range of potential doses or exposures within the exposed population, called "reasonable, maximum exposure" (RME) conditions (64 FR 46976, III.B.4) to identify the receptor of interest. In the RME approach, a hypothetical individual, who is representative of the most highly exposed individuals, is selected. This individual is called the RMEI. As in the case for the identification of an average member of the critical group, the identification of the RMEI uses a series of assumptions about the lifestyle of a hypothetical individual. Also, similarly to an average member of the critical group, general characteristics of the RMEI are pre-determined by the proposed requirements. Specifically, the RMEI will meet all of the following criteria (64 FR 46976, 197.21):

(a) Based upon current understanding, lives within one-half kilometer of the junction of U.S. 95 and Nevada State Route 373, unless NRC determines that the RMEI would receive a higher dose living in another location at the same distance from the potential Yucca Mountain repository.

(b) Has a diet and living style representative of the people who are now residing in the Town of Amargosa Valley, Nevada. The DOE must use the most accurate projections which might be 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 in the assessments conducted for Sections 197.20 and 197.25.

(c) Drinks two liters of water per day from wells drilled into the groundwater at the location where the RMEI lives.

The location of the RMEI and the requirement to use site-specific dietary and lifestyle characteristics are analogous to those specified for an average member of the critical group. RMEI is required to exhibit characteristics of rural-residential lifestyle (64 FR 46976, III.B.4), which is comparable to those of a residential farmer screening group. The RMEI is presumed to have general characteristics comparable to those of the critical group members (i.e., residential farmer screening group) because that group represents the component of the Amargosa Valley population expected to experience the highest potential exposures. The requirement of a consumption rate of two liters per day of contaminated drinking water is also consistent with the survey results (DOE 1997, CRWMS M&O 1999f) obtained for the average member of the critical group (on the average, approximately 750 liters per year of tap water) (see Table 3-16).

EPA's Statement of Consideration (64 FR 46976, III.B.4) discusses a typical practice for calculating BDCFs for RMEI. The critical group pathway analyses and sensitivity studies showed that the BDCF values for most radionuclides were dominated by only two consumption rates (water and leafy vegetables) (CRWMS M&O 2000f) and BDCF values were insensitive to the remaining consumption rates. For all other ingestion pathway parameters, best estimate values were used. See Section 3.3.1 for discussion of development of BDCFs for the groundwater contamination scenario.

3.1.3 Biosphere Features, Events, and Processes

An initial set of FEPs has been created for the YMP TSPA by combining lists of FEPs identified as relevant to the YMP (CRWMS M&O 1999e). This set of FEPs consists of 1261 FEP entries from Nuclear Energy Agency of the Organization for Economic Co-operation and Development working group, 292 entries from YMP literature and site studies, and 82 FEP entries identified during YMP project staff workshops (Freeze and Swift, 1999). These FEP entries have been identified by a variety of methods, including expert judgement, informal elicitation, event tree analysis, stakeholder review, and regulatory stipulation, and the list was compiled using a methodology developed for the NRC by Cranwell et al (1990), and used by the DOE for the Waste Isolation Pilot Plant (DOE 1996). All potentially relevant FEPs have been included, regardless of origin. The compilation included FEP entries mentioned above and 151 layers, categories and headings. It resulted in a FEP list of 1786. This approach has led to considerable redundancy in the list, because the same FEPs are frequently identified by multiple sources, but it also ensured that a comprehensive review of narrowly defined FEPs will be performed.

Each FEP has been classified as either a primary or secondary FEP. The classification resulted in the identification of 310 primary FEPs. Primary FEPs are those FEPs for which detailed screening arguments are developed. The classification and description of primary FEPs strive to capture the essence of all secondary FEPs that are mapped to the primary. Secondary FEPs are either FEPs that are completely redundant or that can be aggregated into a single primary FEP.

The assignments were based on the nature of the FEPs so that the analysis and resolution for screening decisions reside with the subject-matter experts in the relevant disciplines. The resolution of other than system-level FEPs are documented in AMRs prepared by the responsible PMR groups. This section summarizes the screening decisions associated with biosphere-related FEPs. Details of the screening process are documented in the associated AMR (CRWMS M&O 2000a).

Section 115 of the interim DOE guidance (Dyer 1999, Section 115(a)(1)) requires evaluation of biosphere FEPs. In order to assess the applicability of a particular FEP, biosphere analysis chose to adopt the geological setting guidance for evaluating FEPs. The following criteria were considered (Dyer 1999, Section 114 (d) to (e)):

> "Consider only events that are estimated to have at least one chance in 10,000 of occurring over 10,000 years.
>
> Provide the technical basis for either inclusion or exclusion of specific FEP of the geologic setting in the performance assessment. Specific FEP of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission."

In addition to the above criteria, a third criterion, inconsistency with the concept of the reference biosphere and the critical group, was used to screen FEPs for applicability. This criterion is based on Section 113(c) of the DOE guidance (Dyer 1999), which requires that the performance objective of Section 113(b) be demonstrated using the reference biosphere and critical group specified in Section 115. The required characteristics of the reference biosphere and critical group identified in Section 115 are listed in Section 3.1.2.1 of this report. Due to the high degree of speculation associated with attempting to predict future human and climate development and evolution, the third criterion is used to limit the cogitation over these characteristics. Limiting these characteristics to present knowledge and current conditions achieve this goal.

A review of the list of primary FEPs considered applicable to the Yucca Mountain Project identified 47 primary FEPs that were potentially applicable to the biosphere. These primary FEPs, and associated secondary FEPs, were screened for applicability to the YMP by comparing the description of the FEPs against the criteria identified previously. A primary FEP was retained for consideration if one or more of the associated secondary FEPs were considered applicable to Yucca Mountain.

Each of the 47 primary FEPs was screened to determine whether or not it was applicable to Yucca Mountain considering the interim guidance provided by DOE. Appendix B presents a summary of the screening arguments and decisions made for each primary FEP. Twenty-two primary FEPs were determined to be applicable, in part or in total, to the biosphere. The FEPs identified as included by the screening process were used to support the conceptual model of the biosphere presented in the following section. These FEPs are presented in Table 3-2.

Table 3-2. Features, Events, and Processes Applicable to Biosphere

FEP NAME	YMP FEP DATABASE NUMBER
Wells	1.4.07.02.00
Soil type	2.3.02.01.00
Radionuclide accumulation in soils	2.3.02.02.00
Soil and sediment transport	2.3.02.03.00
Precipitation	2.3.11.01.00
Surface runoff and flooding	2.3.11.02.00
Biosphere characteristics	2.3.13.01.00
Biosphere transport	2.3.13.02.00
Human characteristics (physiology, metabolism)	2.4.01.00.00
Diet and fluid intake	2.4.03.00.00
Human lifestyle	2.4.04.01.00
Dwelling	2.4.07.00.00
Agricultural land use and irrigation	2.4.09.01.00
Animal farms and fisheries	2.4.09.02.00
Drinking water, foodstuffs and drugs, contaminant	3.3.01.00.00
Plant uptake	3.3.02.01.00
Animal uptake	3.3.02.02.00
Bioaccumulation	3.3.02.03.00
Ingestion	3.3.04.01.00
Inhalation	3.3.04.02.00
External exposure	3.3.04.03.00
Radiation doses	3.3.05.01.00

Of the FEPs that were excluded from consideration, the majority were excluded on the basis of inconsistency with the requirements for a reference biosphere and critical group as identified in the DOE guidance. Those FEPs that were related to changes in or alteration of environmental conditions, e.g., changes in present day topography, global climate change, effects of glaciers and ice sheets, ozone layer failure, were excluded on the basis that the FEP was not reflective of current conditions as is required by Section 115 of the guidance from DOE. Similarly, other FEPs that consider societal and behavioral characteristics of receptor of interest that are not reflective of current lifestyle and behavioral characteristics of the residents of Amargosa Valley, Nevada, e.g., societal and institutional development, technological development, hunter gatherer lifestyle, were also excluded on the basis of inconsistency with the guidance provided in Section 115. FEPs that were location-dependent such as those that considered groundwater outfalls, i.e., Franklin Lake Playa which is approximately 60 km south of the potential repository location, were excluded on the basis of inconsistency with the critical group location requirement in the guidance.

3.1.4 Description of Conceptual Model

The biosphere conceptual model for the Yucca Mountain consists of assumptions, simplifications, and idealizations that describe the essential aspects of the biosphere in the vicinity of the Yucca Mountain. The model is used to evaluate the transport of radionuclides released from the source of contamination throughout the biosphere to the human receptor. The receptor of interest is discussed in Section 3.1.2.

The biosphere conceptual model provides a mechanism for the evaluation of BDCFs from selected pathways to a defined receptor for two radionuclide-release scenarios. The first release scenario is that of pumping contaminated groundwater to be used in a hypothetical farming community under undisturbed, or nominal, repository performance, and for some disruptive processes and events, such as seismic events and human intrusion. In the second scenario, the release is due to a volcanic discharge through the repository leading to atmospheric dispersal of the contaminants into accessible environment through an ash fall. In both scenarios contamination of soil occurs.

The biosphere conceptual model includes the following components: surface soil above the lower bounds of the plant root zone (including volcanic ash in the case of disruptive volcanic event scenario), surface water, the atmosphere, flora and fauna. In other words, the lowest boundary of the biosphere conceptual model is at the bottom of the plant root zone, and it includes all biological components that may be a part of potential pathway of radionuclides to humans. The biosphere conceptual model does not include processes related to atmospheric transport and dispersion of airborne radionuclides. In the context of postclosure performance assessment, such processes are considered in relation to the atmospheric transport of contaminated ash from the erupting volcano to the receptor's location. This component is modeled within the disruptive event model (*Disruptive Events PMR* (CRWMS M&O 2000q)). Biosphere model does consider airborne activity resulting from resuspension of contaminated soil or contaminated ash. Therefore the contribution from inhalation of resuspended contaminated soil or ash is included in the BDCFs.

The primary function of biosphere conceptual model is to support calculations of BDCFs. The BCDFs account for: (1) environmental transport of radionuclides by converting radionuclide concentrations at the source, such as groundwater, to concentrations in relevant biosphere media such as plants and animals; and (2) radionuclide uptake via, and external exposure to, environmental media and resulting dose factors. BDCFs are therefore functions of environmental transfer factors, exposure factors and dosimetric factors. Environmental transfer factors convert radionuclide concentration in water to concentration in a biosphere medium (e.g., plants, meat, milk, eggs). Exposure factors include parameters such as ingestion rate and exposure time (e.g., how much beef a receptor eats per year, how much time a receptor spends outdoors). Dosimetric factors convert internal and external exposures to radiation to doses. They account for the biological effectiveness of various types of radiation and the different sensitivities of various body tissues to radiation. Dosimetric factors are specific to each radionuclide and the mechanism by which they expose the receptor (e.g., direct radiation, ingestion, and inhalation).

The objective of the biosphere modeling effort is to determine the values of BDCFs for those radionuclides expected to enter the biosphere, considering all of the important exposure pathways. Radionuclide-specific BDCFs quantify radionuclide transport, intake and external exposure, and the resulting doses per unit of activity concentration at the source. They are calculated for a specific receptor of interest and they combine contributions from various exposure pathways, such as ingestion of food, water, inadvertent ingestion of soil, inhalation, and exposure to radionuclide external to the body.

BDCFs are multipliers, or factors, used in the TSPA model to convert radionuclide concentration at the source of contamination into radiation dose that a human receptor would receive from exposure pathways under consideration. For the groundwater contamination scenario (see Section 3.1.5 for discussion of exposure scenarios), annual doses are estimated by multiplying radionuclide concentration in groundwater by the appropriate BDCFs. For disruptive volcanic event scenario the doses are obtained by multiplying surface activity deposition of a radionuclide by the corresponding BDCF.

DCFs are expressed in terms of annual dose, i.e., TEDE or CEDE, per unit of activity concentration at the source of contamination. BDCFs are independent of the actual activity concentration in groundwater or activity concentration in the layer of volcanic ash deposited on the soil surface. Calculations of radionuclide concentrations in groundwater are developed in the TSPA code. They are based on the mass flux break-through curves, which are summarized in the *Saturated Zone Flow and Transport PMR* (CRWMS M&O 2000r). Calculations of contaminated ash deposition for disruptive volcanic events are described in *Igneous Consequence Modeling for TSPA-SR* AMR (CRWMS M&O 2000u), which supports *Disruptive Events PMR* (CRWMS M&O 2000q).

3.1.4.1 Model Development

The biosphere system at Yucca Mountain is represented by the reference biosphere. A starting point for biosphere conceptual model development is the requirement that "[f]eatures, events, and processes that describe the reference biosphere shall be consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain site" (64 FR 8640, Section 63.115(a)(1), Dyer 1999, Section 115). To meet this requirement, any conceptual model of the biosphere around Yucca Mountain must be based on FEPs that are reflective of current conditions. Section 3.1.3 provides a list of FEPs that have been identified as reflective of current conditions and considered applicable to the conduct of performance assessment for Yucca Mountain.

For the groundwater contamination scenario, the entry point for contaminants present in groundwater into the biosphere is a groundwater well head. For the disruptive volcanic event scenario, volcanic ash deposition on the soil is an entry mechanism for the radionuclides released from the repository to the biosphere. It is assumed that the human receptor's water supply is extracted from a groundwater well that is similar to wells that currently exist. For the disruptive volcanic event scenario, an eruption would carry ash contaminated with radioactive material from the potential repository to the vicinity of the human receptor. Volcanic event modeling reported in the *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000u), has been used to identify the characteristics of volcanic eruption and the details of contaminated ash transport.

3.1.4.2 Conceptual Model of the Biosphere

As discussed in the previous sections, the attributes of the current biosphere model are based on a set of FEPs that conform to the proposed rules. These attributes, while sometimes appearing to be abstract, reflect the elements of a semi-arid environment in the Yucca Mountain vicinity and the possible processes leading to radionuclide transport in this environment. Generally, the reference biosphere, where the hypothetical farming community exists, is located geohydrologically downgradient from the potential repository. Therefore, it is conceivable that in the future radionuclide may be present in the groundwater at the well head used by the receptor at the location approximately 20 km south from the potential repository. In the case of volcanic eruption intercepting the potential repository, contaminated volcanic ash may reach the hypothetical farming community in the biosphere.

For the groundwater contamination scenario, a farmer is assumed to use contaminated groundwater for irrigation and consumption. Contaminated groundwater used for irrigation causes contamination of soil, and, subsequently, contamination of edible crops, as well as animal feed. Contaminated animal feed results in contamination of animal food products, such as milk, meat and eggs. In addition, small particles of soil contaminated by irrigation may become resuspended. Resuspended contamination, if deposited on the crops, adds to the contamination caused by irrigation with contaminated water. A person may also inhale resuspended contamination. Contaminated soil is a source of external irradiation to a person from radionuclides emitting penetrating radiation, which are either present in soil or deposited on the soil surface. For the disruptive volcanic event scenario, contamination becomes initially deposited on the ground. However, following the contaminated ash deposition, the processes of radionuclide migration through the biosphere are similar to those for the groundwater contamination scenario.

Figures 3-5 and 3-6 present an illustrative, but not comprehensive, block diagram of the biosphere conceptual model for groundwater contamination scenario and for disruptive volcanic event scenario, respectively. The figures show important mechanisms of radionuclide migration in the biosphere from the source of contamination to the human receptor for the primary pathways relevant to the scenarios under consideration. The diagram for the disruptive volcanic event scenario, where volcanic ash in the source of contamination, does not include components related to irrigation and drinking water consumption. Important parameters controlling radionuclide transport in the biosphere are also identified in the diagrams. These parameters and their specific functions in the model are described in greater detail in Section 3.2.4.

Ingestion, inhalation and external exposure are the major exposure pathways included in the conceptual model of the biosphere. Ingestion pathway includes drinking of contaminated water,

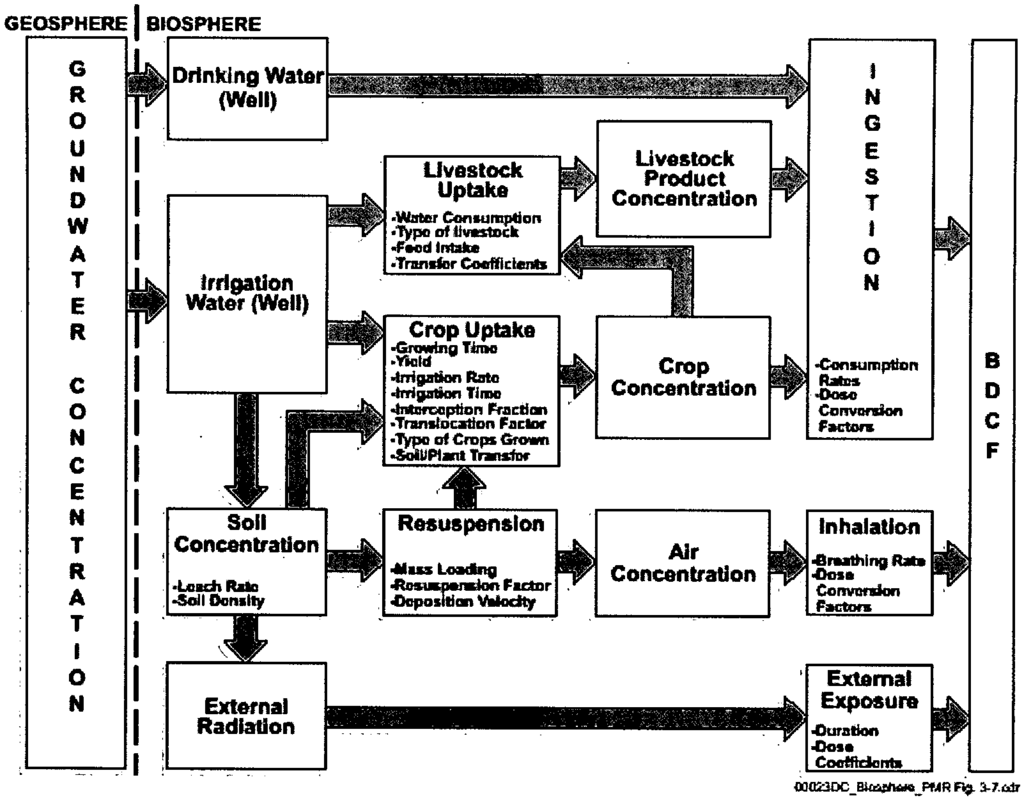


Figure 3-5. Block Diagram of Biosphere Conceptual Model for Groundwater Contamination Scenario

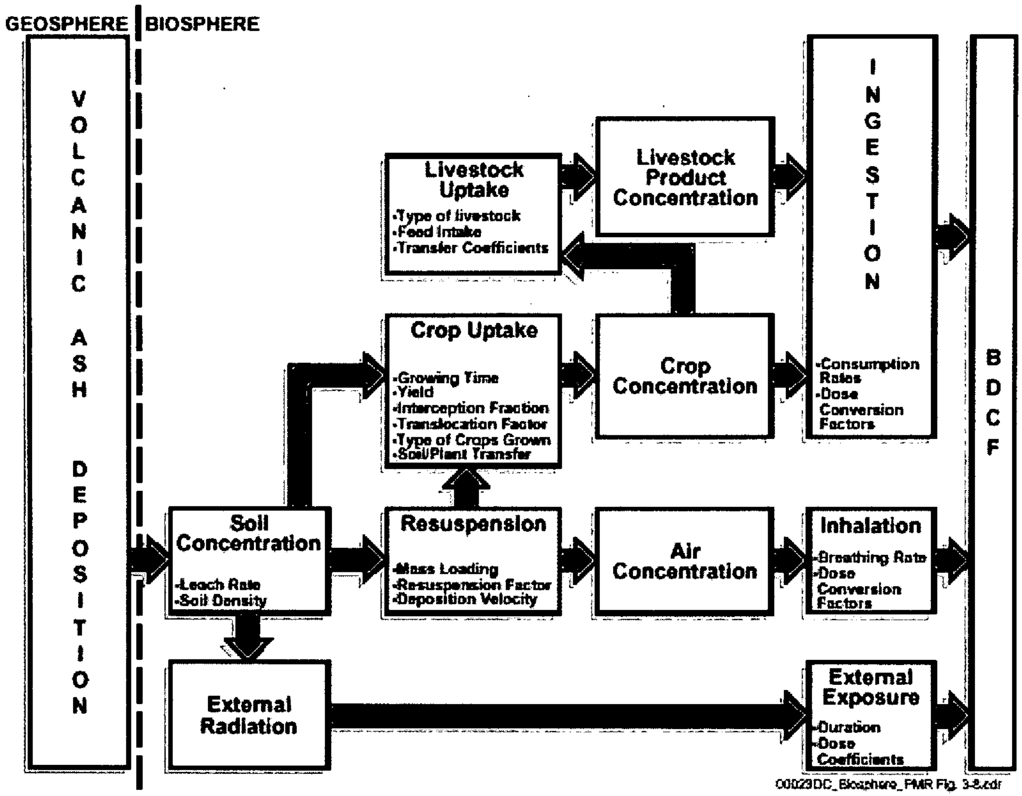


Figure 3-6. Block Diagram of Biosphere Conceptual Model for Disruptive Volcanic Event Scenario

consumption of locally produced crops that have been irrigated with contaminated groundwater, consumption of meat and dairy products from livestock that have been sustained on contaminated water, and ingestion of contaminated soil. The biosphere conceptual model allows for the assumption that livestock and poultry are sustained with some quantity of locally grown feed (e.g., pasture and seasonally harvested alfalfa). Thus, these animals are exposed to the radionuclides by consuming the radionuclides present in, or on, the plant tissues. Alfalfa is the predominant crop produced by the Amargosa Valley community and alfalfa and forage grasses comprise a major proportion of Nye County agricultural land (CRWMS M&O 1998c, Tables 3-10 and 3-11). Another component of the ingestion pathway is the inadvertent ingestion of soil. In most cases, soil ingestion tends to be a minor contributor to exposure compared to the food ingestion pathway (CRWMS M&O 2000f, Section 7; CRWMS M&O 2000k, Section 7).

The primary inhalation pathway is through breathing of resuspended soil and volcanic ash during outdoor activities such as farming and recreation. This pathway includes expected inhalation of ash during disruptive volcanic event. Some of the factors that determine the degree of exposure, through dust resuspension, are the prevailing meteorological conditions (dry/wet and calm/windy), size and mineralogical composition of the soil particles, their ability to sorb radionuclides, and the time spent outdoors by residents.

The external pathway occurs as a result of direct exposure to the radiation emitted by radioactive materials external to the body (e.g., those present in the soil or on the soil surface). Duration of exposures depends on the amount of time spent outdoors.

The magnitude of exposure from a number of pathways described above depends on the radionuclide concentration in soil. The dynamics of the radionuclide concentration in the top layer of soil are governed by a conservation equation where the rate of change in radionuclide concentration in a volume of soil is equal to the quantity flowing in (from either irrigation or ash fall) minus the amount being removed. Mechanisms of potential radionuclide removal from the soil include radioactive decay, plant uptake, leaching into the deeper soil layer and physical loss of soil (i.e., erosion by wind and water). Continual land use with the attendant tilling may accelerate the erosion process.

Countering the removal of radionuclides from the soil is the continual addition of radionuclides from irrigation. For a given set of parameters, continual irrigation may cause an increase in the radionuclide concentration of the soil until a steady-state equilibrium is reached. Because all primary exposure pathways (i.e., ingestion, inhalation, and external exposure) are dependent in some way on the radionuclide concentration in soil, the BDCFs will increase as a function of continuing irrigation until the radionuclide concentration equilibrium is reached in soil. This is demonstrated in the AMR titled *Abstraction of BDCF Distributions for Irrigation Periods* (CRWMS M&O 2000h) and shown in Figure 3-7 of this PMR.

3.1.5 Exposure Scenarios

Exposure scenarios establish the circumstances of human exposure to radionuclides present in the biosphere. Two exposure scenarios were evaluated in this PMR: exposure from groundwater contamination and exposure from a disruptive volcanic event. Groundwater contamination scenario includes the conditions of undisturbed performance as well as some disruptive events and processes that may lead to groundwater contamination, such as seismic events and human intrusion. Each scenario represents a different combination of FEPs and therefore has different exposure pathways.

Exposure scenarios were defined in a two-step process. First, the geosphere-biosphere interface was defined. For the groundwater contamination scenario, the radionuclide entry point to the biosphere is a well head. For the disruptive volcanic event scenario, the interface is from the volcanic ash deposition on the soil surface. Second, the conditions that would lead to radionuclide intake and external exposure were determined and the applicable exposure pathways were identified based on the site-specific environment and assumptions about the human receptor group. For all scenarios, present-day practices by a farming community were considered, and commercial and industrial activities were excluded. Exclusion of activities other than farming was due to the fact that farming activities involve more exposure pathways than other known activities of the region, and that the large demand for groundwater for irrigation associated with farming increases the likelihood of contamination and uptake by humans.

3.1.5.1 Groundwater Contamination Scenario

The groundwater contamination scenario is used to evaluate the radiological consequences of both undisturbed potential repository system performance as well as the consequences of selected disruptive processes and events. The latter include potential consequences of earthquakes and igneous intrusions as well as consequences following a stylized human intrusion event. Human intrusion is assumed to result in breaching of the potential repository's geologic and engineered barriers. The event involves drilling a borehole through a degraded waste container into the aquifer underlying the Yucca Mountain site. Water infiltration through the borehole enables radionuclide transport to the saturated zone. Radionuclides may enter the biosphere when the groundwater is used by humans. For the groundwater contamination scenario, a groundwater well head is considered the source of drinking water; irrigation; animal watering and domestic uses, including gardening.

Groundwater contamination scenario is based on proposed rules (64 FR 8640, Section 63.115; 64 FR 46976, Section 197.21) and interim guidance (Dyer 1999, Section 115) that assumes that the affected hypothetical farming community is located in the Amargosa Valley region 20 km from the potential repository at Yucca Mountain. This location represents the area closest to the potential repository, downgradient for radionuclide releases in the groundwater, where the depth of the water table is accessible for agricultural practices. Soil conditions at this location are generally similar to those further downgradient, near Amargosa Valley, where farming is currently practiced. Contaminated well water is the only way that radionuclides from the potential repository reach this hypothetical farming community.

The receptor of interest is an average member of the critical group or the RMEI. The critical group is representative of individuals from the hypothetical farming community whose behavioral characteristics will result in the highest exposures among the individuals in the community. The average member of the critical group is an adult who lives year-round at this location, uses a well as the primary water source, and otherwise has habits (e.g., consumption of locally-produced foods) that are similar to those of the current population of the Amargosa Valley. The RMEI is assumed to be an individual whose general characteristics are comparable to those of the critical group (see Section 3.1.2) and who is representative of most highly exposed individuals.

The routes taken by radionuclides through the biosphere from the source to a person are called exposure pathways. The analysis considered pathways that are typical for hypothetical farming community. Farming activities usually involve more exposure pathways than other human activities in the Yucca Mountain region, including ingestion through consumption of contaminated water, crops and animal products; inhalation and direct exposure from surface contamination intensified by the significant outdoor activity of a farming lifestyle.

The following exposure pathways were considered for groundwater contamination scenario:

- Consumption of tap water
- Consumption of locally produced leafy vegetables
- Consumption of other (root) locally produced vegetables
- Consumption of locally produced fruit
- Consumption of locally produced grain
- Consumption of locally produced meat (beef and pork)
- Consumption of locally produced poultry
- Consumption of locally produced milk
- Consumption of locally produced eggs
- Consumption of fish
- Inadvertent soil ingestion
- Inhalation of resuspended particulate matter
- External exposure to contaminated soil.

Pathways related to sediments and surface water were not considered because the current environment in the Yucca Mountain region lacks these features.

The contribution to a BDCF from a specific pathway depends on the amount of contamination the human receptor comes in contact with, either through intake or through external exposure. Radioactivity intake may occur through inhalation or ingestion. The magnitude of the BDCF contribution from ingestion depends on the activity concentration in consumed products and the rate of consumption of these products. The magnitude of inhalation contribution to the BDCF (e.g., from breathing resuspended soil and dust during outdoor activities, such as gardening and recreation) is influenced by the amount of resuspended particulate matter in the air, breathing rate, as well as the amount of time a person is exposed to a given concentration of radioactivity in the air. BDCF component from the external exposure pathway results from exposure to a radiation sources that are external to the body, such as contaminated soil. For this pathway, the contribution depends on the amount of time a person is exposed to activity in the soil.

3.1.5.2 Disruptive Volcanic Event Scenario

The disruptive volcanic event scenario provides the framework for evaluation of radiological consequences of volcanic eruption. The source of contamination for this scenario is the deposition of contaminated volcanic ash on the soil surface. For this scenario, it was assumed that a volcanic eruption would result in a thin ash deposition on the soil surface. This assumption was based on the results of TSPA-VA calculations, which predicted the average ash thickness of 0.008 cm at the location 20 km south from the potential repository (Burck 1999). In addition, as a part of sensitivity analysis (Section 3.3.2.2), the consequences of increased concentrations of suspended particulate matter in air, that may be associated with volcanic eruption, were evaluated. The amount of ash deposition is assessed in the *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000u). Work in progress indicates that the results of these analyses will have to be examined to assess the consequences of different than assumed contaminated ash deposition on the ground and particulate matter concentration in air.

The initial surface deposition of ash is assumed to eventually become evenly distributed throughout the upper soil layer and uniformly contribute its activity to that layer. A 15-cm-thick upper soil layer was selected because this depth encompasses the root zone of most agricultural crops (see Section 3.2.4.1.2 for discussion). The average ash-blanket thickness of 0.008 cm (Burck 1999), is much less than 15-cm thickness of surface soil layer. Therefore it was assumed that the ash-soil mixture had physical and chemical properties of native soil.

The conditions for radionuclide intake and external exposure are assumed to be similar to those considered for groundwater contamination scenario. The human receptor is assumed to live year-round in the hypothetical farming community; is involved in the activities typical of the current inhabitants of the region; and has habits, such as consumption of locally-grown foods, that may result in a radiation dose.

For calculation of BDCFs for disruptive volcanic event scenario, the groundwater was considered to be uncontaminated because this factor is considered separately under the groundwater contamination scenario. Doses resulting from the combination of groundwater contamination and volcanic eruption can be calculated in the TSPA model by combining dose contributions from both scenarios.

Because the groundwater is considered to be uncontaminated, pathways resulting from groundwater contamination (e.g., consumption of water and consumption of fish) were excluded. Other pathways were the same as those considered for the groundwater contamination scenario and they were as follows:

- Consumption of locally produced leafy vegetables
- Consumption of other (root) locally produced vegetables
- Consumption of locally produced fruit
- Consumption of locally produced grain
- Consumption of locally produced meat (beef and pork)
- Consumption of locally produced poultry
- Consumption of locally produced milk
- Consumption of locally produced eggs
- Inadvertent soil ingestion
- Inhalation of resuspended particulate matter
- External exposure to contaminated soil.

3.2 MATHEMATICAL REPRESENTATION OF THE BIOSPHERE

The development of a mathematical representation of the conceptual model and the development of an assessment tool (computer code) based on the mathematical representation of such model are the next steps in the biosphere modeling process. In principle, an assessment-specific tool may be developed. For the YMP biosphere modeling, existing computer codes were evaluated to determine their relevancy to the Yucca Mountain assessment context and biosphere system. This evaluation and selection process is described in Section 3.2.1.

GENII-S, *A Code for Statistical and Deterministic Simulations of Radiation Doses to Humans from Radionuclides in the Environment* (Leigh et al. 1993) was chosen as the assessment tool to support the biosphere modeling for TSPA–SR. A brief description of the models used in GENII-S is presented in Section 3.2.2. Model validation is discussed in Section 3.2.3. Section 3.2.4 discusses input parameters in the context of the model and describes the selection of parametric values.

3.2.1 Computer Code Selection

There are available codes designed for modeling of environmental transport and performing multipathway dose calculations. Description of these codes and selection of GENII-S as the applicable code are addressed in this section.

3.2.1.1 Selection Criteria

The following eight criteria were established for selecting a computer code used for postclosure biosphere modeling (Harris 1997). The code should:

1. Be acceptable by regulatory agencies for the purpose of environmental dose assessment.

2. Use methodology specified by regulations (i.e., International Commission on Radiological Protection (ICRP)-30 methodology).

3. Address all or most of the significant FEPs developed for Yucca Mountain.

4. Assess chronic release scenario.

5. Perform stochastic modeling for uncertainty analysis.

6. Stipulate food and water consumption patterns to reflect the characteristics of critical group.

7. Use radionuclide concentrations in groundwater as source term for groundwater contamination scenario.

8. Be an existing computer software.

The evaluation of available codes in the next section is based on these eight criteria.

3.2.1.2 Available Computer Codes

Extensive studies on environmental radiological assessment have been conducted in the past, and several computer codes have been developed. The Energy Science and Technology Software Center (ESTSC) and the Radiation Safety Information Computational Center (RSICC) are the primary sources for DOE and NRC sponsored models and software. These two entities serve as a clearinghouse of environmental fate and transport and various dose assessment software (ESTSC is operated by the DOE Office of Scientific and Technical Information (OSTI), while RSICC is sponsored by Oak Ridge National Laboratory).

Relevant computer codes were evaluated by reviewing the scientific literature, consulting with technical experts, and searching the two scientific software entities described above. Seven available codes were compared against the selection criteria listed in Section 3.2.1.1. The results of comparison are summarized in Table 3-3.

CAP-88PC (Oak Ridge National Laboratory (ORNL) 1995) and AIRDOS-PC (ORNL 1990) use straight-line Gaussian plume models to calculate radiation dose due to chronic atmospheric releases but cannot assess groundwater release scenarios. Similarly, RASCAL (ORNL 1998) only calculates doses from air releases and is intended to be used in an accidental release situation. Although RESRAD (Yu et al. 1993) is used for environmental dose assessment, it is designed for calculating dose from residual radioactive materials in soil and is not suitable for evaluating groundwater and atmospheric releases. MEPAS (Buck et al. 1995) is another multi-pathway environmental pollutant assessment code for both chemical and radioactive contaminants. However, the assessment end point is focused on health risk in MEPAS. Both GENII (Napier et al. 1988) and GENII-S (Leigh et al. 1993), the stochastic version of GENII, can use groundwater as well as atmospheric releases as the source terms and calculate radiation dose to man based on user defined parameters and pathways.

3.2.1.3 Justification for Choosing GENII-S

GENII-S was found to be the most comprehensive code available for biosphere modeling. It is flexible enough to address the FEPs applicable to Yucca Mountain and has been accepted and used by the regulatory agencies for environmental dose assessment. DOE has used this code for the Waste Isolation Pilot Plant performance assessment as a part of application for a certificate of compliance from EPA, and the Center for Nuclear Waste Regulatory Analyses (CNWRA), an NRC supporting contractor, is using GENII-S as one of the codes to conduct the performance assessment for the potential high-level radioactive waste repository at Yucca Mountain. For the postclosure assessment, GENII-S, when coupled with unit groundwater radionuclide concentrations as the source terms, is able to calculate BDCFs for a human receptor based on user-defined parameters and pathways. Because GENII-S meets all eight criteria (Table 3-3), it was selected as the computer code used for the biosphere modeling for the YMP.

GENII-S has been successfully used for the TSPA-VA effort. GENII-S is an acquired software, which was qualified for use on the YMP (CRWMS M&O 1998d). The software consists of executable program and auxiliary files, all of which are maintained under Configuration Management (CSCI: 30034 V1.4.8.5). GENII-S was considered appropriate for this application and was used within the range of validation (see Section 3.2.3 for discussion of model validation).

Table 3-3. Results of Code Comparison

Code Name	Description and Primary Use	Evaluation Criteria[a]							
		1	2	3	4	5	6	7	8
CAP-88PC	Calculates maximum individual and population dose from chronic air releases of radionuclides	x	x		x		x		x
AIRDOS-PC	Calculates maximum individual and population does from chronic air releases of radionuclides	x	x		x				x
RASCAL	Calculated dose from a radiological accident	x	x						x
RESRAD	Calculates site-specific residual radiation contamination guidelines	x	x		x		x		x
MEPAS	Calculates health risks from radionuclides and chemicals via air and water pathways	x	x	x	x		x	x	x
GENII	Calculates doses from air and water releases of radionuclides via various pathways	x	x	x	x		x	x	x
GENII-S	GENII with stochastic analysis capability	x	x	x	x	x	x	x	x

[a] See Section 3.2.1.1.

3.2.2 Description of the Models Numerically Implemented by GENII-S Code

The GENII-S computer code is constructed upon a mathematical representation of radionuclide migration in the biosphere coupled with the models that enable radiation dose assessment. Using a comprehensive set of environmental pathway models, the code calculates the environmental transport of radionuclides following initial contamination of groundwater (undisturbed performance, seismic events and human intrusion) or soil (disruptive volcanic event scenario). Based on the source term and the exposure scenario, radionuclide transport as well as human uptake and external exposure are assessed for key radionuclides. Radionuclide concentrations in water, air, soil, and various foodstuff, combined with intake and external exposure rates are subsequently converted to internal and external radiation doses. In the context of biosphere modeling for the potential repository at Yucca Mountain, the GENII-S code was used to calculate BDCFs rather than radiation doses. The entire process is an effort to describe the complex behavior of radionuclides in the environment and in humans using a mathematical abstraction. The results of this modeling process are influenced by all uncertainties associated with the model itself as well as with the model parameters (see Sections 3.3.1.1.2 and 3.3.2.2 for discussion of uncertainty and sensitivity analysis). A description of the environmental transport and uptake models implemented by the GENII-S computer code, which are important for biosphere modeling for performance assessment, is included Appendix C.

3.2.3 Validation of the Biosphere Model

The YMP biosphere model is a synthesis of two parts – the biosphere conceptual model and the generic mathematical model. The conceptual model was created from facts derived from the characterization of the Yucca Mountain environs, projected future conditions of living in that area, and current guidance. The generic mathematical model exists within the GENII-S computer software. For purposes of model validation, application of the GENII-S software using input parameter values derived from the YMP biosphere conceptual model has been conservatively interpreted to be a YMP-specific model of the biosphere. The validity of the model depends on the accurate characterization of the Amargosa Valley/Yucca Mountain biosphere, the correct derivation of GENII-S input settings and parameter values to represent the biosphere conditions, and the proper operation of the GENII-S software. To validate a model of a more complex nature, direct observation of the outcome may not be possible. In the case of YMP biosphere, observation of the actual outcome will not be possible for many years, if ever.

The current knowledge of the biosphere is extensive and well-documented. Because of the semi-arid climate, low population and other characteristics, the number and complexity of exposure pathways and vectors that need to be considered is limited, and the choices of how to numerically represent biosphere conditions in the model are relatively straightforward. The input parameter values used in GENII-S have been selected, and documented in AMRs. As described in Section 3.2.1.3, GENII-S is a versatile and widely-used computer code. It has been extensively reviewed by the scientific and regulatory communities and has been the subject of several documented environmental analysis software intercomparison studies. By proper selection of settings and input parameter values, it can be used to represent a wide variety of environmental transport pathways and exposure conditions. Because the GENII-S software is an integral part of the YMP biosphere model, verification that it is working properly is an essential part of the model validation.

In recognition of the unique nature of the YMP biosphere model, a validation process was developed to further enhance confidence that the YMP biosphere model is technically sound and appropriate for its intended use. Specifically:

- The features, events and processes at work in the YMP biosphere were assessed and parameterized in a technically defensible manner.

- The GENII-S software, as installed, operates correctly and gives results consistent with the inputs.

- The YMP BDCFs are reasonable when compared with results of other calculations and alternative conceptual models.

To verify the GENII-S code, as installed, operates correctly and gives results consistent with the inputs, the GENII-S software, as received from the RSICC, was subjected to YMP software qualification. The qualification process made use of test cases supplied by the software developer to verify that the software, as installed on YMP computers, produced outputs consistent with values expected for a prescribed set of inputs. In addition, a special test case tailored to exercise all the GENII-S pathways and features relevant to the YMP analyses was developed. The expected results of the case were calculated by hand using the equations from the GENII-S mathematical model. Acceptance criteria were established for comparison of the GENII-S output with the results of the hand calculations (agreement between GENII-S results and published or hand calculation results within ±5 percent). The test cases were successfully completed and the software was designated qualified software. The qualification of the GENII-S software is documented in (CRWMS M&O 1998d).

The validation process consisted of two elements:

Comparison of the YMP BDCFs With Results of Other GENII-S Calculations and Conceptual Models–This validation element ensures that the YMP BDCFs are reasonably consistent with results of similar modeling efforts. Two recent applications of the GENII-S computer code to the YMP biosphere (LaPlante and Poor 1997, CRWMS M&O 1998e) provided a basis for comparison of the predicted dose to a human receptor as a result of radioactive contaminants in the environment. For most radionuclides addressed in the two referenced reports the annual TEDE from unit concentrations in groundwater agreed fairly well (within a factor of 8 or less) with the YMP BDCFs (CRWMS M&O 2000a). There were differences between some input parameter values used for the YMP BDCF determinations and the values used in the other analyses. However, those differences were inconsequential with regard to groundwater contamination BDCF values.

Independent Review by the Subject Expert–To enhance confidence in the YMP biosphere model, an independent technical review of the model was commissioned. The review, by a principal architect of the GENII computer code and nationally-known expert in environmental dose assessment, focused on characterization of the biosphere, the process for deriving GENII-S inputs, and the values of those inputs. First, the independent reviewer examined a variety of characterization reports and other descriptive information and determined that the YMP biosphere model reasonably reflects the current environmental conditions in the Amargosa Valley. Next, the reviewer considered the methods used to produce values for the GENII-S input parameters, as documented in various AMRs. It was concluded that the methods, references, and data sources used by the YMP analysts were sound. Finally, the specific values of the GENII-S input parameters used to develop BDCFs were examined. With minor exceptions, the reviewer concluded that the GENII-S input values were reasonable for the environmental conditions of the biosphere model. The significance of these exceptions was minimal for the groundwater contamination scenario. The details of the independent technical review of the biosphere conceptual model and parameterization are documented in (CRWMS M&O 2000a).

Based on the successful completion of the validation process and meeting all the predetermined validation criteria, it was determined that the YMP biosphere model is appropriate and adequate for its intended use (CRWMS M&O 2000a).

3.2.4 GENII-S Input Parameters

Since the biosphere system is complex in nature, any biosphere model is, inevitably, a simplified version of the reality on which it is based. For the biosphere dose assessment, selection of models and model parameters follows general assessment philosophy, which provides an indication of how uncertainties in the biosphere model and the model parameters should be addressed. For biosphere modeling, the assessment philosophy uses generally conservative assumptions in order to ensure that the results are unlikely to underestimate the corresponding values of BDCFs for the considered radionuclide transport and uptake conditions and mechanisms.

For the biosphere modeling, some parameters were obtained from field measurements and the regional survey, while the others were derived from existing literature. Literature data regarding the determination of parameter values are highly variable. They range from large amounts for some parameters to small or negligible amounts for other parameters. The sources of information span scientific articles in reviewed journals, unpublished 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 data applicability for the conditions other than the original ones, and the ability to define the distributions and ranges of parameters.

This section focuses on parameter value selection for the user-defined parameters in the GENII-S model. When performing BDCF calculations, a large quantity of parameters is encountered. These parameters can be classified into two main groups: (1) the parameters that influence, or are related to, the transport and accumulation in the biosphere; (2) the parameters related to characteristics of the human receptor (i.e., consumption patterns, dosimetric parameters, lifestyle characteristics, and land use). Following the general approach, each parameter's value represents reasonably conservative estimates. Not every input parameter was selected as a probabilistic distribution. In general, parameters with large uncertainty or with a major influence on the final BDCF were selected as distributions. Otherwise, a fixed value was used.

To better explain how the parameters are used in the context of the biosphere model, the description is structured around the model representations shown in Figures 3-5 and 3-6. The section titles in most cases correspond to the compartment titles in these figures.

3.2.4.1 Parameters Pertaining to the Environmental Transport of Radionuclides

This section describes parameters relevant to environmental migration of radionuclides from the source of contamination. The strategy was to use the values of environmental parameters that correspond to the conditions in the vicinity of the Yucca Mountain.

3.2.4.1.1 Drinking Water and Irrigation Water

Drinking Water and Irrigation Water parameters (see Figure 3-5) describe the selection of water sources and water treatment for the human receptor.

Irrigation Water Source – Groundwater is the only source of irrigation water for the local production of terrestrial food (leafy vegetables, other vegetables, fruits, and grains), fresh feed (for beef cattle and dairy cows), and stored feed (poultry and eggs). The estimates for these parameters are based on firsthand observation of current climate, irrigation infrastructure, and agricultural practices in the vicinity of Yucca Mountain, particularly in the Amargosa Valley (CRWMS M&O 2000c, p. 16).

Fraction of Water That Is Contaminated – Based on the guidance from DOE on the use of the proposed NRC regulations regarding the definition of the critical group (Dyer 1999, Section 115), it is conservatively assumed that 100 percent of the local groundwater available in the hypothetical farming community in which the critical group resides is contaminated. Thus, for each of the following parameters, it is assumed that the fraction of the water that is contaminated is 1.0:

- Drinking water for human consumption
- Water for beef cattle and dairy cow consumption
- Water for poultry and laying hen consumption
- Irrigation water for terrestrial food (leafy and root vegetables, fruit, and grain for human consumption)
- Irrigation water for production of fresh and stored feed (grain, hay, and forage for consumption by beef cattle and dairy cows, poultry, and laying hens).

This assumption results in conservative estimates for the fractions of water for human and animal consumption, and crop and feed production that are contaminated (CRWMS M&O 2000c, p. 16).

Drinking Water Treatment and Holdup Time – It is assumed that there is no treatment (i.e., no application of a process to remove contaminants) of local drinking water, and no holdup time (time between pumping and consumption). Even though parts of the communities of Beatty and Pahrump have centralized water systems, most of the area surrounding Yucca Mountain is served only by private, individual wells, particularly in the Amargosa Valley (CRWMS M&O 2000c, p. 16).

3.2.4.1.2 Soil Concentration

Parameters related to soil concentration compartment in Figures 3-5 and 3-6 include soil characteristics (soil depth and density), parameters that characterize radionuclide addition to soil by irrigation (irrigation time, irrigation rate, irrigation time periods, home irrigation rate, and home irrigation duration), as well as the parameters that help quantify the rate of radionuclide removal from soil by leaching (leaching coefficient) and by crop harvesting (crop yield).

Depth of Surface Soil – Surface soil depth (or soil plow depth) defines the portion of the soil where the deposition from the atmosphere, irrigation, and resuspension occur. Most of the reviewed documents suggested 15 cm for this parameter, the same as the GENII-S default value. In addition, the 15 cm surface soil depth was preferred, because FGR 12 (Eckerman and Ryman 1993, Section III) provides sets of external dose coefficients for 0 cm, 1 cm, 5 cm, 15 cm, and infinite contaminated soil depth. Therefore, it is consistent to use the 15 cm surface soil depth for both plant growth and calculation of BDCF contribution form external exposure to radionuclides (CRWMS M&O 1999a, pp. 22 to 23).

Surface Soil Density – Surface soil density can be obtained from depth of surface soil and soil bulk density. The soil bulk densities in farming areas of Amargosa Valley range from 1.35 to

1.70 g/cm^3 (LaPlante and Poor 1997, Table 2-7). A mean value of 1.5 g/cm^3 (1500 kg/m^3) was selected. Surface soil density was calculated to be 225 kg/m^2 (CRWMS M&O 1999a, pp. 23 to 24).

Irrigation Time – The annual irrigation time is the number of months per year that irrigation is applied for a crop type. Annual irrigation time of crops known to grow in the Amargosa Valley was calculated as the growing season length for the crop multiplied by the number of growing seasons for that crop. Irrigation time for different types of crops was calculated using the available site-specific information for specific crops that belong to this type. The results are summarized in Table 3-4 (CRWMS M&O 2000c, pp. 17 to 18, 29 to 30).

Table 3-4. Estimates of Irrigation Time for Various Crop Types

Crop Type	Irrigation Time (months)			
	Distribution	Reasonable Estimate	Minimum	Maximum
Leafy vegetables	Triangular	3.2	2.0	4.9
Other (Root) vegetables	Uniform	n/a	3.2	4.6
Fruit	Uniform	n/a	2.9	6.0
Grain	Uniform	n/a	4.9	8.0
Poultry (corn)	Fixed	4.9	4.9	4.9
Eggs (corn)	Fixed	4.9	4.9	4.9
Beef (alfalfa and other hay)	Fixed	12.0	12.0	12.0
Milk (alfalfa and other hay)	Fixed	12.0	12.0	12.0

Irrigation Rate – The irrigation rate was calculated using the soil water balance based on a steady-state condition (i.e., soil water at the beginning of the year equals that at the end of the year). This equation accounts for the water needs of the plant being irrigated (transpiration) and the major site-specific inputs (precipitation) and outputs (evaporation and deep percolation) of water. Irrigation rate for different types of crops was calculated using the available site-specific information for specific crops that belong to this type. The results are summarized in Table 3-5 (CRWMS M&O 2000c, pp. 18 to 21, 29 to 30).

Table 3-5. Estimates of Irrigation Rate for Various Crop Types

Crop Type	Irrigation Rate (in./yr.)			
	Distribution	Reasonable Estimate	Minimum	Maximum
Leafy vegetables	Triangular	42.11	28.17	80.37
Other (root) vegetables	Uniform	n/a	47.34	51.58
Fruit	Uniform	n/a	30.00	45.37
Grain	Uniform	n/a	55.85	80.37
Poultry (corn)	Fixed	80.37	80.37	80.37
Eggs (corn)	Fixed	80.37	80.37	80.37
Beef (alfalfa and other hay)	Fixed	94.66	94.66	94.66
Milk (alfalfa and other hay)	Fixed	94.66	94.66	94.66

Irrigation Time Periods – The prior irrigation time periods, are the number of years that the land has been irrigated before the intake occurs. These time periods are used to assess buildup of radionuclides in soil and were derived based on leaching rates and the half-lives of the radionuclide under consideration. Irrigation time periods are provided in Table 3-6 (CRWMS M&O 2000e, CRWMS M&O 2000g). The first time (period 1) considered for the previous irrigation period was zero (i.e., no previous irrigation with contaminated water) for all radionuclides. Irrigation periods 2 through 6 were defined (based on the leaching coefficient or radionuclide half-life) so that the series of BDCFs would be approximately equally spaced between the values for period 1 and the asymptotic value after an infinitely long period of previous irrigation. The BDCFs calculated by the GENII-S for each of these irrigation periods were used in CRWMS M&O 2000h to derive the parameters characterizing soil build-up effects for all loss mechanisms in the GENII-S code.

Home Irrigation Rate – Home irrigation rate is a measure of the amount of contaminated groundwater applied to the environment (in./yr.) and is used to determine the level of contamination of the soil in the assessment of BDCF contribution from soil exposure time.

The irrigation rate of turf grass was calculated for this purpose. Turf was chosen because lawns are common in southern Nevada, turf requires year-round irrigation in this region, and turf has a high water requirement relative to garden crops and ornamental plants; thus, it will result in a realistic and conservative estimate of home irrigation rate. The reasonable, conservative distribution of home irrigation rate was approximated to be uniform with a minimum value of 52 in./yr. and a maximum value of 97 in./yr.

Duration of Home Irrigation – Duration of home irrigation is the number of months per year that groundwater is applied to the environment and is used to determine when a person may be exposed to soil that has been contaminated from groundwater irrigation. For the same reasons described in the analysis of home irrigation rate (CRWMS M&O 2000t, Sec. 4.1.5, 5.5, 6.5, and Appendices A and B), the irrigation requirements of turf grass were considered in this analysis.

Table 3-6. Irrigation Time Periods

Radionuclide	Period Number					
	1	2	3	4	5	6
	Number of Years of Prior Irrigation					
Carbon-14	0	752	1674	2864	4537	7401
Strontium-90	0	5	12	21	33	53
Technetium-99	0	1	2	3	4	5
Iodine-129	0	1	2	3	4	5
Cesium-137	0	8	18	30	48	78
Actinium-227	0	6	13	22	35	56
Thorium-229	0	858	1910	3269	5179	8448
Uranium-232	0	9	21	36	57	93
Uranium-233	0	9	21	36	57	93
Uranium-234	0	9	21	36	57	93
Uranium-236	0	9	21	36	57	93
Uranium-238	0	9	21	36	57	93
Neptunium-237	0	1	3	5	8	14
Plutonium-238	0	23	51	88	139	227
Plutoniumu-239	0	148	329	563	893	1456
Plutoniumu-240	0	148	329	563	893	1456
Americium-241	0	114	253	432	685	1117
Americium-243	0	511	1138	1947	3084	5031
Additional radionuclides of interest for one million years						
Lead-210	0	6	12	21	33	54
Protactinium-231	0	2	4	7	10	17
Radium-226	0	135	300	513	814	1327
Thorium-230	0	860	1913	3270	5182	8452
Plutonium-242	0	148	329	563	893	1456

Cool and warm season grasses are irrigated year-round in southern Nevada, so the reasonable, conservative estimate for this parameter is a fixed value of 12 months. The reasonably expected value to be used in a deterministic run of GENII-S is 12 months.

Leaching Factors – Leaching factor, or leaching coefficient, is an element-specific parameter that quantifies the rate of the contaminant removal from the surface soil and translocation to underlying soil by leaching. Leaching induced by over-watering is a common process in the Amargosa Valley because this practice minimizes salt build-up (CRWMS 2000c, Appendix B). Radionuclides removed from the surface soil by leaching are no longer available for many of the possible pathways including plant uptake, inhalation, and ingestion of surface soil. A theoretical formula was used to calculate leaching coefficients for GENII-S input, which, among other parameters, uses the soil solid-liquid partition coefficients. The selected values of soil solid-liquid partition coefficients were those recommended for sandy-textured soils, the types of soils found in Amargosa Valley. Values for the other parameters used in the formula were selected from site-specific information sources or appropriate analog data reported in the reviewed articles. The leaching coefficients for 14 elements are listed in Table 3-7 (CRWMS M&O 2000d, p. 19). In the BDCF calculations, preliminary leaching coefficients were used. For four elements of interest (carbon, strontium, cesium, and protactinium) the final leaching coefficients reported in the AMR differed from the preliminary ones. The impact of using preliminary coefficients was evaluated. It was concluded that the impact was not significant. Work in progress used modified leaching factors to recalculate BDCF. The results were compared with those presented in AMR. There is no or very little difference for most of radionuclides, except C-14 and Cs-137 for the groundwater contamination scenario. These "new" results will be incorporated into subsequent revision of this report.

Table 3-7. Estimates of Leaching Coefficients

Element	Leaching Coefficient (1/yr.)
Carbon	1.32E-01
Strontium	4.47E-02
Yttrium	3.98E-03
Technetium	2.77E+00
Iodine	5.92E-01
Cesium	2.42E-03
Radium	1.35E-03
Actinium	1.50E-03
Thorium	2.12E-04
Protactinium	1.23E-03
Uranium	1.93E-02
Neptunium	1.32E-01
Plutonium	1.23E-03
Americium	3.56E-04

Crop Yield – Estimates of crop yields were based on local, site-specific information for Nye County or southern Nevada. The estimates were based on home-garden production if available, then commercial yields, or potential home-garden yields, depending on the crop type. The resulting estimates are summarized in Table 3-8 (CRWMS M&O 2000c, pp. 22 to 24, 29 to 30).

3.2.4.1.3 Resuspension

Parameters related to the resuspension compartment in Figures 3-5 and 3-6 quantify the amount of airborne particulate matter. These parameters are used in calculations of the dust deposition on plant surfaces and in calculations for the inhalation pathway.

Deposition Velocity – The deposition velocity is a parameters used to describe the natural process of particulate settling out of the air by the process of dry deposition. Deposition velocity is a function of many factors (e.g., particle size, surface roughness, and climate). There are two types of deposition velocities used in GENII-S, one for particles that settle on crop surfaces, and one for air transport of particles. The former is relevant for the performance assessment (the latter is relevant to contaminant discharge into the air followed by the atmospheric transport). A literature review indicated a typical value of 0.001 m/sec for deposition velocity. This value was selected as reasonably expected (CRWMS M&O 1999a, pp. 16 to 18).

Resuspension Factor – Crop resuspension factor is used to quantify the amount of dust that becomes resuspended and is available for settling (deposition) on a plant surface. It is defined as the ratio of mass loading of soil in air to soil surface density. The crop resuspension factor was calculated using the site-specific values of total suspended particulate concentration for mass loading. The mean value of resuspension factor calculated from site-specific total suspended particulate data is 8.3×10^{-11} 1/m. A lognormal distribution was suggested for crop resuspension factor with 0.1^{th} percentile value of 9.6×10^{-12} 1/m and 99.9^{th} percentile value of 7.2×10^{-10} 1/m (CRWMS M&O 1999a, pp. 18 to 19).

This value is lower than has been used in some other recent analyses (LaPlante and Poor 1997, CRWMS M&O 1998e). The differences in the values of resuspension factor are currently being evaluated to determine their significance. However, the results of sensitivity analysis (Section 3.3.1.1.2) indicated that this parameter has very little influence on the groundwater contamination BDCF values.

Table 3-8. Estimates of Crop Yield for Various Crop Types

Crop Type	Crop Yield (kg/m^2)			
	Distribution	Reasonable Estimate	Minimum	Maximum
Leafy vegetables	Triangular	1.82	0.59	4.11
Other (root) vegetables	Triangular	4.33	1.73	5.87
Fruit	Uniform	n/a	1.57	2.25
Grain	Uniform	n/a	0.33	0.78
Poultry (corn)	Uniform	n/a	0.59	0.78
Eggs (corn)	Uniform	n/a	0.59	0.78
Beef (alfalfa and other hay)	Uniform	n/a	0.25	1.15
Milk (alfalfa and other hay)	Uniform	n/a	0.25	1.15

Resuspended Particulate Matter – Resuspended particulate matter is the mass of suspended particles per volume of air (g/m^3). This parameter is referred to as mass loading in CRWMS M&O (2000t, Sections 4.1.1, 5.1, and 6.1) and by the GENII-S. This parameter is used to calculate the concentration of radionuclides in the air resulting from resuspension of soil contaminated by irrigation. Mass loading was estimated directly from measurements of PM_{10} (i.e., airborne particulate matter $\leq$ 10 μm, measured as $\mu g/m^3$) collected for the YMP (CRWMS M&O 2000t). The resulting estimates are a minimum of 7.4×10^{-7} g/m^3 and a maximum value of 6.4×10^{-5} g/m^3. A reasonably expected estimate is 8.7×10^{-6} g/m^3 (CRWMS M&O 2000t, Section 6.1). More consideration of mass loading is discussed in Section 3.3.2.2 under sensitivity analysis for disruptive volcanic event scenario.

3.2.4.1.4 Crop Uptake

There are two main mechanisms of radionuclide transfer to a plant (Crop Uptake compartment in Figures 3-7 and 3-8): direct deposition on plant's surfaces and the root uptake. Deposition on plant's surfaces may result from resuspension of contaminated soil and from irrigation with contaminated water. Parameters related to deposition from irrigation include irrigation time (see Section 3.2.4.1.2), irrigation rate (see Section 3.2.4.1.2), and crop interception fraction for irrigation; parameters related to deposition from resuspension include those described in Section 3.2.4.1.3, as well as the crop interception fraction for resuspension. Activity deposited on a plant can be removed by weathering, with the removal rate depending on the growing time and the weathering half-life. The fraction of deposited activity that is transferred to the edible part of a plant is controlled by the translocation factor. Root uptake depends on fraction of roots in upper soil, soil-to-plant transfer factors, and transfer scaling factors.

Crop Interception Fraction – The crop interception fraction is the fraction of contaminant material, deposited either by dry or wet deposition processes, that is retained on the plant, with the remainder reaching the ground. Because in GENII-S the dry and wet deposition processes are considered separately, the crop interception fraction in this case is only applicable to deposition process due to irrigation. The fraction of resuspended activity deposited on the plant surfaces via dry deposition process is calculated independently using an empirical formula (Napier et al. 1988, p. 4.69). The formula uses the values of biomass and plant dry-to wet ratio. Crop interception fraction for irrigation was calculated using an empirical formula that depends on crop yield, irrigation parameters, and the contaminant. It was determined that a reasonable estimate of the crop interception fraction is 0.259 and, assuming a normal distribution, the minimum value is 0.044 and the maximum value is 0.474 (CRWMS M&O 2000c, 26 to 30).

Growing Time – Growing time is the number of days from planting to harvest per growing season. The growing time for different crop types were calculated using the available site-specific information for specific crops of each type. The results are summarized in Table 3-9 (CRWMS M&O 2000c, pp. 24, 29 to 30).

Weathering Half-life – Weathering half-life (or weathering time) is a parameter that describes the removal of radionuclides that have been initially deposited on crop surfaces by environmental processes (e.g., wind, washout, and possibly volatilization). Weathering removal tends to occur in an exponential manner with the characteristic weathering half-life. Most of the reviewed documents indicated appropriate values for weathering half-life on the order of two weeks. Therefore, the value of 14 days, which is also a GENII-S default, was selected (CRWMS M&O 1999a, pp. 25 to 27).

Table 3-9. Estimates of Growing Time for Various Crop Types

Crop Type	Growing Time (days)			
	Distribution	Reasonable Estimate	Minimum	Maximum
Leafy vegetables	Triangular	64.5	45	75
Other (root) vegetables	Uniform	n/a	70	98
Fruit	Uniform	n/a	88	184
Grain	Uniform	n/a	75	244
Poultry (corn)	Fixed	75	75	75
Eggs (corn)	Fixed	75	75	75
Beef (alfalfa and other hay)	Triangular	47	46	135
Milk (alfalfa and other hay)	Triangular	47	46	135

Translocation Factors – Translocation is the process by which a chemical element initially deposited on the leaf surface of a plant is absorbed and translocated to the edible part of the plant. Translocation factors in the GENII-S consist of a set of ten individual parameters for various plants typically consumed by both humans and animals. Default values for translocation factors in GENII-S are based on the conservative assumptions of 1.0 for leafy vegetables and forage, and 0.1 for other crops, where a values of 1.0 indicates that the contaminant is fully available in the edible portion of the plant. Published data on translocation factor is scarce and the uncertainty of the measurement is quite high, because it depends on plant species, stage of plant development, weathering conditions, and the element and its chemical form. Based on the literature review, a decision was made to retain the conservative GENII-S default values for the translocation factors (CRWMS M&O 1999a, pp. 27 to 29).

Fraction of Roots in Upper Soil – Fraction of roots in upper soil describes the part of plant roots located in the upper layer of soil, and therefore, participating in the plant root uptake of radionuclides from soil. This parameter is unique to the GENII-S model and can not be referenced to documents unrelated to GENII-S. Conceptually, soil depth is separated into two compartments: (1) surface soil (upper soil) and (2) deep soil. The upper soil, in which all radionuclides are deposited initially, is more contaminated than the deep soil. To be conservative, all roots were assumed to be located in the upper soil, with no roots in the deep soil. This assumption was also used in a Yucca Mountain biosphere model study by the CNWRA (LaPlante and Poor 1997, p. B-1). Therefore, a value of one was selected for this parameter to reflect the maximum fraction (CRWMS M&O 1999a, p. 24).

Fraction of Roots in Deep Soil – Fraction of roots in deep soil is a complementary parameter to the fraction of roots in upper soil (see above). Because the fraction of roots in upper soil is assumed to be one, the fraction of roots in deep soil is assumed to be zero (CRWMS M&O 1999a, p. 24).

Soil-to-Plant Transfer Factors – Soil-to-plant transfer factor (or concentration ratio in some documents) is defined as a ratio of radioactivity concentration in the edible part of plant (Bq/kg) to the radioactivity concentration in soil (Bq/kg). Some authors use a fresh weight based concentration in plant, while others use a dry weight based concentration. The difference between them is dry-to-wet ratio. The GENII-S model uses a dry weight based concentration of contaminant. The element-specific (i.e., independent of the specific isotope of an element) transfer factors are defined for four types of plant food for ingestion pathways considered in GENII-S: leafy vegetables, root vegetables, fruits, and grain. Leafy vegetables category includes fresh forage used for cattle to produce milk and meat. Grain category includes animal feed used to produce poultry and eggs. Each food group usually contains many specific plant foods. (The soil-to-plant transfer factors are element-specific, rather than radionuclide-specific, because plants generally do not distinguish between different isotopes of an element.) Thus, transfer factors for each group have a large range. The site-specific information on vegetable types planted and consumed by the critical group is not available, neither are the actual transfer factors of these vegetables grown in the local area. Therefore, generic values were reviewed and selected from available literature as listed in Table 3-10 (CRWMS M&O 2000s, pp. 14 to 22).

Soil-to-Plant Transfer Scale Factor – The soil-to-plant transfer scale factor is used as a multiplier for the soil-to-plant transfer factors (see Table 3-10) to account for the variability range of this parameter. The scale factor is used in statistical simulations, so that fixed values of transfer factor can be scaled up and down with a specified statistical distribution. In GENII-S, one scale factor is used for all types of plant food and elements considered. Since the transfer scale factor is a GENII-S-specific parameter, there are not many documents that address its value and distribution. The range depends on the element, food type, and the soil conditions. It is not uncommon that the values of transfer scale factor for a given element and food type span over two orders of magnitude. To account for such a large range of variability, combined with the uncertainty resulting from the lack of site-specific data, a sufficiently wide distribution of soil-to-plant transfer scale factor was necessary. Based on the literature review, a lognormal distribution with a geometric standard deviation (GSD) of 3.2 was selected. The 0.1^{th} and 99.9^{th} percentile values (GENII-S requirement) can be calculated as 0.027 and 36.4 (CRWMS M&O 2000s, p. 17-18).

Crop Biomass – Crop biomass is the amount of standing plant biomass that is available to intercept radionuclides in the atmosphere and in contaminated irrigation water. Crop biomass varies as a function of plant type. Four types of plant for human food and six types for animal feed are considered in the GENII-S. Based on the review of published documents, crop biomass parameters ranged from 1.5 to 2.0 kg/m^2 for leafy vegetables, 2.0 to 4.0 kg/m^2 for root vegetables, 0.7 to 3.0 kg/m^2 for fruit, 0.4 to 1.0 kg/m^2 for grain, 0.7 to 1.1 kg/m^2 for fresh forage for beef, 0.7 to 1.5 kg/m^2 for fresh forage for milk, 0.8 to 1.1 kg/m^2 for stored feed for beef or milk, and 0.8 to 1.2 kg/m^2 for stored feed for poultry or eggs. There was no single agreed upon value for a particular type of crop biomass in the literature. Therefore, GENII-S default values, within the literature data range, were selected. The values selected for crop biomass are summarized in Table 3-11 (CRWMS M&O 1999a, pp. 19 to 22).

Dry-to-Wet Ratio – Dry/wet ratio, or dry-to-wet weight conversion factors, describes dry weight content of fresh crops. Because the soil-to-plant transfer factor defined in the GENII-S is based on the ratio of dry weight of the crop to dry weight of soil, dry/wet ratio is needed to calculate radionuclide concentration in fresh crops. Dry/wet ratio depends on the type of crop. Four types of crop for humans and six types for animals (each containing many plant species) are used in the GENII-S. A literature data review resulted in the selection of the values for the dry-to-wet ratio as shown in Table 3-12 (CRWMS M&O 1999a, pp. 31 to 33).

Table 3-10. Estimates of Soil-to-Plant Transfer Factors

Element	Soil-to-Plant Transfer Factors (dimensionless)			
	Leafy	Root	Fruit	Grain
Carbon	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Strontium	2.0E+00	1.2E+00	2.0E-01	2.0E-01
Yttrium	1.5E-02	6.0E-03	6.0E-03	6.0E-03
Technetium	4.0E+01	6.6E+00	1.5E+00	7.3E-01
Iodine	3.4E-03	5.0E-02	5.0E-02	5.0E-02
Cesium	1.3E-01	4.9E-02	2.2E-01	2.6E-02
Radium	8.0E-02	1.3E-02	6.1E-03	1.2E-03
Actinium	3.5E-03	3.5E-04	3.5E-04	3.5E-04
Thorium	4.0E-03	3.0E-04	2.1E-04	3.4E-05
Protactinium	2.5E-03	2.5E-04	2.5E-04	2.5E-04
Uranium	8.5E-03	1.4E-02	4.0E-03	1.3E-03
Neptunium	3.7E-02	1.7E-02	1.7E-02	2.7E-03
Plutonium	3.9E-04	2.0E-04	1.9E-04	2.6E-05
Americium	2.0E-03	4.7E-04	4.1E-04	9.0E-05

Table 3-11. Summary of the Recommended Biomass Values

Crop Type	Biomass kg m^{-2}
Leafy vegetables	2.0
Root vegetables	2.0
Fruit	3.0
Grain	0.8
Stored feed for beef	0.8
Stored feed for poultry	0.8
Stored feed for milk	1.0
Stored feed for eggs	0.8
Fresh forage for beef	1.0
Fresh forage for milk	1.5

3.2.4.1.5 Crop Concentration

The final activity concentration in a plant depends on the length of the holdup, or storage time for the crop.

Table 3-12. Summary of the Recommended Dry-to-Wet Ratio Values

Crop Type	Dry-to-Wet Ratio
Leafy vegetables	0.10
Root vegetables	0.25
Fruit	0.18
Grain	0.91
Stored feed for beef	0.18
Stored feed for poultry	0.91
Stored feed for milk	0.18
Stored feed for eggs	0.91
Fresh forage for beef	0.20
Fresh forage for milk	0.20

Holdup Time – Holdup times represent the number of days between the harvest of a particular crop or product and its consumption by humans. The holdup time for leafy vegetables, poultry, eggs, and milk is 1 day. The holdup time for other (root) vegetables, fruit, and grain (for human consumption) is 14 days. The holdup time for beef is 20 days. These estimates represent fixed distributions. Holdup times between harvest and consumption are considered for radioactive decay. Because the source of radioactive contamination from a potential repository is aged spent nuclear fuel and aged reprocessing wastes, the decay half-lives are very long compared to the holdup times. Therefore, holdup times are not critical for the present analysis and fixed generic values are appropriate (CRWMS M&O 2000c, pp. 24 to 25, 29 to 30).

Feed Storage Time – Feed storage times represent the number of days between harvest of a particular crop and its consumption by animals. The storage time for stored feed for consumption by poultry and laying hens is 14 days and is based on the recommended value for grain for human consumption, which was generalized to include grain for consumption by animals. Feed storage times between harvest and consumption are considered for radioactive decay. Because the source of radioactive contamination from a potential repository is aged spent nuclear fuel and aged reprocessing wastes, the decay half-lives are very long compared to the feed storage times. Therefore, feed storage times are not critical for the present analysis and fixed generic values are appropriate (CRWMS M&O 2000c, pp. 25, 29 to 30).

3.2.4.1.6 Livestock Uptake

Livestock Uptake compartment in Figures 3-5 and 3-6 represents radionuclide transfer to animal food products. This section contains descriptions of parameters related to this process.

Dietary Fraction – The dietary fraction for poultry and laying hens is the proportion of their food consumption that is from stored feed. For the current biosphere effort, it is assumed that the diet for poultry and laying hens consists entirely of locally produced stored feed.

The dietary fraction for beef cattle and dairy cows represents the proportion of their food consumption that cattle derive from fresh forage. For current biosphere effort, it is assumed that the diet for beef cattle and dairy cows consists entirely of fresh forage. These estimates represent locally relevant, values for the parameters. Furthermore, it is assumed that, like beef cattle, the diet for dairy cows consists entirely of fresh forage, which is a reasonable, although conservative assumption (CRWMS M&O 2000c, pp. 25, 29 to 30).

Animal Feed and Water Consumption Rates – Besides the vegetable or plant food ingestion pathways, consumption of animal products is another pathway of radionuclide intake for humans. Animal products can become contaminated due to radionuclide transfer when the animal consumes contaminated animal feed and water. The animal feed and water consumption rates become important parameters for calculation of contamination levels of animal products. Intake by animals is dependent on the animal species, age, and growth rate. Four types of animal products are considered in the GENII-S: beef, poultry, milk, and eggs. Fresh forage is considered for beef cattle and dairy cows, while stored feed is considered for producing poultry and eggs. The results of the review, in terms of the recommended values for the animal feed and water consumption rates, are summarized in Table 3-13 (CRWMS M&O 1999a, pp. 29 to 31).

Table 3-13. Summary of the Recommended Animal Feed and Water Consumption Rates

Category	Consumption Rate
Beef cattle feed consumption (kg/d.)	68
Dairy cow feed consumption (kg/d.)	55
Poultry feed consumption (kg/d.)	0.12
Laying Hen feed consumption (kg/d.)	0.12
Beef cattle water consumption (L/d.)	50
Dairy cow water consumption (L/d.)	60
Poultry water consumption (L/d.)	0.3
Laying hen water consumption (L/d.)	0.3

Transfer Coefficients for Animal Products – The transfer coefficient from animal diet to animal product is defined as a ratio of radionuclide concentration in animal product (Bq/kg or Bq/L) to animal daily radionuclide intake (Bq/d.). Thus its units are d./kg or d./L. There are four types of animal products considered by ingestion pathways in the GENII-S: beef, poultry, milk, and eggs. Each type of animal product has its own element-specific transfer coefficient. Based on the literature search, the following transfer coefficients, listed in Table 3-14, were selected (CRWMS M&O 2000s, pp. 23 to 29).

Animal Uptake Scale Factor – An animal uptake scale factor is used as a multiplier for the animal diet-to-animal product transfer factors (see above) to account for the variability range of this parameter. The scale factor is used in statistical simulations, so that a fixed value of transfer factor can be scaled up and down with a specified statistical distribution. In GENII-S, one scale factor is used for all types of animal food products considered. Analogous to the soil-to-plant transfer scale factor, the animal uptake scale factor is a special parameter designed for GENII-S. Based on the literature review, a lognormal distribution with a GSD of 2.0 was determined to be

Table 3-14. Transfer Coefficients for Animal Products

Element	Transfer Coefficients for Animal Products			
	Beef (d./kg)	Poultry (d./kg)	Milk (d./L)	Eggs (d./kg)
Carbon	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Strontium	8.0E-03	3.5E-02	1.5E-03	3.0E-01
Yttrium	1.0E-03	1.0E-02	2.0E-05	2.0E-03
Technetium	1.0E-04	3.0E-02	9.9E-03	3.0E+00
Iodine	7.0E-03	1.8E-02	1.0E-02	3.0E+00
Cesium	5.0E-02	4.4E+00	8.0E-03	4.0E-01
Radium	9.0E-04	3.0E-02	1.3E-03	2.0E-05
Actinium	2.5E-05	4.0E-03	2.0E-05	2.0E-03
Thorium	6.0E-06	4.0E-03	5.0E-06	2.0E-03
Protactinium	1.0E-05	4.0E-03	5.0E-06	2.0E-03
Uranium	3.0E-04	1.2E+00	6.0E-04	1.0E+00
Neptunium	1.0E-03	4.0E-03	5.0E-06	2.0E-03
Plutonium	1.0E-05	4.0E-03	1.1E-06	8.0E-03
Americium	2.0E-05	6.0E-03	2.0E-06	4.0E-03

suitable to scale animal uptake. For a lognormal distribution, the 0.1th and 99.9th percentile values can be calculated as 0.117 and 8.51 (CRWMS M&O 2000s, p. 25).

3.2.4.1.7 Uptake by Fish

Transfer of radionuclides from water to aquatic organisms is not represented in Figure 3.5. It is quantified by the bioaccumulation factors for aquatic food.

Bioaccumulation Factors for Aquatic Food – The bioaccumulation factor is an element-specific parameter that quantifies contaminant transfer from water to aquatic organisms, such as fish. It is defined as a ratio of radionuclide concentration in fresh water fish (Bq/kg) to radionuclide concentration in water (Bq/L) and is given in units of L/kg. Among the eight aquatic foods considered in GENII-S code, only fresh water fish was identified as applicable to the current biosphere model. A literature review resulted in the selection of the values in Table 3-15 for the bioaccumulation factors (CRWMS M&O 2000s, p. 30).

3.2.4.2 Characteristics of the Human Receptor

Characteristics of the human receptor described in this section are related to the key exposure pathways: ingestion, inhalation and external exposure (compare corresponding compartments in Figures 3-5 and 3-6). Dosimetric parameters for these pathways are described in a separate section (Section 3.2.4.2.4).

Table 3-15. Bioaccumulation Factors

Element	Bioaccumulation Factor for Fish (L/kg)
Carbon	5.0E+04
Strontium	6.0E+01
Yttrium	3.0E+01
Technetium	2.0E+01
Iodine	4.0E+01
Cesium	2.0E+03
Radium	5.0E+01
Actinium	2.5E+01
Thorium	1.0E+02
Protactinium	1.1E+01
Uranium	1.0E+01
Neptunium	3.0E+01
Plutonium	3.0E+01
Americium	3.0E+01

3.2.4.2.1 Ingestion

Consumption Rates for Drinking Water and Locally Produced Food – Locally produced food consumption rate is the amount of locally produced food consumed by the receptor of interest measured per person per year by mass (dry foods) or volume (liquid). Consumption rates for drinking water and locally produced food were derived based on the regional survey and taking into consideration critical group approach, as outlined in Section 3.1.2.1. Recommended distribution-based and mean consumption rates for locally produced food by type and tap water are summarized in Table 3-16. (CRWMS M&O 2000b).

Soil Ingestion Rate – Soil ingestion rates are based on inadvertent and geophagic (purposeful) average daily intake of soil. The values of soil ingestion rate were established through the literature data search. Literature data scrutiny resulted in the selection of a soil ingestion rate of 50 mg/d. for the reasonable representation, which is consistent with the EPA recommended value for adults (EPA 1997, p. 4-21; CRWMS M&O 1999a, pp. 24 to 25).

Soil ingestion rate through inhalation of relatively large particles (larger than 10 μm) that could be trapped in the nose and then swallowed was also evaluated. By using measured maximum value of total suspended particulates (TSP) at the Yucca Mountain site (310 $\mu g/m^3$), and a typical breathing rate of 23 m^3/d., it was estimated that about 7 mg/d. of dust could be inhaled. Even if all inhaled dust is subsequently swallowed, it amounts to only about 14% of 50 mg/d. soil ingestion rate. Soil ingestion following inhalation is insignificant. In addition, the results of pathway analysis indicated that soil ingestion pathway is an insignificant contributor to the BDCFs for groundwater contamination. However, soil ingestion is an important pathway for the disruptive volcanic event scenario.

Table 3-16. Recommended Distribution-Based and Fixed (Mean) Annual Consumption Rates for Locally Produced Food by Type and Tap Water

Food Type	Distribution	Consumption rate, kg or L per yr. [a]			
		Minimum [b]	Maximum	Mean	95th Percentile
Leafy vegetable	Loguniform	1.2	60	15	46
Root vegetable	Loguniform	0.65	30	7.8	25
Grains	Loguniform	8.6E-11	12	0.48	0.00
Fruit	Loguniform	0.18	98	16	45
Poultry	Loguniform	2.1E-05	11	0.80	7.0
Meat	Loguniform	7.1E-07	53	2.9	12
Fish	Loguniform	6.6E-08	8.8	0.47	1.5
Eggs	Loguniform	0.23	33	6.7	20
Milk	Loguniform	3.0E-09	1.0E02	4.1	25
Tap Water	Uniform	0.00	1.5E03	7.5E02	1.5E03

[a] Consumption rates have been rounded off to two significant digits.

[b] For each food type where the recommended distribution is log uniform, the actual minimum is zero. However, to accommodate the GENII-S input parameters, the minimum was estimated such that the statistics obtained in the regional survey were maintained.

Aquatic Food Consideration – The receptor of interest is assumed to ingest locally produced aquatic food, which are of freshwater origin only. The hypothetical farming community in which the critical group resides is located in the desert far from the nearest ocean. A freshwater fishpond is assumed to be located close to the critical group. This assumption is based on the presence of a commercial catfish farm in the Amargosa Valley (CRWMS M&O 1998c, pp. 1 to 14), where the critical group is assumed to be located (Dyer 1999, p. 19 of enclosure, CRWMS M&O 2000c, p. 22). Due to the lack of permanent bodies of surface water in the vicinity of Yucca Mountain, groundwater is assumed to be a source of water for the fish farm.

3.2.4.2.2 Inhalation

Inhalation Exposure Time – Inhalation exposure time is an estimate of the amount of time (hr./yr.) a person spends breathing air containing resuspended dust particles contaminated with radionuclides from irrigation water. Assumptions about inhalation exposure time were developed (CRWMS M&O 2000t, Section 5.2) based on DOE revised interim guidance (Dyer 1999, p. 19 of Enclosure) and characteristics of the critical group based on data from the U.S. Bureau of the Census (U.S. Census Bureau 1999).

Based on analysis (CRWMS M&O 2000t, Section 6.2), the distribution of inhalation exposure time is triangular and is described by a minimum value of 3,483.38 hr./yr., a mode (referred to as the best estimate in GENII-S, Leigh et al. 1993, p. 5-33) of 3,918.5 hr./yr., and a maximum of 6,353.5 hr./yr.

Chronic Breathing Rate – Chronic breathing rate (m^3/d.) is the volume of air that is inhaled by a person per unit of time and is used to calculate the BDCF contribution from inhaling contaminated dust particles. A literature review was conducted to identify the most appropriate value of chronic breathing rate (CRWMS M&O 2000t, Sections 5.3 and 6.3). The ICRP value of 23 m^3/d. for light activity work (ICRP 1975, p. 346) was selected as the reasonable, conservative estimate for this analysis.

3.2.4.2.3 External Exposure

Soil Exposure Time – Soil exposure time is the amount of time (hr./yr.) that a person spends outside in areas contaminated with radionuclides from groundwater irrigation (CRWMS M&O 2000t, Table 2, p. 15). Assumptions about soil exposure time were developed (CRWMS M&O 2000t, Section 5.2) based on DOE revised interim guidance (Dyer 1999, p. 19 of Enclosure) and characteristics of the critical group based on data from the U.S. Bureau of the Census (U.S. Census Bureau 1999). The reasonable, conservative distribution of soil exposure time is triangular with a minimum estimate of 206.75 hr./yr., a mode (referred to as the best estimate in GENII-S, Leigh et al. 1993, p. 5-33) of 827.0 hr./yr., and maximum estimate of 3,947.0 hr./yr. (CRWMS M&O 2000t, Section 6.4).

3.2.4.2.4 Dosimetric Parameters

BDCF calculations in GENII-S are carried out by converting the radioactivity intake to doses for ingestion and inhalation, and by converting direct exposure to doses for external sources of radioactivity. (Exposure here means the product of activity concentration in air or soil and the time a person is exposed to this concentration.) Therefore, DCFs for inhalation and ingestion, and dose coefficients for external exposure are needed for GENII-S to calculate the BDCF. DCFs are used to convert radionuclide intake by inhalation or ingestion to CEDE, while dose coefficients are used to convert the magnitude of external exposure to effective dose equivalent (EDE).

For inhalation and ingestion, the highest DCF values were used for BDCF calculations. These values are provided as a set of data for GENII-S default set of values and represent the most conservative conditions for radionuclides under consideration. To ensure the accuracy of these dosimetric parameters, they were compared to DCF values from other sources, such as FGR 11 (Eckerman et al. 1988), ICRP-30 (ICRP 1979, ICRP 1980, ICRP 1981), and 10 CFR 20 (10 CFR 20). Among the DCF sets under consideration, the comparison between GENII-S and FGR 11 was the most meaningful, because both DCF sets were developed in the late 1980s and, therefore, reflect similar states of knowledge in the area of radiation dosimetry. As the results of the comparison, relative differences were 7 percent or less for about 86 percent of the primary radionuclides under consideration (CRWMS M&O 1999d). These differences are acceptable considering the level of inherent uncertainties involved in the calculations of BDCFs. Of the remaining radionuclides, two (Tc-99 and Np-237) had more conservative values of BDCFs than those listed in FGR 11, and only one, Sr-90, was less conservative by 15%. Considering the above, it is unlikely that application of GENII-S DCFs would result in an underestimate of the total doses from radionuclide releases into groundwater from the potential repository. Therefore, based on the results of this analysis, it was determined that the assessment of BDCF contribution from internal exposure be conducted without any modification of the relevant GENII-S dosimetric parameters.

For external exposure, dose coefficient values from the FGR 12 were used for the BDCF calculations. The FGR 12 (Eckerman and Ryman 1993) contains the most recent EPA compilation of dose coefficients for exposure to contaminated soil and for air submersion. Therefore, FGR 12 values were used to replace older GENII-S values (CRWMS M&O 1999d).

3.3 DEVELOPMENT OF BIOSPHERE DOSE CONVERSION FACTORS

The anticipated standard (64 FR 8640) against which the performance of the potential repository will be judged requires the calculation of annual radiation dose to a human receptor through multiple pathways. Calculation of radiation doses is carried out in TSPA. Within the TSPA model the results of process modeling come together to produce expected annual doses. Biosphere model is one of the component process models providing input to the TSPA code.

Radiation doses are assumed to be proportional to the activity concentration at the source of contamination and depend on the reference biosphere- and scenario-specific conditions of human exposure to the radionuclides. The outcome of biosphere modeling, BDCFs, facilitate conversion of radionuclide concentrations at the source (i.e., activity per unit volume of well water for groundwater contamination scenario, and activity per unit area of surface soil for disruptive volcanic event scenario) to a potential radiation dose. BDCFs represent the transport and uptake for a unit of activity concentration at the source, including its migration through the environment to the human receptor, radionuclide intake or external exposure and the resulting radiation dose per unit activity concentration at the source.

Radionuclide-specific BDCFs were calculated for the two major scenarios based on the source of contamination: groundwater contamination scenario and the disruptive volcanic event scenario assuming contamination of soil by volcanic ash deposited on the soil surface. Groundwater contamination scenario was used to evaluate the BDCFs for undisturbed performance of the repository as well as for consideration of consequences of some disruptive events, such as seismic events, and human intrusion. Contamination of soil with volcanic ash was used to calculate BDCFs for the disruptive volcanic event scenario. Calculations for both scenarios provides a quantitative evaluation of uncertainty of biosphere modeling outcome (BDCFs) with regard to the uncertainty in the values of input parameters. This uncertainty is represented by a distribution of potential BDCF values.

Although two human receptors, an average member of the critical group and the RMEI (see Section 3.1.2 for details), were considered in the analysis, the calculations of BDCF were carried out for average member of the critical group only. Both receptors are considered consuming average food consumption rates (see Table 3.16). The RMEI requires consuming 2 liters of water per day, while the average member of the critical group survey consumes about 750 liters of water per year (2.05 l/day) (see Table 3-16). Therefore, these two receptors are virtually identical.

3.3.1 Biosphere Dose Conversion Factors for Groundwater Contamination Scenario

BDCFs for groundwater contamination scenario were calculated for the following eighteen radionuclides of interest: Carbon-14, Strontium-90, Technetium-99, Iodine-129, Cesium-137, 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 (CRWMS M&O 2000m, Section 7.1). In addition, another five radionuclides were considered for one million years: lead-210, protactinium-231, radium-226, thorium-230, and plutonium-242 (CRWMS M&O 2000m, Section 7.1).

Calculations of BDCFs were performed in a series of individual calculations for the eighteen radionuclides under consideration. Radionuclide inventory was specified in terms of radionuclide concentrations in groundwater at the well head in units of pCi/L. BDCFs expressed as annual TEDE per unit activity concentration in groundwater, were calculated in units of mrem/yr. per pCi/L.

When contaminated groundwater is used to irrigate agricultural soil, the concentration of each contaminant in the soil will build up at a rate determined by the chemical properties and radioactive half-life of the material. Long-lived isotopes of elements that bind readily to soil particles may not reach an equilibrium concentration for many hundreds of years, whereas relatively short-lived or mobile radioisotopes may approach their maximum concentrations after only a few years of irrigation. To account for the radionuclide buildup in soil, BDCFs were calculated for each of the six prior irrigation time periods listed in Table 3-6 (Section 3.2.4.1.2). The prior irrigation time periods are the number of years that the land has been irrigated before the intake occurs. The first of six BDCFs was always with no prior irrigation. The remaining five were selected so that the BDCFs at each period would be equally spaced between the no-previous irrigation and the long-term asymptotic value. When the half-life of the radionuclide decay dominated the removal (over leaching), the periods were calculated as before, but used the decay rate rather than the leaching rate.

3.3.1.1 Biosphere Dose Conversion Factor Abstraction

Statistical approach to BDCF calculations makes it possible to determine how uncertainties within the analysis parameters translate into uncertainty in modeling results and to provide a quantitative evaluation of this uncertainty with regard to the biosphere modeling outcome represented by a distribution of potential BDCF values. Although many of the input parameters were represented by a distribution, behaviors and characteristics of the receptor of interest were described by a set of discrete values (mean consumption rates of locally grown food and best estimates for relevant inhalation and external exposure parameters). Parametric distributions were subsequently sampled to arrive at stochastic representations of BDCFs.

BDCFs for each radionuclide of interest and prior irrigation time steps were calculated using GENII-S computer code with the input parameters discussed in Section 3.2.4. In the statistical process, input parameters were sampled from their distributions, where applicable, using Latin Hypercube method (see glossary in Appendix A), to produce 130 different realizations, and, consequently, 130 different BDCF outcomes. The number of realizations was set to 130 because it was the maximum that the code could perform due to the computing limitations, however this number is sufficient to obtain statistically valid results. Using the Latin Hypercube sampling method, it is ensured that samples are taken evenly in the range. The relationship between the minimum sample size (N) and number of sampled parameters (n) is $N = 1.33\ n$ (LaPlante and Poor 1997, p. 3-2). Therefore, 130 realizations are sufficient for about 40 distribution parameters. Sampling statistics (arithmetic mean and standard deviation) for 18 radionuclides considered for the groundwater contamination scenario for 10,000 years after the potential repository closure, for six irrigation time periods are summarized in Table 3-17 (CRWMS M&O 2000e). The BDCFs for additional radionuclides that are important for possible radionuclide releases from the potential repository for up to 1 million years after the repository closure are listed in Table 3-18. The BDCFs for these radionuclides were calculated for the 4th irrigation time period (see Table 3-6).

Most of the BDCF values presented in Table 3-17 increase with the duration of previous irrigation (increasing time steps), indicating the effect of radionuclide buildup in soil. The values of BDCFs represent combined contributions from all pathways under consideration for a particular exposure scenario. Not every individual pathway component of BDCF is influenced by the changing radionuclide concentration in soil. For example, the contributions to BDCF due to ingestion of drinking water and the intake of the radionuclide that enters the food chain by deposition on the plant's surfaces from the irrigation water are insensitive to radionuclide buildup in soil. Examples of buildup-sensitive pathways that contribute to BDCF include external exposure to radiation from contaminated soil, inhalation of resuspended soil particles, and the radionuclides taken up by edible crop through their root system (CRWMS M&O 2000h).

Using the ratio of the mean value of period 6 (longest) to period 1 (no prior irrigation) from Table 3-17, allowed the soil buildup factor to be determined. The result of this calculation, in the decreasing order of soil buildup, is shown in Table 3-19. Also shown in Table 3-19 are the appropriate times for period 6 of previous irrigation. The periods of previous irrigation are correlated with the period of time it takes until the equilibrium radionuclide concentration in soil is reached under the continuous irrigation conditions.

For most radionuclides (13 of the 18 radionuclides considered for the groundwater contamination scenario), radionuclide buildup represented by the buildup factor was less than 15 percent. For these radionuclides, it was conservatively recommended that the BDCF distributions appropriate to the longest periods of irrigation be used (CRWMS M&O 2000g, Section 7.1). These distributions (one for each radionuclide) can be efficiently sampled by the TSPA computer code to generate the dose to the defined receptor from radionuclide contamination in the groundwater.

Of the remaining 5 radionuclides, Thorium-229 showed the greatest degree of buildup, by a factor of 2.85 relative to no-prior-irrigation conditions. The increase of BDCF for Thorium-229 with time of previous irrigation is shown in Figure 3-7 (CRWMS M&O 2000h). The figure depicts data points (BDCFs) and the predicted curve for Thorium-229. The second highest buildup factor, equal to 2.21, was for Cesium-137.

Table 3-17. Summary Results of Biosphere Dose Conversion Factors for Groundwater Contamination Scenario for Average Member of the Critical Group for 10,000 Years

Radionuclide	Arithmetic Mean and Standard Deviation	Biosphere Dose Conversion Factors for Irrigation Periods (mrem/yr. per pCi/L)					
		1	2	3	4	5	6
Carbon-14	Mean	4.06E-03	4.06E-03	4.06E-03	4.06E-03	4.06E-03	4.06E-03
	Standard Deviation	2.48E-04	2.48E-04	2.48E-04	2.48E-04	2.48E-04	2.48E-04
Strontium-90	Mean	1.82E-01	2.26E-01	2.71E-01	3.06E-01	3.33E-01	3.51E-01
	Standard Deviation	3.57E-02	8.80E-02	1.50E-01	2.02e-01	2.40E-01	2.67E-01
Technetium-99	Mean	4.02E-03	4.07E-03	4.08E-03	4.08E-03	4.08E-03	4.08E-03
	Standard Deviation	1.60E-03	1.68E-03	1.68E-03	1.68E-03	1.68E-03	1.68E-03
Iodine-129	Mean	3.61E-01	3.62E-01	3.62E-01	3.62E-01	3.62E-01	3.62E-01
	Standard Deviation	6.86E-02	6.87E-02	6.88E-02	6.88E-02	6.88E-02	6.88E-02
Cesium-137	Mean	8.77E-02	1.09E-01	1.31E-01	1.52E-01	1.73E-01	1.94E-01
	Standard Deviation	2.36E-02	2.72E-02	3.35E-02	4.05E-02	4.86E-02	5.69E-02
Actinium-227	Mean	1.81E+01	1.81E+01	1.81E+01	1.82E+01	1.82E+01	1.82E+01
	Standard Deviation	3.08E+00	3.07E+00	3.07E+00	3.08E+00	3.08E+00	3.08E+00
Thorium-229	Mean	4.59E+00	6.71E+00	8.67E+00	1.04E+01	1.19E+01	1.31E+01
	Standard Deviation	7.95E-01	1.19E+00	1.84E+00	2.49E+00	3.07E+00	3.53E+00
Uranium-232	Mean	1.71E+00	1.75E+00	1.81E+00	1.86E+00	1.91E+00	1.94E+00
	Standard Deviation	2.91E-01	2.91E-01	2.92E-01	2.94E-01	2.95E-01	2.96E-01
Uranium-233	Mean	3.77E-01	3.79E-01	3.81E-01	3.83E-01	3.85E-01	3.88E-01
	Standard Deviation	6.40E-02	6.40E-02	6.41E-02	6.43E-02	6.45E-02	6.49E-02
Uranium-234	Mean	3.70E-01	3.72E-01	3.74E-01	3.76E-01	3.78E-01	3.80E-01
	Standard Deviation	6.28E-02	6.29E-02	6.29E-02	6.32E-02	6.33E-02	6.36E-02
Uranium-236	Mean	3.51E-01	3.53E-01	3.55E-01	3.56E-01	3.58E-01	3.60E-01
	Standard Deviation	5.95E-02	5.96E-02	5.96E-02	5.99E-02	6.00E-02	6.03E-02
Uranium-238	Mean	3.39E-01	3.41E-01	3.44E-01	3.46E-01	3.49E-01	3.52E-01
	Standard Deviation	5.81E-02	5.81E-02	5.82E-02	5.84E-02	5.85E-02	5.89E-02
Neptunium-237	Mean	6.76E+00	6.77E+00	6.78E+00	6.79E+00	6.80E+00	6.82E+00
	Standard Deviation	1.15E+00	1.15E+00	1.15E+00	1.15E+00	1.15E+00	1.15E+00
Plutonium-238	Mean	4.11E+00	4.12E+00	4.14E+00	4.15E+00	4.16E+00	4.17E+00
	Standard Deviation	6.97E-01	6.98E-01	6.97E-01	6.97E-01	6.97E-01	6.97E-01
Plutonium-239	Mean	4.57E+00	4.66E+00	4.75E+00	4.84E+00	4.94E+00	5.03E+00
	Standard Deviation	7.74E-01	7.75E-01	7.75E-01	7.77E-01	7.79E-01	7.82E-01
Plutonium-240	Mean	4.56E+00	4.65E+00	4.74E+00	4.83E+00	4.92E+00	5.00E+00
	Standard Deviation	7.73E-01	7.74E-01	7.74E-01	7.76E-01	7.78E-01	7.80E-01
Americium-241	Mean	4.65E+00	4.74E+00	4.82E+00	4.90E+00	4.97E+00	5.04E+00
	Standard Deviation	7.88E-01	7.89E-01	7.92E-01	7.95E-01	7.97E-01	8.02E-01
Americium-243	Mean	4.64E+00	5.29E+00	5.92E+00	6.50E+00	7.04E+00	7.50E+00
	Standard Deviation	7.87E-01	8.03E-01	8.53E-01	9.14E-01	9.78E-01	1.05E+00

Table 3-18. Summary Results of Additional Biosphere Dose Conversion Factors for Groundwater Contamination Scenario for Average Member of the Critical Group for 1 Million Years Consideration

Radionuclide	Biosphere Dose Conversion Factors (mrem/yr. per pCi/ m^2)	
	Arithmetic Mean	Arithmetic STD
Lead-210	7.55E+00	1.44E+00
Protactinium-231	1.37E+01	2.32E+00
Radium-226	1.61E+01	1.67E+01
Thorium-230	2.32E+01	2.49E+01
Plutonium-242	4.50E+00	7.22E-01

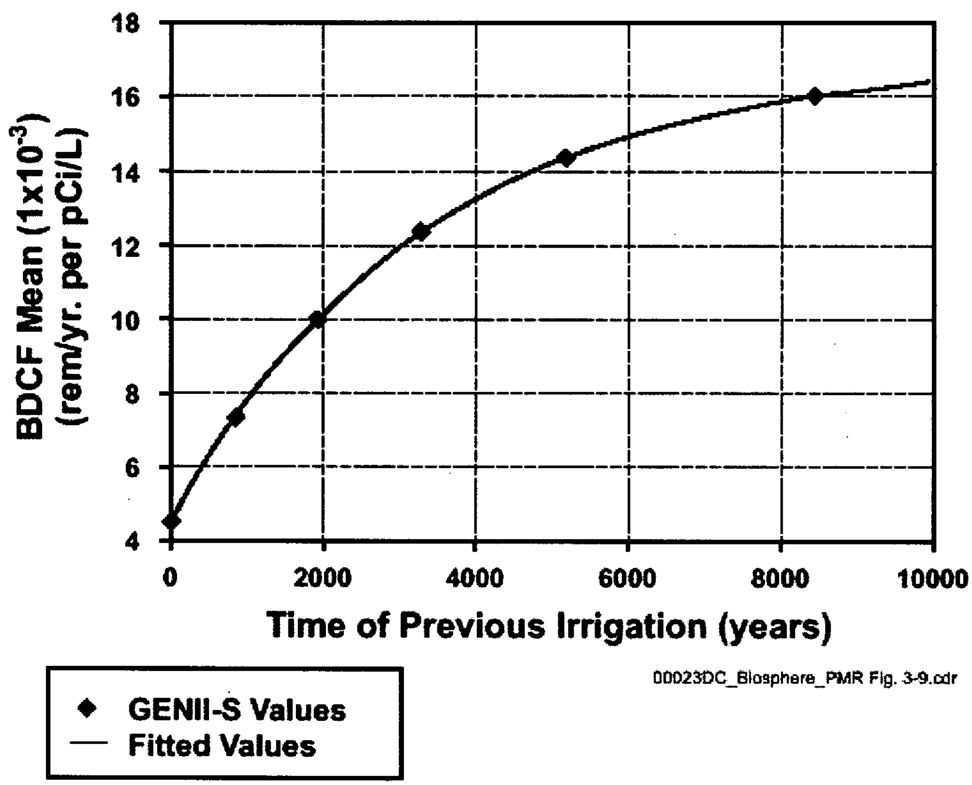


Figure 3-7. Comparison of GENII-S Predicted Values of the Biosphere Dose Conversion Factors for Thorium-229 as a Function of Previous Irrigation Periods with Predicted Analytical Fit

Table 3-19. Soil Buildup Factors for Radionuclides

Radionuclide	Soil Buildup Factor	Period 6 Time (Years)
Thorium-229	2.85	8448
Cesium-137	2.21	78
Strontium-90	1.93	53
Americium-243	1.62	5031
Uranium-232	1.13	93
Plutonium-239	1.10	1456
Plutonium-240	1.10	1456
Americium-241	1.08	1117
Uranium-238	1.04	93
Uranium-233	1.03	93
Uranium-234	1.03	93
Uranium-236	1.03	93
Technetium-99	1.01	5
Plutonium-238	1.01	227
Actinium-227	1.01	56
Neptunium-237	1.01	14
Iodine-129	1.00	5
Carbon-14	1.00	7401

Some of the radionuclides predicted to have more significant buildup in soil, such as Americium-243, Thorium-229, and Uranium-232, have not been significant contributors to dose in previous TSPA evaluations. In addition, for Thorium-229 and Americium-243, the period needed for buildup is on the order of thousands years. It could be considered speculative to assume continuous farming activity on a single plot of irrigated land over such extended periods of time.

The GENII-S code used to calculate the BDCFs does not consider the mechanism of radionuclide removal by soil erosion. The rate of soil removal by erosion under natural conditions is generally in approximate equilibrium with the rate of soil formation from the transformation of underlying bedrock, alluvium, colluvium, or other geologic material comprising the parent material. Under these conditions, the soil depth (or thickness) is maintained at a near constant depth through time (Troeh et al. 1980, p. 4). Anthropogenic activities, including tilling of cropland, removal of vegetation, and grazing of pasture or rangeland, typically tend to accelerate the natural rate of soil removal. Disturbed soil is generally left with less protection against the action of water and wind. Thus, the formation of new soil cannot keep pace with the accelerated erosion rate, and the soil material may progressively become thinner (Troeh et al. 1980, pp. 5 to 6). The estimated annual rate of soil loss, for the major soil series in the vicinity of the proposed human receptor was found to be generally between 0.06 and 0.08 cm/yr. (CRWMS M&O 2000d).

To incorporate the results of BDCF calculations into the TSPA-SR predictive code in a computationally efficient manner, statistical distributions were fitted to BDCF data and distribution parameters were determined (CRWMS M&O 2000g). As noted before, a distribution of BDCFs represents the uncertainty in the BDCFs due to the uncertainties in the biosphere model parameters. The recommended distributions and geometric parameters for TSPA-SR for those radionuclides that show a small degree of buildup are presented in Table 3-20. Statistical distributions for these radionuclides are given for the maximum period of previous irrigation (period 6). For the five radionuclides where the GENII-S predictions show a significant, i.e., greater than 15 percent, buildup, statistical distributions of BDCF were determined after incorporation of the soil loss effect. The recommended geometric parameters for the distribution of BDCF for these radionuclides are also summarized in Table 3-20 (CRWMS M&O 2000h).

Table 3-20. Recommended BDCF Distributions and Geometric Parameters for TSPA-SR

Radionuclide	Distribution				
	Lognormal		Shifted lognormal		
	Geometric Mean mrem/yr. per pCi/L	Geometric SD	Off-set mrem/yr. per pCi/L	Geometric Mean mrem/yr. per pCi/L	Geometric SD
Radionuclides That Show a Small Degree (less than 15 percent) of Soil Buildup Effects					
Carbon-14			3.4675E-03	0.5536E-03	1.5177
Technetium-99			2.1631E-03	1.4948E-03	1.8423
Iodine-129	3.562E-01	1.187			
Actinium-227	1.801E+01	1.162			
Uranium-233	3.848E-01	1.161			
Uranium-234	3.769E-01	1.162			
Uranium-236	3.564E-01	1.164			
Uranium-238	3.512E-01	1.159			
Neptunium-237	6.738E+00	1.163			
Plutonium-238	4.109E+00	1.161			
Plutonium-239	4.976E+00	1.151			
Plutonium-240	4.953E+00	1.151			
Americium-241	5.012E+00	1.156			
Radionuclides Showing Buildup Greater than 15 Percent					
Americium -243	5.030E+00	1.163			
Thorium-229	5.392E+00	1.167			
Uranium-232	2.064E+00	1.150			
Cesium-137	1.841E-01	1.163			
Strontium-90			1.525E-01	1.121E-01	2.736

The lognormal distribution occurs when the natural logarithm (i.e., to base *e*) of the random variable is distributed normally, i.e., $ln(x_i)$ is normal with a defined mean (μ) and standard deviation (σ). A shifted lognormal distribution occurs when $ln(x_i\text{-}s)$ (where s is a constant) is distributed normally with a defined mean (μ) and standard deviation (σ). Thus for a shifted lognormal distribution, the three parameters (s, μ, and σ) required to characterize the distribution are the shift (or axis translation) s, the mean, μ, of $ln(x_i\text{-}s)$, and the standard deviation, σ, of $ln(x_i\text{-}s)$.

3.3.1.2 Sensitivity and Uncertainty Analysis for Groundwater Contamination Scenario

The purpose of the sensitivity analysis was to determine which pathways and input parameters have the most influence on the BDCF value for groundwater contamination scenario for each radionuclide of interest. GENII-S allows certain parameters to be represented as probabilistic distributions that reflect the uncertainty or variability in that parameter. Other parameters may be represented only as fixed values in the code. Uncertainty analysis shows quantitatively the effect of propagation of input parameter uncertainties on the calculated BDCFs. Information on pathway sensitivity, input parameter sensitivity, and BDCF uncertainty provide a context for the BDCF estimates and focuses attention and resources on parameters and modeling decisions that could have the greatest influence on BDCF values for the groundwater contamination scenario (CRWMS M&O 2000f).

Sensitivity of Biosphere Dose Conversion Factors to Independent Variables

When calculating the BDCFs for an average member of the critical group, several parameters describing human activities that influence dose to the receptor of interest were set at mean values to meet the proposed 10 CFR 63 criteria (64 FR 8640, Section 63.115(b)(4)). To conduct the sensitivity analysis, an additional set of BDCF calculations was done. These calculations were identical to those to determine BDCF values, except that distributions (ranges) were specified for twelve GENII-S input parameters that had been fixed at mean values for purposes of the BDCF calculations. Distributions were specified for inhalation exposure time and soil exposure time, as well as consumption rates for leafy vegetables, root vegetables, grains, fruit, poultry, meat, fish, eggs, milk, and tap water. An understanding of the sensitivity of BDCFs to these parameters is helpful in applying the concept of the RMEI, defining the critical group, and identifying important elements of the interface between the geosphere and biosphere models.

For purposes of the sensitivity analysis, each radionuclide-specific BDCF determination consisted of 130 realizations in which values for each of 40 independent (input) variables were selected randomly by GENII-S according to distributions that were specified for the variables. Thus, for each of the 18 radionuclides of interest, 130 sets of data were available for analysis. Each set contained the specific values of the 40 independent variables used by GENII-S in that trial, plus the value of the dependent variable (output) which was the annual TEDE per unit activity concentration in groundwater (or BDCF) that was calculated using those input values.

Data Analysis Method–The input and output data from the GENII-S calculations were analyzed using stepwise linear regression. Stepwise linear regression is an efficient method for providing insights into the structure of the data. Stepwise linear regression analysis produces a best fit model that contains those independent variables that best explain the variance in a given output. The goal of this analysis was to determine the smallest set of independent variables that does the best job of accounting for the variance in BDCF.

Eighteen stepwise linear regression analyses were run, one for each radionuclide. The same set of 130 values for each of the 40 independent variables was used in each analysis. The first step in the analysis was to perform a linear transformation of the data to better accommodate the input needs of the statistical analysis software package (S PLUS 2000) and to provide for generation of standardized regression coefficients.

Next, a stepwise linear regression analysis was performed on the data for each radionuclide. In each analysis, S PLUS 2000 did successive trials that included and excluded different independent variables, then reported the subset of variables that explained the greatest part of the variance in the output, along with standardized regression coefficients for those variables.

The resulting standardized regression coefficients indicate the magnitude by which the calculated BDCF changes for each increment of change in an input variable. Standardization of the regression coefficient removes the effect of the unit of measure from the regression results. The standardized regression coefficients are used to rank the importance of the independent variables in accounting for the variance in the BDCF.

Results–The results of the stepwise linear regression analyses indicate that a small subset of input variables consistently explains most of the variance in the radionuclide-specific BDCFs. For the majority of radionuclides of interest, seven or fewer independent variables accounted for greater than 90 percent of the variance in the BDCF. Parameters associated with consumption of leafy vegetables and drinking water consistently ranked among the most important for all radionuclides. Following are key observations from the results:

- Leafy vegetable consumption rate was the most significant contributor to variance in the BDCF for all radionuclides except Carbon-14, Technetium-99, and Cesium-137. For Technetium-99 it was the second-ranked contributor.

- Drinking water consumption rate was the second most important contributor to variance for all the heavy elements, Strontium-90, and Iodine-129. It was third in importance for Technetium-99 and Cesium-137.

- Crop interception fraction—the fraction of contamination in irrigation water that adheres to the plant surfaces—was the third most important contributor for all radionuclides except Carbon-14, Technetium-99, and Cesium-137.

- Milk consumption rate is the leading contributor to BDCF variance for Technetium-99 and was also a significant factor for Iodine-129.

- Fish consumption rate accounts for essentially all the BDCF variance for Carbon-14 and is also the most important contributor for Cesium-137.

- Soil-plant transfer factor is a significant contributor to BDCF variance only for the biologically mobile radionuclide Technetium-99.

- Beef consumption rate is the second leading contributor to BDCF variance for Cesium-137 and was also a significant factor for Iodine-129 and Strontium-90.

The above results are consistent with the relatively low biological mobility of the heavy elements and the fact that all the heavy element isotopes of interest are alpha particle emitters that must be taken into the body to contribute to the dose. The results suggest two key pathways for the heavy elements: consumption of drinking water and deposition of radioactive material on crops (by irrigation and resuspension) with subsequent human ingestion of the crops. Ingestion of crops and animal products is also indicated as the most important pathway for the biologically mobile radionuclides Strontium-90, Technetium-99, Iodine-129 and Cesium-137. However, the relatively high significance of animal and crop transfer coefficients for some of these radionuclides suggest that biological incorporation into the crops is the most important mechanism, as opposed to the surface deposition process implied by the heavy element results.

Parameters that were not important to the BDCF variation for any radionuclide, or were only of minor importance to a few, include:

- Growing time for vegetables, grains, fruits, forage, beef, and milk
- Irrigation rates and irrigation time for any crops except leafy vegetables
- Animal uptake factor
- Yields for most foodstuffs.

The reason that these parameters are not sensitive to the BDCF variation is because they have relative small ranges.

When developing inhalation inputs and considering associated sensitivities, additional attention was provided to potential variations in particle size and in air mass loading due to surface disturbing activity. These variations were shown to result in very small changes to the inhalation pathway contribution to BDCFs, and small changes in the soil ingestion pathway contribution, the effective pathway for larger (greater that 10 μm) particle inhalation (CRWMS M&O 2000f).

<u>**Sensitivity of Biosphere Dose Conversion Factors to Pathways**</u>

Examining the relative importance of different pathways to the BDCF provides a different perspective on sensitivity. To determine the contributions of different pathways to the BDCF values, a single GENII-S deterministic assessment was performed for each radionuclide. Both deterministic and stochastic methods can be used to perform pathway analysis. The deterministic method provides a single value of BDCF, which can be directly used for the pathway contribution calculation. The stochastic method, on the other hand, provides a distribution of BDCF. Calculation of mean value for these distributions of BDCF must be completed before they can be used for pathway contribution calculation. Since the mean and distribution of input parameters are selected consistently, difference between the two methods is insignificant. The deterministic method was chosen for its simplicity. In this deterministic assessment, a best estimate (or average value) was used for each of the 40 input parameters that had been specified as distributions for purposes of the input parameter sensitivity analysis described in the previous section.

For the groundwater contamination scenario, inhalation and external exposure pathways are not significant, and the ingestion pathway accounts for essentially all the BDCF. For all radionuclides of interest except Carbon-14 and Cesium-137, ingestion of drinking water is the most important contributor to BDCF, followed by ingestion of leafy vegetables. Together, consumption of drinking water and leafy vegetables account for 80 to 95 percent of the BDCF values for those radionuclides, with the balance resulting from consumption of fruits and other vegetables. For the biologically mobile radionuclides Strontium-90, Technetium-99 and Iodine-129, the contributions to the BDCF values are slightly different. Although consumption of drinking water and leafy vegetables are still the most important contributors to the BDCFs, consumption of other vegetables, fruit, eggs, meat, and milk are more significant than for the heavy elements.

For Carbon-14 the ingestion pathway still dominates the total BDCF. However, consumption of fish, which is assumed to be raised in ponds filled from groundwater sources, is by far the greatest single contributor. For Cesium-137, fish consumption is also the leading contributor to the BDCF, followed by consumption of drinking water, leafy vegetables and meat.

The pathway contributions to the BDCFs for the radionuclides of interest are summarized in Table 3-21 (CRWMS M&O 2000f).

Table 3-21. Pathway Contribution to Groundwater Contamination Scenario Biosphere Dose Conversion Factors

Radionuclide	Drinking Water	Leafy Vegetables	Fruit	Other Vegetables	Eggs	Milk	Meat	Fish	Other
Carbon-14	3	1	–	–	1	–	–	92	2
Strontium-90	54	34	2	3	–	–	5	2	1
Technetium-99	51	35		2	2	8	–	–	2
Iodine-129	55	31	–	2	2	4	3	–	3
Cesium-137	29	16	1	1	–	2	12	37	2
Actinium-227	61	35	2	2	–	–	–	1	–
Thorium-229	59	34	2	2	–	–	–	4	–
Uranium-232	61	34	2	2	–	–	–	–	2
Uranium-233	61	34	2	2	–	–	–	–	2
Uranium-234	60	34	2	2	–	–	–	–	2
Uranium-236	60	34	2	2	–	–	–	–	2
Uranium-238	60	35	2	2	–	–	–	–	2
Neptunium-237	61	34	2	2	–	–	–	1	1
Plutonium-238	61	34	2	2	–	–	–	1	–
Plutonium-239	61	34	2	2	–	–	–	1	–
Plutoniumu-240	61	34	2	2	–	–	–	1	–
Americium-241	61	34	2	2	–	–	–	1	–
Americium-243	61	34	2	2	–	–	–	1	–

Note: Table values are in percent and totals may not equal 100 percent because of rounding.

Biosphere Dose Conversion Factor Uncertainty

For most radionuclides of interest, the BDCF values obtained from the 130 GENII-S realizations have a range of about one to two orders of magnitude. Technetium-99 produced the widest range of results, the largest BDCF value exceeding the smallest by a factor of 105.

3.3.2 Biosphere Dose Conversion Factors for Disruptive Volcanic Event Scenario

Twelve radionuclides were identified as relevant for calculation of disruptive volcanic event scenario BDCFs: Actinium-227, Americium-241, Americium-243, Cesium-137, Protactinium-231, Plutonium-238, Plutonium-239, Plutonium-240, Strontium-90, Thorium-229, Uranium-232, Uranium-233 (CRWMS M&O 2000m, Section 7.1). The list of radionuclides of interest is different than that considered for groundwater contamination scenario because it reflects the radionuclide inventory directly released from the repository during volcanic eruption, as opposed to radionuclides transported with groundwater through the geosphere. Calculations were performed in a series of individual runs for the twelve radionuclides under consideration. The receptor of interest considered for the disruptive volcanic event scenario was an average member of the critical group. Radionuclide inventory was specified in terms of basic concentrations that exist after transport of volcanic ash has occurred. The inventory activity units selected (pCi for activity and per m^2 for soil inventory) resulted in basic concentrations in surface soil in the units of pCi/m^2. BDCFs expressed as annual TEDE per unit activity deposition per unit area, were calculated in units of mrem/yr. per pCi/m^2.

Similar to the case of BDCF for groundwater contamination scenario, calculations of BDCFs for disruptive volcanic event scenario were performed in a series of stochastic runs to propagate the uncertainties of input parameters into the output BDCFs. A Latin Hypercube sampling method was used in the stochastic analysis with the number of realizations set to 160, which was the maximum that the software could perform due to the computing limitation. This number was sufficient to obtain statistically valid results.

3.3.2.1 Biosphere Dose Conversion Factor Abstraction

Input values were analogous to those considered for groundwater contamination scenario with the exception of parameters related to pathways using contaminated water. Parameters related to irrigation, such as irrigation rate and irrigation time, as well as consumption of water were not used by the code under the assumption of no radionuclide contamination present in water (see description of exposure scenario in Section 3.1.5.2). Statistical output (mean and standard deviation) is summarized in Table 3-22 (CRWMS M&O 2000j).

In the case of volcanic dispersion of the radionuclides, the same loss mechanisms as in GENII-S were considered. In this case, the leaching loss was only considered during a single year of agricultural land use (the receptor uptake period). No attempt was made to address the effect of leaching losses due to prolonged irrigation over many years. This approach is conservative. An Issue Resolution Status Report on volcanic activity recommended that the event be evaluated in a probabilistic manner. Thus the dose at year *n* had to be calculated as the sum of the expected doses from events (probability weighted) at each of the previous years. The additional loss mechanism of soil erosion, therefore, could be used to justifiably reduce the expected dose from such an event.

Table 3-22. Statistical Output for Disruptive Volcanic Event Scenario Biosphere Dose Conversion Factors

Radionuclide	Biosphere Dose Conversion Factors (mrem/yr. per pCi/ m^2) [a]	
	Arithmetic Mean	Arithmetic STD
Strontium-90	7.792E-06	1.196E-05
Cesium-137	1.809E-06	9.175E-07
Actinium-227	2.990E-06	1.405E-06
Thorium-229	9.437E-07	3.848E-07
Protactinium-231	1.592E-06	6.715E-07
Uranium-232	8.070E-07	8.770E-07
Uranium-233	1.768E-07	1.935E-07
Plutonium-238	3.620E-07	7.276E-08
Plutonium-239	4.019E-07	8.074E-08
Plutonium-240	4.012E-07	8.061E-08
Americium-241	5.375E-07	2.308E-07
Americium-243	5.748E-07	2.303E-07

[a] In the source document, the BDCFs are given in units of rem/yr. per pCi/m^2. For consistency with other cases, the units were converted to mrem/yr. per pCi/m^2.

For the disruptive volcanic event scenario, it is required to have a capability to evaluate the expected dose as a function of time. (Expected is used here with its normal statistical meaning, i.e., the integral over time of the product of event probability and associated dose.) After a volcanic event, the effect of continual irrigation is to leach the radionuclides from the soil/ash mixture without any replacement. Once leached out in a specified farming scenario, the radionuclides are removed from the accessible environment and no longer contribute to dose. Therefore prolonged irrigation in a hypothetical farming community following the volcanic event would lead to a reduction of expected dose. To retain conservatism while avoiding much speculation on the number of years of land use, it is assumed that the receptor only uses the land for a single year. If additional years of use for the land had been considered, the resulting BDCFs for these later times would be reduced to some degree by virtue of the radionuclide removal processes in the intervening period (between the ash fall and the year for which BDCFs were calculated). The radionuclide removal processes include leaching, wind erosion (which is more significant on tilled land than on undisturbed tracts of natural terrain), crop removal, and radioactive decay. Given this conservative approach there are no additional processes to be incorporated into the abstraction process for the volcanic data.

3.3.2.2 Sensitivity and Uncertainty Analysis for Disruptive Volcanic Event Scenario

As discussed in Section 3.3.1.2, GENII-S allows certain parameters to be represented as probabilistic distributions that reflect the uncertainty or variability in that parameter. Other parameters may be represented only as fixed values in the code. The details of sensitivity and uncertainty analysis for disruptive volcanic event scenario can be found in the *Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis* AMR (CRWMS M&O 2000k).

Sensitivity of Biosphere Dose Conversion Factors to Independent Variables

As in the groundwater contamination scenario sensitivity analysis discussed in Section 3.3.1.2, an additional set of BDCF calculations was done. These calculations were identical to those used to determine BDCF values, except that distributions (ranges) were specified for eleven GENII-S input variables that had been fixed at best estimate values for purposes of the BDCF calculations. Distributions were specified for inhalation exposure time and soil exposure time, as well as consumption rates for leafy vegetables, root vegetables, grains, fruit, poultry, meat, fish, eggs, milk, and tap water. Fish consumption was not considered in this sensitivity analysis because groundwater and surface water are assumed not to be contaminated in the disruptive volcanic event scenario. Each radionuclide-specific BDCF determination consisted of 130 realizations in which values for each of the 39 independent variables were selected randomly by GENII-S according to distributions that were specified for the variables. Thus, for each of the 12 radionuclides of interest, 130 sets of data were available for analysis. Each set contained the specific values of the 39 input variables used by GENII-S in that trial, plus the value of the dependent variable—the annual TEDE (or BDCF) that was calculated using those input values.

Data Analysis Method–To determine the importance of the independent variables in accounting for the variance in the BDCF, the input and output data from the GENII-S calculations were analyzed using stepwise linear regression. A discussion of the stepwise linear regression analysis method is provided in Section 3.3.1.2.

Results–As for the groundwater contamination scenario, the results of the stepwise linear regression analyses indicate that a subset of input parameters explains most of the variance in the radionuclide-specific BDCFs. No more than 16 parameters were included in the final regression model for any radionuclide. A majority of the final models contained fewer than 11 parameters and accounted for 75 to 85 percent of the variation in the BDCF. Following are key observations from the results:

- The soil-plant transfer factor was the most significant contributor to variance in the BDCF for all but two radionuclides, and for these (Cesium-137 and Thorium-229), it was the second-ranked contributor.
- Mass loading (of dust in the ambient air) is a significant contributor to BDCF variance for a number of alpha-emitting radionuclides.
- Soil exposure time (number of hours per year that a person is exposed to the contaminated soil surface) is the most significant contributor to BDCF variance for Cesium-137 and the third ranking contributor for two other radionuclides.
- Consumption rates for leafy vegetables, root vegetables, and fruits are important contributors to BDCF variance for many radionuclides.

- Beef consumption rate is the second leading contributor to BDCF variance for Strontium-90 and is ranked third for Cesium-137.

These contributions to the BDCF variances are consistent with key pathways that involve uptake of radioactive material from the soil by crops with subsequent human ingestion of the crops and meat, inhalation of dust raised from the contaminated soil, and external exposure.

Parameters that were not important to the BDCF variance for any radionuclide or only of minor importance to a few include:

- Crop interception fraction
- Growing time for vegetables, grains, fruits, beef, and milk
- Fruit and vegetable crop yields
- Irrigation rates and irrigation times
- Consumption rates for poultry, milk, and grain
- Yields for milk, eggs, poultry, fruit, and vegetables.

Sensitivity of Biosphere Dose Conversion Factors to Elevated and Extreme Mass Loadings

Additional attention was provided in the sensitivity analysis to possible variations in the air mass loading parameter. This was done to ensure understanding of the effect on the disruptive volcanic event scenario BDCF values if the mass loading varied greatly from the range used in the BDCF calculations. The BDCFs were calculated based on a predicted very thin ash layer. This results in a mass loading similar to that for the undisturbed performance and a modest inhalation pathway contribution to the BDCFs.

To develop ranges of mass loading to evaluate the associated changes to BDCFs, two approaches might have been pursued. The one chosen used ranges based on measured values following the eruption of Mount St. Helens. The alternative method of eventually arriving at mass loading values would involve developing predictions for the physical parameters that help determine the amount of respirable dust in the breathing air. This would include predicting ash thickness, ash particle size, changes in particle size over time due to mechanical and chemical weathering, redistribution of ash in the environment around the critical group, and the amount and effect of surface-disturbing activities.

Disruptive volcanic event scenario BDCFs were calculated based on a mass loading distribution with a mean value of 8.7 $\mu g/m^3$ (CRWMS M&O 2000t). Based on measured values in areas affected by the Mount St. Helens eruption reported in references (Bernstein 1986) (Buist 1986), two higher levels of air particulate mass loading were hypothesized and the effects on the calculated BDCF values determined. The first value, (100 $\mu g/m^3$) is a factor of 11.5 times the mean mass loading value used in the BDCF calculations. It corresponds to the higher of the reported measurements taken in non-occupational settings during the post-eruption period. The second value (800 $\mu g/m^3$) corresponds to the highest measured values for all but the most extreme occupational exposure conditions. It is a factor 92 times the mean mass loading value used in the BDCF calculations. To simplify the assessment of impact on BDCF values, these postulated conditions will be approximated as factors of 10 ("elevated" case) and 100 ("extreme" case) above the mean mass loading value used in the BDCF calculations.

Assuming the radioactivity ejected from the repository is uniformly distributed throughout the respirable ash particles, increasing the air mass loading by a factor of 10 or 100 will produce a proportionate increase in the inhalation pathway component of the BDCF. This assumption is believed to be quite conservative. This increased mass loading is assumed to persist throughout the year. If the airborne material includes a significant fraction of larger, non-respirable particles, the BDCFs would be lower because larger particles are more likely to be trapped in the upper airways, from which they are typically removed by the mucocilliary clearance process, swallowed and excreted via the gastrointestinal tract. Because the inhalation DCFs exceed the ingestion DCFs by 1 to 3 orders of magnitude for all radionuclides of interest except Cesium-137 (for which the two DCFs are approximately equal) the assumption of 100 percent respirable particles is conservative.

Table 3-23 (CRWMS M&O 2000k) shows the approximate factors by which the disruptive volcanic event scenario BDCF values would need to be multiplied to reflect the hypothetical 10X and 100X increases in the airborne mass loading discussed above. The references cited before (Bernstein 1986) (Buist 1986) indicate that air mass loading may far exceed even the postulated "extreme" level during and shortly after heavy ash fall. However, it is plausible that warnings issued by public health officials, together with the natural tendency of people to avoid exposure to high levels of dust would have the effect of limiting the integrated exposure to receptors of interest during periods of ash fall and maximum resuspension. In the aftermath of the Mount St. Helens ash fall, concern over the health effects of ash inhalation caused public health officials to issue numerous warnings and advisories on how to avoid or minimize ash inhalation.

If other scenarios involving increased mass loading are hypothesized, for example, exposure during ash fall, an increase in the inhalation pathway component of the BDCF will result.

Table 3-23. Biosphere Dose Conversion Factor Multipliers to Approximate Effects of Higher Air Mass Loading Assumption

Radionuclide	Fraction of BDCF From Inhalation	BDCF Multiplier for "Elevated" Air Mass Loading (10X)	BDCF Multiplier for "Extreme" Air Mass Loading (100X)
Strontium-90	<0.001	~1	~1
Cesium-137	<0.001	~1	~1
Actinium-227	0.37	4.3	37.6
Thorium-229	0.37	4.3	37.6
Protactinium-231	0.13	2.2	13.9
Uranium-232	0.18	2.6	18.8
Uranium-233	0.17	2.6	17.8
Plutonium-238	0.16	2.4	16.8
Plutonium-239	0.16	2.4	16.8
Plutonium-240	0.16	2.4	16.8
Americium-241	0.13	2.2	13.9
Americium-243	0.12	2.1	12.9

That increase is equal to the ratio between the increased mass loading and the mass loading in the BDCF calculation serving as the basis, provided similarities exist in assumed particle size.

Sensitivity of Biosphere Dose Conversion Factors to Pathways

To determine the contributions of different pathways to the BDCF values, a single GENII-S deterministic assessment was performed for each radionuclide. In this deterministic assessment, a best estimate (or average) value was used for each of the 39 input parameters that had been specified as distributions for purposes of the input parameter sensitivity analysis described in the previous section.

For the disruptive volcanic event scenario, soil ingestion is the dominant pathway and inhalation is an important contributor to the BDCF for isotopes of actinium, americium, protactinium and plutonium. For Thorium-229, the inhalation and soil ingestion pathways are approximately of equal importance, with lesser contributions from external exposure and food ingestion. For Strontium-90 and isotopes of uranium, ingestion of vegetables and fruits is the dominant pathway. However, inadvertent soil ingestion and inhalation are also significant contributors for uranium. External exposure is the dominant pathway for Cesium-137, which emits a relatively high-energy gamma, with a minor contribution from ingestion of fruit, vegetables, and meat.

The pathway contributions to the BDCFs for the radionuclides of interest are summarized in Table 3-24 (CRWMS M&O 2000k).

Table 3-24. Pathway Contributions to Disruptive Volcanic Event Scenario Biosphere Dose Conversion Factors

Radionuclide	External Exposure	Inhalation	Soil Ingestion	Leafy Vegetables	Other Vegetables	Fruit	Meat	Eggs	Milk	Other
Strontium-90	–	–	–	42	35	9	10	–	2	2
Cesium-137	82	–	–	3	1	9	4	–	–	1
Actinium-227	–	37	45	13	–	2	–	–	–	2
Thorium-229	15	37	35	12	–	–	–	–	–	2
Protactinium-231	5	13	64	13	2	3	–	–	–	–
Uranium-232	–	18	21	15	31	13	–	–	–	2
Uranium-233	–	17	21	15	31	13	–	–	–	3
Plutonium-238	–	16	77	3	2	2	–	–	–	–
Plutonium-239	–	16	77	3	2	2	–	–	–	–
Plutonium-240	–	16	77	3	2	2	–	–	–	–
Americium-241	4	13	64	11	3	4	–	–	–	–
Americium-243	11	12	59	10	3	4	–	–	–	–

Note: Table values are in percent and totals may not equal 100 percent because of rounding.

Biosphere Dose Conversion Factor Uncertainty

The BDCF values obtained from the 130 GENII-S realizations spanned a range of less than one order of magnitude for a number of radionuclides. For others, the range was much greater, up to nearly three orders of magnitude for Strontium-90.

A more useful way of expressing the uncertainty is to define an interval around the observed mean value within which there is a certain level of confidence that the true value of the mean will fall. Assuming that the distribution of the results of the 130 GENII-S realizations is a normal distribution, it can be shown that there is 95 percent confidence that the true mean of the population of BDCF values will fall within approximately ±36 percent of the observed arithmetic mean for Strontium-90 (the radionuclide that gave the widest range of BDCF values) and within 4 to 22 percent of the observed mean for the other 11 radionuclides.

3.4 WATER USAGE ANALYSIS

For the groundwater contamination scenario, the transport of radionuclides from the potential repository to the accessible environment is through the movement of water in the geosphere. The radioactive contaminants enter the biosphere through a well head with the water pumped for domestic, agricultural, and other purposes. However, modeling water usage and the resulting dilution of radionuclides in the saturated zone from pumping by the projected receptors would be complicated and speculative. Both well location and contamination plume geometry would have to be stochastically modeled. The pumping rate and local saturated zone conditions would also affect the withdrawal dynamics of each well resulting in a time-dependent dilution and radionuclide concentration.

In proposed NRC rules for the reference biosphere and critical group (64 FR 8640) and the guidance provided by DOE (Dyer 1999) an approach that removes uncertainty associated with dilution due to pumping dynamics and eliminates speculation on the relative location of the plume and the wells is proposed. The proposed approach is defined in Section 115 of DOE guidance (Dyer 1999) and 63.115 of the draft rule (64 FR 8640). The proposed regulatory approach conservatively assumes that all radionuclides passing through the 20-km locus from the potential repository are captured by water used by a defined hypothetical farming community of 15 to 25 farms with approximately 100 people. The guidance and proposed regulations both specify that the characteristics of the hypothetical community located hydrogeologically down gradient from Yucca Mountain are to be based on the present day characteristics of the Amargosa Valley community (Dyer 1999, Section 115(b)(4)). Thus, if the total annual quantity of groundwater used by the community can be determined, the annual average concentration of each radionuclide in the water pumped by the community would equal the annual mass of that radionuclide crossing the 20-km boundary divided by annual quantity of groundwater used by the community.

The basis for the water usage analysis is justified by the rationale discussed in Section IV of the Supplementary Information in the FR announcement (64 FR 8640). The TSPA-SR code uses the average concentration of each radionuclide to calculate dose from selected pathways to the specified receptor by using the BDCFs discussed in Section 3.3 of this report. The *Saturated Zone Flow and Transport PMR* (CRWMS M&O 2000r) provides the total mass of each radionuclide crossing the specified boundary and this analysis provides the total quantity of water into which the radionuclides are assumed to be contained. Uncertainties in the analysis as directed by Dyer (1999) are derived using standard statistical techniques. The analysis is abstracted as a sampling algorithm for inclusion into the TSPA-SR computer code.

Although the DOE guidance (Dyer 1999) and the NRC proposed 10 CFR 63 (64 FR 8640) are specific in defining water usage requirements, some details could be subject to alternative interpretation. These alternative interpretations of water usage are evaluated and presented in CRWMS M&O (2000l).

3.4.1 Interpretation of the Proposed Regulatory Requirement

3.4.1.1 Population Basis

Section 115 of the DOE interim guidance (Dyer 1999) specifies that the projected hypothetical farming community shall be comprised of approximately 100 people and that the characteristics of the community shall be based upon those existing in present day Amargosa Valley. If the present community of Amargosa Valley is considered a farming community, then it is a relatively simple matter to scale current day water use from the present population to that of the proposed population of 100 in the hypothetical community.

Given sufficient data, this approach can provide an estimate of annual groundwater use. However, to provide uncertainty estimates, the approach requires modification. Rather than use a population of 100 directly, the analysis used the number of residences that, on average, contain 100 people (based on the census data). This modification is necessary because the 1990 census data did not present Amargosa Valley as a farming community, for only a small percentage of the present day population in Amargosa Valley are employed in agriculture (U.S. Census Bureau 1999). It was determined that the wording of the interim guidance (Dyer 1999) did not intend this interpretation.

3.4.1.2 Number of Farms Basis

In the Supplementary Information provided in 64 FR 8640 (Section VI), NRC provided additional insight into their intended meaning of the hypothetical farming community. It was stated that the water usage should be based upon a community of approximately 100 people living on 15 to 25 farms. The 1990 census data indicate, as discussed above, that such a distribution of persons and farms is inconsistent with the present day Amargosa Valley demographics. Thus a logical interpretation of the guidance is to establish the hypothetical farming community based on the active farming units within Amargosa Valley. This approach was adopted to estimate annual water usage. The alternative approach of basing the water usage on population alone was also evaluated to provide an indication of the impact of this alternative interpretation.

3.4.2 Agricultural Water Usage

The water usage data for Amargosa Valley used for this analysis were obtained from the State of Nevada (State of Nevada 1997). These were the most recent data available. These data provide information by water withdrawal permit or certificate number and include the following parameters for withdrawal permit or certificate:

- Permit number
- Owner of Record
- Area of land to which the permit is granted (or designators for nonirrigation uses such as mining use, commercial use, municipal use, or other use)
- Land area under cultivation
- Estimated volume of water used
- Location of the land (Range, Township, Section, ¼ and ¼)
- Other comments such a land use (e.g., alfalfa, fruit, pasture, trees, etc.).

The original intent was to use each permit record in 1997 as the base to derive the average annual water use per farm. These data would allow calculation of the standard deviation of the average annual water usage to provide an estimate of uncertainty of the total annual water usage of the hypothetical farming community of between 15 and 25 farms. This estimate would be based on current Amargosa Valley characteristics.

However, it became apparent from the information about the owner of record and location of land that some plots were owned by a single entity and were geographically adjacent. Thus they could be combined as a single but larger farming unit for the purpose of estimating average water usage per farm. This approach was termed consolidated farms. The consolidated farm approach has a high average annual usage per farm because the combined farming units are larger. If the 15 to 25 farms scenario is used, then this approach would lead to a higher prediction of annual water usage than the alternative approach (non-consolidated farms) based on individual existing permits.

The consolidated farm approach was thought to better represent the present day farming activities in Amargosa Valley. However, without historical research, it would be difficult to demonstrate that this situation had applied over previous years, as parcels of land can change ownership. Of more concern was the possibility that in the near future the economic climate could change, leading to smaller farms and lower average water usage. The consolidated farm approach would then be inappropriate for TSPA-SR. Thus the consolidated farm approach was not recommended but was evaluated to demonstrate the effect of such land groupings.

3.4.3 Domestic Water Usage

Domestic water usage was estimated from available data (State of Nevada 1997). The quantity of water used annually for domestic purposes was a small fraction (less than half a percent of the agricultural usage). Therefore, domestic usage was conservatively ignored and not discussed further.

3.4.4 Population Statistics

Population data were obtained from the 1990 Census (U.S. Census Bureau 1999). The average residence in Amargosa Valley was estimated to contain 3.06 people with standard deviation of 1.67). Based on these data, it was estimated that a community of 100 people would contain between 26.6 and 38.9 (95 percent confidence interval) households (CRWMS M&O 2000l).

3.4.5 Water Usage Results

The estimate of average annual water usage per farm was 96.92 acre-ft/yr. for the unconsolidated farm approach. This approach gave a 95th percentile range of 59.15 acre-ft/yr. to 134.69 acre-ft/yr. When annual average water usage was calculated using residences rather than non-consolidated farms, the estimate was substantially lower (24.02 acre-ft./yr.) because of the larger number of residences than farms. When the water usage estimate was based on consolidated farms, the average annual water use per farming unit increased to 246.7 acre-ft/yr. Table 3-25 provides a summary of the results from the various approaches used to estimate groundwater usage.

Table 3-25. Summary of Predicted Total Annual Agricultural Water Usage Based on Data With and Without the Consolidation of Farming Units (Water usage expressed as acre-ft/yr.)

Approach	Basis	Expected Number	Lower Limit	Expected Value	Upper Limit
Non-consolidated Farm Unit	Population (100 people)	32.73 Households	456	786	1116
	Farms	20 Farms	1183	1938	2694
Consolidated Farm Unit	Population (100 people)	32.73 Households	272	786	1300
	Farms	20 Farms	1993	4934	7875

3.4.6 Recommendation for Total System Performance Assessment–Site Recommendation on Annual Water Usage

It is recommended that water usage estimates based on non-consolidated farming units be used in TSPA-SR. This is understood to be the intent of NRC in their Supplementary Information. If the groundwater usage recommendation were to be based upon the population of 100 living in about 33 households, then the 1997 demographics of Amargosa Valley indicate that the hypothetical community would only contain about 5 farms. This number is significantly less that 15 to 25 prescribed and was considered sufficient to eliminate this approach. The recommended approach is conservative relative to the alternative interpretation when used to derive radionuclide concentration and dose in TSPA model. Also the approach provides results that are relatively insensitive to future changes in the size and number of active farms.

The number of farming units on which to base the annual groundwater withdrawal is uncertain (from 15 to 25 farms) (see Table 3-26). It should be noted that the recommended implementation of the algorithm is stochastic within the TSPA model. First an estimate of the expected use per farm is made (a uniform distribution over the 95th percentile range of uncertainty). This stochastic value of annual water usage per farm is then multiplied by a random sampling (uniform) of the number of farms specified (15 to 25).

Table 3-26. Total Estimated Annual Water Usage as a Function of Number of Farms (Water usage expressed as acre-ft/yr.)

Number of Farms	Lower Limit	Expected Value	Upper Limit
15	887	1454	2020
20	1183	1938	2694
25	1479	2423	3367

3.5 SUMMARY OF OTHER VIEWS AND ALTERNATIVE CONCEPTUAL MODELS

Review of publicly available documents produced by the DOE and external agencies and organizations indicates that there are no alternative conceptual models or major opposing views to the overall biosphere modeling process within the constraints of the proposed regulatory framework for the reference biosphere. The main reason for the absence of opposing views concerning alternative conceptual models is that the strategy for conceptualizing the biosphere model, for both the TSPA-VA (CRWMS M&O 1998e) and the TSPA-SR (CRWMS M&O 2000n), is consistent with similar activities being pursued by the international scientific community (BIOMOVS II 1994; BIOMOVS II 1996; National Research Council 1995) to the extent they apply to unconstrained portions of the reference biosphere. Further, the Revised Interim Guidance Pending Issuance of New NRC Regulation (proposed 10 CFR 63) for Yucca Mountain (Dyer 1999) constrains biosphere model to the reference biosphere specified in the draft regulations (64 FR 8640, Section 115).

Documents produced by the DOE and external agencies and organizations are reviewed during the process of developing the biosphere model. These agencies and organizations include the Performance Assessment Peer Review Panel, Advisory Committee on Nuclear Waste (ACNW), Nuclear Waste Technical Review Board (NWTRB), and the State of Nevada. Table 3-27 provides a summary of issues from such documents, and the related approach taken in this PMR to address the issue. Section 4 of this document discusses the subissue acceptance criteria applicable to the biosphere model.

There are no alternative conceptual models to the overall biosphere model as discussed above. Alternative views for the model components evaluated during the biosphere modeling process are summarized in Table 3-28.

Table 3-27. Summary of Issues

ISSUE	SOURCE	APPROACH
Buildup of Radionuclides in Surface Soil The TSPA-VA assumption for the time period for irrigation (one year) could lead to sizable underestimates of radionuclide concentrations in the soil, the amount depending on the particular radionuclide. This will lead to underestimates of the radionuclide uptake by crops and doses to individual(s).	TSPA Peer Review (Budnitz 1999), VA Volume 3 (DOE 1998),	Section 3.3.1.1 discusses the use of representative soil parameter values to calculate leaching coefficients. These leaching coefficients support the analysis of soil buildup and erosion process effecting the BDCF abstractions for TSPA–SR. Section 3 also addresses parameter and model uncertainty, technical basis for bounding assumptions and statistical representation of parameter variability. For most radionuclides, buildup was less than 15%. BDCF distributions appropriate to the longest irrigation periods for conservatism are sampled by TSPA code to account for buildup of radionuclides in soil.
Inadequate use of site-specific data Analysis should confirm site-specific values for each of biosphere parameters as well as their associated uncertainties. Need to ensure that advantage has been taken of all biosphere relevant information that is available in the published literature.	TSPA Peer Review (Budnitz 1999), VA Volume 3 (DOE 1998)	Many input parameters are factored into the GENII-S code for calculation of the BDCFs. These input parameters are discussed in Section 3.2.4. Each parameter type incorporates relevant site specific or published literature values. Most environmental parameters are selected to correspond to the conditions in the vicinity of Yucca Mountain and the human receptor parameters are based on habit survey or best available data. The BDCF analysis approach makes it possible to determine how uncertainties within the parameters translate into uncertainty in modeling results and provide quantitative evaluation of uncertainty with regard to the biosphere modeling outcome (Section 3.3.1.2).
Quantification of the conservatisms and uncertainties Identification of uncertainties and conservatisms associated with the values for code input parameters is necessary. The magnitude of the uncertainties in the biosphere input parameters has led to an amplification of the impacts of the already large uncertainties associated with the TSPA analyses.	TSPA Peer Review (Budnitz 1999), VA Volume 3 (DOE 1998)	Many input parameters are factored into the GENII-S code for calculation of the BDCFs. These input parameters are discussed in Section 3.2.4. Each parameter type incorporates relevant site specific or published literature values. Most environmental parameters are selected to correspond to best estimate of conditions identified as reasonable representations and limiting the use of conservative assumptions. The human receptor parameters are based on habit survey or best available data. The BDCF analysis approach makes it possible to determine how uncertainties within the parameters translate into uncertainty in modeling results and provide quantitative evaluation of uncertainty with regard to the biosphere modeling outcome (Section 3.3.1.2).

Table 3-27. Summary of Issues (Continued)

ISSUE	SOURCE	APPROACH
Dose Conversion Factors A critical review of the values that were used in setting the dose conversion factors in FGR No. 11 (Eckerman et al. 1988) and No. 12 (Eckerman and Ryman 1993) is necessary. Of particular interest is how these factors vary depending on the chemical nature of the radionuclides. Also attention should have been directed to the GI absorption factor for each key radionuclide.	TSPA Peer Review (Budnitz 1999)	Analysis of the DCF used in the GENII-S code is discussed in Section 3.2.4. DCFs for ingestion pathway account for internal incremental organ doses for a given radionuclide. DCFs incorporate chemical behavior within the physiological processes for uptake of radionuclides. This analysis of dosimetric parameters indicates that doses calculated by the dose assessment component of GENII-S are consistent with doses calculated using similar methods that are generally accepted by the scientific community and regulatory agencies (NRC and EPA).
Alternative Biosphere Models Question/concern was raised concerning plans to discuss alternative biosphere models.	Meeting Summary (Scott 1998a) 105th Meeting of the ACNW	Review of publicly available documents produced by the DOE and external agencies and organizations indicates that there are no alternative conceptual models within the constraints of the proposed regulatory framework for the reference biosphere. The main reason for the absence of opposing views concerning alternative conceptual models is that the strategy for conceptualizing the biosphere model, for both the TSPA-VA (CRWMS M&O 1998e) and the TSPA-SR (CRWMS M&O 2000n), is consistent with similar activities being pursued by the international scientific community (BIOMOVS II 1994; BIOMOVS II 1996; National Research Council 1995) to the extent they apply to unconstrained portions of the reference biosphere. Section 3.1.4 discusses the conceptual model for the biosphere. The reference biosphere and critical group are bounded by DOE guidance and proposed NRC criteria such as: - Arid to semi-arid conditions - Farming community approximately 20-km from the site - Land use, lifestyle, diet, etc. assumed constant over time. These criteria limit the biosphere system being studied/modeled and eliminate the need to consider alternative models such as alternative location of population at risk, or consideration of future population and socioeconomic impacts on demographics. Therefore, this document does not address alternative conceptual models for the biosphere.

Table 3-27. Summary of Issues (Continued)

ISSUE	SOURCE	APPROACH
Appropriate Reference Biosphere State of Nevada representative stated that alternatives to the farming community/critical group reference biosphere need to be reevaluated, because the climate will change.	Meeting Summary (Scott 1998b) 104th Meeting of the ACNW	Review of publicly available documents produced by the DOE and external agencies and organizations indicates that there are no alternative conceptual models within the constraints of the proposed regulatory framework for the reference biosphere. The main reason for the absence of opposing views concerning alternative conceptual models is that the strategy for conceptualizing the biosphere model, for both the TSPA-VA (CRWMS M&O 1998e) and the TSPA-SR (CRWMS M&O 2000n), is consistent with similar activities being pursued by the international scientific community (BIOMOVS II 1994; BIOMOVS II 1996; National Research Council 1995) to the extent they apply to unconstrained portions of the reference biosphere. Section 3.1.4 discusses the conceptual model for the biosphere. The reference biosphere and critical group are bounded by DOE guidance and proposed NRC criteria such as: - Arid to semi-arid conditions - Farming community approximately 20-km from the site - Land use, lifestyle, diet, etc. assumed constant over time. DOE guidance also constrains the reference biosphere to current climate. These criteria limit the biosphere system being studied/modeled. The limits imposed by criteria eliminate the need to consider alternative models such as alternative location of population at risk, or consideration of future population and socioeconomic impacts on demographics. Therefore, this document does not address the climate change issue with in the biosphere model.
Definition of critical group and individual receptor Consideration of a child receptor in particular would improve the estimation of radiological effects on the critical group.	TSPA Peer Review (Budnitz 1999)	The definition of critical group is presented in the proposed NRC rules and does not require consideration of dose to a child. NRC and EPA both propose criteria that define the receptor of interest as an adult. Section 3.1.2 discusses the human receptor for the BDCF calculations based on the NRC and EPA criteria.
Well-location assumption The biosphere BDCF calculations assumed that all of the locally produced food consumed by the reference person was grown with water having the same maximum levels of contamination. In the TSPA-VA modeling, the contamination plumes would not cover the entire Amargosa Valley.	VA Volume 3 (DOE 1998)	The NRC's proposed rule statement of consideration defines an approximation that eliminates speculation on the relative location of the plume and wells. The proposed approach conservatively assumes that all radionuclides passing through the 20-km locus from the repository are captured by water used by the hypothetical farming community. Water usage for the hypothetical farming community in which the critical group resides was analyzed (Section 3.4). Water usage information is used within the TSPA code.

Table 3-27. Summary of Issues (Continued)

ISSUE	SOURCE	APPROACH
Dilution from Pumping The geosphere/biosphere interface was defined (TSPA-VA) as a well located at the point of highest concentration of contaminants in the groundwater. Natural discharge points were not considered. Dilution from mixing contaminated water with uncontaminated water during well pumping was not considered. An improved definition and modeling of this interface would lend further credibility to the calculations.	VA Volume 3 (DOE 1998)	The NRC' s proposed rule statement of consideration defines an approximation that removes uncertainty associated with dilution due to pumping dynamics and eliminates speculation on the relative location of the plume and wells. The proposed approach conservatively assumes that all radionuclides passing through the 20-km locus from the repository are captured by water used by the hypothetical farming community. Water usage for the hypothetical farming community in which the critical group resides was analyzed (Section 3.4). Water usage information is used within the TSPA code. In addition, the TSPA-SR (CRWMS M&O 2000n) assumes that all the mass of radionuclides crossing the 20 km locus is captured in the pumped water.
Consistency among Modeling Assumptions Modeling assumptions should be consistent across different process models, unless there is a defensible technical rationale.	VA Volume 3 (DOE 1998)	The AMRs that document assumptions have been subjected to thorough interdisciplinary reviews to help ensure consistency among assumptions made in more than one document about a given parameter. In addition, the PMRs that summarize and integrate the results of the AMRs have been subjected to a review by a single review team, one of whose main objectives is to identify inconsistencies among the PMRs. Finally, assumptions used in the AMRs that feed TSPA are documented in the TSPA document. These measures provide confidence that consistent assumptions are used as appropriate among the various models that support the TSPA.
Ecosystem Studies NEPA requires ecosystem-level studies for projects such as the repository, especially in relation to increasing soil temperatures at Yucca Mountain.	State of Nevada (Malone 1999)	Section 3.1.4 discusses the conceptual model for the biosphere. The reference biosphere and critical group are bounded by DOE guidance and proposed NRC criteria. such as: - Arid to semi-arid conditions - Farming community approximately 20-km from the site - Land use, lifestyle, diet, etc. assumed constant over time. These criteria limit the biosphere system being studied/modeled. Impacts for biosphere assessments are limited to the receptor of interest, which is a human in a hypothetical farming community 20-km from Yucca Mountain. The limits imposed by criteria eliminate the need to consider for the reference biosphere impacts to the ecosystem such as increased soil temperatures. Impacts for the biosphere assessment are to the receptor of interest which is a human in a hypothetical farming community 20-km from Yucca Mountain.

Table 3-28 Alternative Views for Biosphere Modeling Components

Model Component	Alternative view	Component used	Reference
Reference biosphere	N/A*	Consistent with current knowledge of the conditions in the region surrounding the Yucca Mountain site	3.1.1, 3.1.4.1
Human receptor	N/A*	Adult; average member of the critical group, RMEI	3.1, 3.1.2
Critical group	Subsistence farmers, residents, inhabitants	Residential farmers	3.1.2.2
RMEI	N/A*	RMEI	3.1.2.3
FEPs	Various	FEPs that are applicable for the Yucca Mountain biosphere	3.1.3
Exposure scenarios	Various	Groundwater contamination, disruptive volcanic event	3.1.5
Computer code	CAP-88PC, AIRDOS-PC, RASCAL, MEPAS	GENII-S	3.2.1
Food and water consumption rate	NA*	Fixed values	3.2.4.2.1
DCF	ICRP-30, 10CFR 20, FGR 11	GENII-S, and 12	3.2.4.2.4
Water usage analysis	Population basis	Number of farms basis	3.4.1
Number of farms	Consolidated	Non-consolidated	3.4.2

*The applicable proposed regulations restrict the bound for this component.

4. RELATIONSHIP OF BIOSPHERE PMR TO THE NUCLEAR REGULATORY COMMISSION ISSUE RESOLUTION STATUS REPORTS

4.1 SUMMARY OF THE KEY TECHNICAL ISSUES

As part of the review of site characterization activities, the NRC has undertaken an ongoing review of information on Yucca Mountain site characterization activities to allow early identification and resolution of potential licensing issues. The principal means of achieving this goal is through informal, pre-licensing consultation with the DOE. This approach attempts to reduce the number of, and to better define, issues that may be in dispute during the NRC licensing review, by obtaining input and striving for consensus from the technical community, interested parties, and other groups on such issues.

The NRC has focused pre-licensing issue resolution on those topics most critical to the post-closure performance of the potential geologic repository. These topics are called Key Technical Issues (KTIs). Each KTI is subdivided into a number of subissues. The KTIs are:

- Activities Related to Development of the EPA Standard
- Container Lifetime and Source Term
- Evolution of the Near-field Environment
- Igneous Activity (IA)
- Radionuclide Transport
- Repository Design and Thermal Mechanical Effects
- Structural Deformation and Seismicity
- Thermal Effects on Flow (TEF)
- Total System Performance Assessment and Integration (TSPAI)
- Unsaturated Zone and Saturated Zone Flow Under Isothermal Conditions (USFIC)

Identifying KTIs, integrating their activities into a risk-informed approach, and evaluating their significance for post-closure performance helps ensure that NRC's attention is focused on technical uncertainties that will have the greatest affect on the assessment of repository safety.

Early feedback among all parties is essential to define what is known, what is not known and where additional information is likely to make a significant difference in the understanding of future repository safety. The Issue Resolution Status Reports (IRSRs) are the primary mechanism used by the NRC staff to provide feedback to the DOE on the status of KTI subissues. IRSRs focus on NRC acceptance criteria for issue resolution and the status of issue resolution, including areas of agreement or when the staff has comment or questions. Open meetings and technical exchanges between NRC and DOE provide additional opportunities to discuss issue resolution, identify areas of agreement and disagreement and plans to resolve any disagreements.

KTIs are subdivided into a number of subissues. For most subissues, the NRC staff has identified technical acceptance criteria that the NRC may use to evaluate the adequacy of information related to the KTIs. The NRC has also identified two cross cutting programmatic criteria that apply to all IRSRs related to the implementation of the Quality Assurance Program and the use of expert elicitation. The following sections provide a summary level discussion of the KTIs by subissues (Section 4.2) and a discussion of the specific NRC acceptance criteria (Section 4.3).

4.2 RELATIONSHIP OF THE BIOSPHERE PMR TO THE KEY TECHNICAL ISSUES

The *Biosphere PMR* provides technical analyses that relate to three of the KTIs and their associated IRSRs. Table 4-1 shows these KTIs and their subissues (subissues that relate to this PMR are shown in italics). The KTIs and subissues that relate to the *Biosphere PMR* are discussed in the following sections. Unsaturated and Saturated Zone Flow Under Isothermal Conditions and Igneous Activity KTI subissues pertaining to the *Biosphere PMR* are associated with the integrated subissues in Total System Performance Assessment and Integration KTI (NRC 2000, p. 30).

Table 4-1. Issue Resolution Status Report/Key Technical Issues (IRSR/KTI) and Subissues Related to the Biosphere PMR

NRC Key Technical Issues	Subissues
Total System Performance Assessment and Integration	*System Description and Demonstration of Multiple Barriers* *Scenario analysis* *Model abstraction* *Demonstration of the Overall Performance Objective*
Unsaturated and Saturated Zone Flow Under Isothermal Conditions	Climate change Hydrologic effects of climate change Present-day shallow groundwater infiltration Deep percolation (present and future) *Saturated zone ambient flow conditions and dilution processes* Matrix diffusion
Igneous Activity	Probability *Consequences*

4.2.1 Total System Performance Assessment and Integration Issue Resolution Status Report

The objective of this KTI is to describe an acceptable methodology for conducting performance assessments of repository performance and using these assessments to demonstrate compliance with the overall performance objective and requirements for multiple barriers (NRC 2000, p. 3). The acceptance criteria for each of the four subissues address the key aspects of the DOE's TSPA model for the Yucca Mountain site (NRC 2000, p.4):

- System Description and Demonstration of Multiple Barriers
- Scenario Analysis

- Model Abstraction
- Demonstration of the Overall Performance Objective

The subissues for this KTI that relate to the *Biosphere PMR* are described in the following subsections.

4.2.1.1 System Description and Demonstration of Multiple Barriers

This subissue focuses on the demonstration of multiple barriers and expectations on the contents of the DOE's TSPA and supporting documents. Under this subissue the transparency and traceability of the analysis aspect is addressed. The acceptance criteria for the transparency and traceability aspect address: (i) TSPA document style, structure and organization; (ii) features, events, and process identification and screening; (iii) abstraction methodology; (iv) data use and validity; (v) assessment results; and (vi) code design, data flow, and supporting documentation (NRC 2000, p. 10). The *Biosphere PMR* was carefully structured to be complete, clear and consistent. This report and supporting analyses provide ample reference information and description of processes and abstraction to support traceability and transparency for information flow and coupling with the TSPA code.

4.2.1.2 Scenario Analysis

This subissue considers the process of identifying possible processes and events that could affect repository performance; assigning probabilities to categories of events and processes; and the exclusion of processes and events from the performance assessment. Scenario analysis is a key factor in ensuring the completeness of the TSPA (NRC 2000, p. 4).

A systematic method was applied to identify and screen FEPs for biosphere transport and uptake. Approximately three hundred and thirty biosphere FEPs have been identified and categorized as either primary or secondary FEPs. The primary FEPs capture the issues associated with the secondary FEPs. The FEPs are further divided into "included" and "excluded" FEPs. Included FEPs are those directly considered in TSPA models and process models that support TSPA. Analyses have focused on the identification and screening of FEPs. This work partially addresses this subissue. Additional discussion to address FEPs related criteria is in the *TSPA-SR Methods and Assumptions* (CRWMS M&O 2000n).

4.2.1.3 Model Abstraction

This subissue focuses on the information and technical approaches needed to develop defensible model abstractions and their integration into TSPA. The following aspects of model abstraction are addressed under this subissue: data used in the development of conceptual approaches or process models, the abstracted models, and estimates of system performance (NRC 2000, pp. 29-32). Specifically, this subissue requires documentation of data used to develop conceptual or process models for model abstractions, verification of the consistency of the abstractions, and explanation of their integration (such as coupling and dependencies) into the TSPA. For the biosphere model, this KTI focuses on four elements of the abstraction process:

- Airborne Transport of Radionuclides (NRC 2000, p. 118)
- Dilution of Radionuclides in Groundwater due to Well Pumping (NRC 2000, p. 124)
- Dilution of Radionuclides in Soil due to Surface Processes (NRC 2000, p. 130)
- Location and Lifestyle of Critical Group (NRC 2000, p. 134)

The element of airborne transport of radionuclides is directly related to the direct release and transport aspect of model abstraction. Airborne transport involves the igneous activity KTI (Section 4.2.3) and as an integrated subissue evaluates the transport of radionuclides in volcanic eruption columns and subsequent advection and dispersion of the contaminated tephra cloud in the atmosphere (NRC 2000, p. 118). The biosphere addresses only the incorporation of mass loading of radionuclides deposited on the ground surface as a result of volcanic eruptions into parameters for calculation of BDCFs for the disruptive event scenario (Section 3.3.2).

The element of dilution of radionuclides in groundwater due to well pumping is addressed in the biosphere process by an alternative approach based on an approximation that removes uncertainty associated with dilution due to pumping dynamics. This approach is consistent with information presented in the statement of consideration to the proposed rule (64 FR 8640, p. 8645). Water usage is discussed in Section 3.4. Dilution of radionuclides due to well pumping is associated with the Unsaturated and Saturated Zone Flow Under Isothermal Conditions KTI (NRC 2000, p. 124).

The element of dilution of radionuclides in soil due to surface processes is addressed in Section 3.3.1.1 of this document. An analysis has been completed to evaluate the effects of erosion and dilution on radionuclide concentration in the soil (CRWMS M&O 2000d). An abstraction using the soil erosion data and BDCF abstraction parameters for use in the TSPA code to account for soil build up effects is discussed in section 3.3.1.1. Dilution of radionuclides in soil due to surface processes relates to the calculation of the redistribution of radionuclides in the soil due to deposition of a volcanic ash blanket or application of contaminated water on the soil (NRC 2000, p. 130).

The element location of the critical group is associated with the (i) Unsaturated and Saturated Zone Flow Under Isothermal Conditions; (ii) Radionuclide Transport; and (iii) Igneous Activity KTIs (NRC 2000 p. 134). Radionuclide transport is not associated with the Biosphere PMR. The scope of the lifestyle of the critical group integrated subissue encompasses key aspects of critical group BDCF calculations. The discussion of the human receptor used to develop the BDCFs for use in the TSPA code is addressed in Section 3.1.2 of this document. The critical group and its location are consistent with NRC's proposed rule (64 FR 8640, p. 8677).

4.2.1.4 Demonstration of the Overall Performance Objective

This subissue addresses the NRC staff's expectation for the content of a license application. This subissue emphasizes the importance of aspects of the TSPA that will facilitate independent reviews and analysis of the TSPA. The final requirements for the overall performance objective will be established after the rule is published in final form, and the acceptance criteria will be modified (as needed) to be consistent with the final regulations (NRC 2000, p. 141).

Although no acceptance criteria for this subissue have been developed in the IRSR, the YMP is committed to improving documentation of data, technical analyses and calculations about the Yucca Mountain site. The development of this document and the associated AMRs focused on improving the transparency and traceability for incorporation of site data and analyses into the BDCFs and the abstractions of biosphere processes for use in the TSPA.

4.2.2 Unsaturated and Saturated Zone Flow Under Isothermal Conditions

The objective of the USFIC KTI is to assess all aspects of the ambient hydrogeologic regime at Yucca Mountain that have the potential to compromise the performance of the potential repository (NRC 1999, p. 3). The subissue, saturated zone ambient flow conditions and dilution processes, is related to the TSPAI integrated subissue model abstraction element of dilution of radionuclides due to well pumping (NRC 2000, p 31). The specific acceptance criterion for the USFIC KTI is to be evaluated only if the DOE takes credit for wellbore dilution in TSPA analysis. The DOE does not take credit for well bore dilution as described in Section 3.4 and the *Saturated Zone Flow and Transport PMR* (CRWMS M&O 2000r). The *Biosphere PMR* addresses the TSPAI integrated subissue in relation to the USFIC acceptance criteria (Table 4-2).

4.2.3 Igneous Activity

The main objective of the IA KTI is to evaluate the significance of IA to the repository performance by confirming data and evaluating the conceptual model for estimating the probability and consequence of igneous activity (Reamer 1999, enclosure p. 5). The IA subissues are related to the TSPAI integrated subissues for biosphere (NRC 2000 p. 31). IA subissues and acceptance criteria are not directly addressed by this document. The *Biosphere PMR* addresses the TSPAI integrated subissues in relation to the IA acceptance criteria (Table 4-2). Biosphere developed BDCFs for the disruptive event scenario are used by the TSPA code to calculate consequence for the abstracted event parameters. Section 3.3.2 discusses the development of the disruptive event BDCFs.

4.3 NRC ACCEPTANCE CRITERIA

Specific technical acceptance criteria for each subissue that relate to this PMR are summarized in Table 4-2, along with the approach used to address the criteria and the sections of the PMR that describe these approaches. The *Biosphere PMR* also addresses the NRC's two programmatic criteria for QA and the use of expert elicitation. The programmatic criteria apply to all subissues and are not repeated under each subissue in the table.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
SUBISSUE 1—System Description and Demonstration of Multiple Barriers	
Transparency and Traceability of the Analysis for Subissue 1	
TSPA Documentation Style, Structure, and Organization	
Criterion T1 - Documents and reports are complete, clear, and consistent.	The Biosphere PMR was carefully structured to be complete, clear, and consistent. The review of the draft document included checks for completeness, clarity and consistency.
Criterion T2 - Information is amply cross-referenced.	The Biosphere PMR contains ample references to data sources, codes, assumptions, and conclusions.
Features, Events, and Processes Identification and Screening	
Criterion T1 - The screening process by which FEPs were included or excluded from the TSPA is fully described.	Section 3.1.3 summarizes excluded and included FEPs including the rationale for these decisions.
Criterion T2 - Relationships between relevant FEPs are fully described.	Section 3.1.3 describes the relationship between primary and secondary FEPs. The AMR supporting this section (CRWMS M&O 2000a) provides additional documentation including the TSPA disposition of FEPs, IRSR issues relevant to specific FEPs, and analysis and discussion on specific FEPs.
Abstraction Methodology	
Criterion T1 - The levels and method(s) of abstraction are described starting from assumptions defining the scope of the assessment down to assumptions concerning specific processes and the validity of given data.	For the biosphere model, descriptions are provided in this process model report of process and the abstraction of the radionuclide specific BDCFs for inclusion into the TSPA code. The description includes a summary of data and assumptions used to construct the biosphere model. The AMRs (CRWMS M&O 2000a, CRWMS M&O 2000g and CRWMS M&O 2000h) describing the model and the abstractions provide additional details regarding data and assumptions.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Criterion T2 - A mapping (e.g., a road map diagram, a traceability matrix, a cross-reference matrix) is provided to show what conceptual features (e.g., patterns of volcanic events) and processes are represented in the abstracted models, and by what algorithms.	The Biosphere PMR provides a sufficient basis for the decisions and assumptions that were made during the abstraction process.
Criterion T3 - An explicit discussion of uncertainty is provided to identify which issues and factors are of most concern or are key sources of disagreement among experts.	The Biosphere PMR provides a discussion of uncertainties and limitations for the biosphere process model. The AMRs describing the describing the calculation of biosphere dose conversion factors (CRWMS M&O 2000e, CRWMS M&O 2000j and CRWMS M&O 2000a) provide additional details regarding uncertainties and limitations.
Data Use and Validity	
Criterion T1 - The pedigree of data from laboratory tests, natural analogs, and the site is clearly identified.	Section 1.3 of this PMR summarizes the quality status of the data and software used in the component models.
Criterion T2 - Input parameter development and basis for their selection is described.	Section 3.2.4 of this report discusses input parameter development and the basis for using the parameters. AMRs (CRWMS M&O 2000c, CRWMS M&O 2000b, CRWMS M&O 1999a, CRWMS M&O 2000s, and CRWMS M&O 2000t) provide additional details regarding input parameter development and the basis for input selection.
Criterion T3 - A thorough description of the method used to identify performance confirmation program parameters.	The Performance Confirmation Plan (CRWMS M&O 2000p) specifically addresses the methodology for identifying and selecting parameters that are important to performance based upon TSPA sensitivity analyses and the repository safety strategy. Methods used to collect information for each parameter will be described by the performance confirmation plan or relevant supporting documents to support the license application. Performance confirmation test selection and rationale is also described in the plan based upon the significance of the parameter being measured, and the ability of the test to distinguish construction, emplacement, or time dependent changes in the parameter significant to performance.
Assessment Results	
Criterion T1 - PA results (i.e., the peak expected annual dose within the compliance period) can be traced back to applicable analyses that identify the FEPs, assumptions, input parameters, and models in the PA.	The TSPA summarizes features, processes, conceptual models, and their implementation into the TSPA. This discussion will be based in part on information provided by in Section 3.1.3.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Assessment Results (continued)	
Criterion T2 - The PA results include a presentation of intermediate results that provide insight into the assessment (e.g., results of intermediate calculations of the behavior of individual barriers)	TSPA provides performance analysis results for the total system and will include intermediate results for the components of the system.
Code Design and Data Flow	
Criterion T1 - The flow of information (input and output) between the various modules is clearly described.	TSPA provides a description of information flow between component models including couplings between information and data, conceptual and process-level models, and abstracted models.
Criterion T2 - Supporting documentation (e.g., user's manuals, design documents) clearly describes code structure and relationships between modules.	TSPA describes the TSPA code and provides a reference to supporting documentation such as the user's guide.
Subissue 2 –Total system Performance Assessment Methodology: Scenario Analysis	
Identification of Initial Set of Processes and Events for Subissue 2	
Criterion T1 - DOE has identified a comprehensive list of processes and events that: (i) are present or might occur in the YM region (YMR) and (ii) includes those processes and events that have the potential to influence repository performance	Section 3.1.3 describes the FEPs important to the biosphere conceptual model. The AMR supporting this section (CRWMS M&O 2000a) provides a list of the processes and events applicable to the biosphere. The AMR provides a description of the screening arguments and dispositions for the FEPs and has been thoroughly reviewed by subject matter experts. TSPA describes the development of the FEPs database and includes a description of the FEPs process in sufficient detail to demonstrate the comprehensiveness of the database.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Classification of FEPs for Subissue 2	
Criterion T1 - DOE has provided adequate documentation identifying how its initial list of processes and events has been grouped into categories.	Section 3.1.3 of this document describes the FEP in this document. CRWMS M&O 2000a supporting this section provides documentation and justification for screening arguments and TSPA dispositions. TSPA provides documentation on the mapping of FEPs into primary and secondary categories. For comprehensiveness, TSPA maintains traceability of the secondary to the related primary FEPs. TSPA also describes the development of the FEPs database, including identifying and classifying relevant FEPs.
Criterion T2 - Categorization of processes and events is compatible with the use of categories during the screening of processes and events.	The NRC staff will review the categorization of processes and events as described in the various PMRs. Section 3.1 of this PMR describes the FEPs applicable to this PMR. The AMR supporting this section (CRWMS 2000a) provides documentation and justification for screening arguments and TSPA dispositions. TSPA provides documentation on mapping of FEPs into primary and secondary categories. TSPA describes the categorization of processes and events in sufficient detail to determine that events are not narrowly defined and that the categorization of processes and events is compatible with the use of categories during the screening of processes and events.
Screening for Subissue 2	
Criterion T1 - Categories of processes and events that are not credible for the YM repository because of waste characteristics, repository design, or site characteristics are identified and sufficient justification is provided for DOE's conclusions	Section 3.1.3 of this PMR describes the FEPs in this PMR. The AMR supporting this section (CRWMS M&O 2000a), provides documentation and justification for screening arguments and TSPA dispositions. Documentation includes a statement of the screening decision for each FEP. Justification is provided for each excluded FEP including the criterion on which it was excluded and the technical basis for the screening argument.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Screening for Subissue 2 (continued)	
Criterion T2 - The probability assigned to each category of processes and events not screened based on criterion T1 or criterion T2 is consistent with site information, well documented, and appropriately considers uncertainty.	Section 3.1.3 of this PMR describes the FEPs in this PMR. The AMR supporting this section (CRWMS M&O 2000a) provides documentation and justification for screening arguments and TSPA dispositions. Probability estimates for FEPs are based on technical analysis of the past frequency of similar events consistent with site information, well documented, and appropriately considers uncertainty.
Criterion T3 - DOE has demonstrated that processes and events screened from the PA on the basis of their probability of occurrence, have a probability of less than one chance in 10,000 of occurring over 10,000 years.	Section 3.1.3 of this PMR describes the FEPs in this PMR. The AMR supporting this section (CRWMS M&O 2000a) provides documentation and justification for screening arguments and TSPA dispositions. Justification is provided for each excluded FEP including the criterion on which it was excluded and the technical basis for the screening argument. The probability assigned to FEPs may be one of the screening criteria. FEPs may be excluded from the TSPA only if they can be shown to have a probability of occurrence of less than one chance in 10,000 of occurring over 10,000 years (64 FR 8640, 63.114).
Criterion T4 - DOE has demonstrated that categories of processes and events omitted from the PA on the basis that their omission would not significantly change the calculated expected annual dose, do not significantly change the calculated expected annual dose.	Section 3.1.3 of this PMR describes the FEPs in this PMR. The AMR supporting this section (CRWMS M&O 2000a) provides documentation and justification for screening arguments and TSPA dispositions. For omitted categories, documentation includes the criterion on which it was excluded and the technical basis for the screening argument.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Formation of Scenarios for Subissue 2	
Criterion T1 - DOE has provided adequate documentation identifying: (i) whether processes and events have been addressed through consequence model abstraction or scenario analysis and (ii) how the remaining categories of processes and events have been combined into scenario classes.	TSPA provides documentation and justification for screening arguments and TSPA dispositions. FEPs that have not been excluded are identified as either expected FEPs or disruptive FEPs. Expected FEPs will be included in the TSPA nominal scenario, which is simulated by the base case model described in the TSPA documentation. Disruptive scenarios are constructed from expected FEPs and combinations of disruptive FEPs. Section 3.1.3 of this PMR describes the FEPs addressed in this PMR. The PMRs provide descriptions of process-level models, model abstractions, and supporting analyses in sufficient detail to conclude that processes and events have been addressed through consequence model abstraction or scenario analysis and that the remaining categories of processes and events have been combined into scenario classes.
Criterion T2 - The set of scenario classes is mutually exclusive and complete.	TSPA provides documentation and justification for screening arguments and TSPA dispositions. In addition, TSPA describes the development of the FEPs database including a description of the construction and screening of scenarios. Together, the entire set of PMRs and TSPA will provide NRC staff with sufficient documentation to evaluate whether the set of scenario classes is mutually exclusive and complete and whether expected FEPs are addressed either through model abstraction of through incorporation into scenarios.
Screening of Scenarios for Subissue 2	
Criterion T1 - Scenario classes that are not credible for the Yucca Mountain repository because of waste characteristics, repository design, or site characteristics— individually or in combination— are identified and sufficient justification is provided for DOE's conclusions.	TSPA provides justification for screening arguments and TSPA dispositions. Scenarios are screened using the same regulatory, probability, and consequence criteria used for screening individual FEPs. Documentation of this process includes identification of any scenarios that have been screened from the analysis and the technical basis for that screening decision. Information pertinent to this acceptance criterion is not addressed in the Biosphere PMR.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Screening of Scenarios for Subissue 2 (continued)	
Criterion T2 - The probability assigned to each scenario class is consistent with site information, well documented, and appropriately considers uncertainty.	TSPA provides justification for screening arguments and TSPA dispositions. Probability estimates for scenario classes are based on analyses similar to probabilities assigned for individual FEPs. Information pertinent to this acceptance criterion is not addressed in the Biosphere PMR.
Criterion T3 - Scenario classes that combine catagories of process and events may be screened from the PA on the basis of their probability of occurrence, provided: (i) the probability used for screening the scenario class is defined from combinations of initiating processes and events and (ii) DOE has demonstrated that they have a probability of less than one chance in 10,000 of occurring over 10,000 years.	TSPA provides justification for excluding scenario classes. The probability assigned to scenario classes is one of the screening criteria. Scenario classes may be excluded from the TSPA only if they can be shown to have a probability of occurrence of less than one chance in 10,000 of occurring over 10,000 years (64 FR 8640, 63.114). Justification is provided for each excluded scenario class, including the criterion on which it was excluded and the technical basis for the screening argument. In addition, the AMR (CRWMS M&O 2000a) describes the development of the FEPs database including a description of screening and specifying scenarios for TSPA analysis. Information pertinent to this acceptance criterion is not addressed in the Biosphere PMR.
Criterion T4 - Scenario classes may be omitted from the PA on the basis that their omission would not significantly change the calculated expected annual dose, provided DOE has demonstrated that excluded categories of processes and events would not significantly change the calculated expected annual dose.	TSPA provides justification for excluding scenario classes. For excluded scenario classes, documentation includes the criterion on which it was excluded and the technical basis for the screening argument. In addition, the AMR describes the development of the FEPs database including a description of screening and specifying scenarios for TSPA analysis. Information pertinent to this acceptance criterion is not addressed in the Biosphere PMR.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Subissue 3 - Total System Performance Assessment Methodology: Model Abstraction	
Air Transport of Radionuclides for Subissue 3	
Criterion T1 - Sufficient data (field, laboratory, or natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the airborne transport of RNs abstraction in TSPA. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the TSPA.	TSPA code requires inputs from several PMRs for analyses of disruptive events to support final output for TSPA. These inputs include the disruptive events analysis reported in Disruptive Events PMR (CRWMS M&O 2000q) and analysis reported in Section 3.3.2. Section 3.1.5 describes the scope of analyses for supporting TSPA for disruptive events.
Criterion T2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the airborne transport of RNs abstraction, such as the magnitude of eruption and deposition velocity, are technically defensible and reasonably account for uncertainties and variability.	Section 3.2.4 discusses input parameters for GENII-S and Section 3.3.2 discusses the disruptive event biosphere dose conversion factors to support dose consequence calculations in TSPA. Air transport parameters and ashfall values are described in the Disruptive Events PMR (CRWMS M&O 2000q) and supporting analysis.
Criterion T3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the airborne transport of RNs abstraction.	The Biosphere PMR does not address airborne transport of RNs. Alternative model approaches to address airborne transport of RNs are described in the Disruptive Events PMR (CRWMS M&O 2000q) and supporting analysis.
Criterion T4 - Airborne transport of RNs abstraction output is justified through comparison to output of detailed process models or empirical observations (laboratory testing, natural analogs, or both).	The Biosphere PMR does not address airborne transport of RNs. Alternative model approaches to address airborne transport of RNs are described in the Disruptive Events PMR (CRWMS M&O 2000q).
Criterion T5 – Important site features, physical phenomena and couplings, and consistent and appropriate assumptions are incorporated into the airborne transport of RNs abstraction.	The AMRs that document assumptions, features, physical phenomena and couplings have been subjected to thorough interdisciplinary reviews to help ensure consistency among documented values. In addition, the PMRs that summarize and integrate the results of the AMRs have been subjected to a review by a single review team, one of whose main objectives is to identify inconsistencies among PMRs. Finally, the TSPA will document the couplings from the AMRs supporting performance assessment. These measures provide confidence that consistency is maintained as appropriate among the various TSPA models.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Dilution of Radionuclides in Groundwater for Subissue 3	
Criterion T1 - Sufficient data (field, laboratory and/or natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the dilution of radionuclides in groundwater due to well pumping abstraction in the TSPA.	The element of dilution of radionuclides in groundwater due to well pumping is addressed in the biosphere process by an alternative approach based on an approximation that removes uncertainty associated with dilution due to pumping dynamics. This approach is consistent with information presented in the statement of consideration to the proposed rule (64 FR 8640). Water usage is discussed in Section 3.4. 10 CFR 63.115 (64 FR 8640) provides a reference biosphere and receptor group criteria that allow use of a simple model that avoids speculation associated with detailed dilution modeling. The average annual concentration of the radionuclides in the groundwater is derived by distributing the mass of radionuclides crossing the 20-km boundary annually uniformly over the total annual water usage. The biosphere effort described in this document derived the annual volume of water estimated to be used by the community. The Saturated Zone Flow and Transport PMR developed the mass of each radionuclide crossing the 20-km boundary annually. The TSPA code divides the latter by the former to derive the annual average concentration from which the annual expected dose to an average member of the critical group is obtained when multiplied by the BDCFs. In deriving the annual water usage, this element is addressed to the extent possible with the simplistic but conservative dilution model found in the groundwater usage AMR (Groundwater Usage by the Proposed Farming Community CRWMS M&O 2000l). In addition, the TSPA assumes that all the mass of radionuclides crossing the 20-km boundary is captured in the pumped water. Additional information is in the TSPA. This integrated subissue involves the Unsaturated and Saturated Zone Flow Under Isothermal Conditions KTI subissue 5, saturated zone ambient flow conditions and dilution processes acceptance criterion 7. USFIC subissue 5 acceptance criterion 7 is considered resolved at this time, because it is only evaluated if credit is taken for wellbore dilution. The DOE does not take credit for wellbore dilution in TSPA.
Criterion T2 - Parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the dilution of radionuclides in groundwater due to well pumping abstraction, such as the pumping well characteristics and water usage by the receptor groups, are technically defensible and account for uncertainties and variabilities.	
Criterion T3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the dilution of radionuclides in groundwater due to well pumping abstraction.	
Criterion T4 - Dilution of radionuclides in groundwater due to well pumping abstraction output is verified through comparison to outputs of detailed process models and/or empirical observations (laboratory testings or natural analogs, or both).	
Criterion T5 - Important hydrogeologic features, physical phenomena and couplings, and consistent and appropriate assumptions are incorporated into the dilution of radionuclides in groundwater due to well pumping abstraction.	

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Dilution of Radionuclides in Soil Subissue 3	
Criterion T1 - Sufficient data (field, laboratory and/or natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the dilution of radionuclides in soil due to surface processes abstraction in TSPA.	This document discusses the abstraction of the soil processes in Section 3.3.1.1. The soil analysis (CRWMS M&O 2000d) incorporates representative sandy soil K_d values and other parameter values including bulk soil density, precipitation, evaporation, and irrigation rate based on data from the Amargosa Valley to calculate leaching coefficients and the rates of soil removal by erosion. These parameters support the analysis of soil build up and erosion process effecting the BDCF abstractions for TSPA.
Criterion T2 - Parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the dilution of radionuclides in soil due to surface processes abstraction, such as depth of the plowed layers and mass loading factor, are technically defensible and reasonably account for uncertainties and variabilities.	DOE 's development of parameter values, assumed ranges, probability distributions and bounding assumptions is controlled by implementing procedures compliant with the QARD. These procedures require measures intended to help ensure technical defensibility and appropriate accounting for uncertainties and variabilities. The AMRs and PMR for the biosphere have been developed in accordance with these procedures. The AMR *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000d) addresses soil parameters. The AMR, *Abstraction of BDCF Distributions for Irrigation Periods* (CRWMS M&O 2000h) describes how the build-up due to irrigation and erosion due to other processes are abstracted for use in TSPA code. Section 3.3.1.1 of this document summarizes the abstraction process.
Criterion T3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the dilution of radionuclides in soil due to surface processes abstraction.	The AMR *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000d) addresses selection of parameter values and alternative approaches to evaluation of soil erosion and build up. Section 3.2.4.1.2. discusses soil parameters pertinent to the biosphere model. The analysis of soil processes is coupled with the BDCF abstraction to account for radionuclide build-up/erosion for use in TSPA.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Dilution of Radionuclides in Soil Subissue 3	
Criterion T4 - Dilution of radionuclides in soil due to surface processes output is verified through comparison to output of detailed process models and/or empirical observations (laboratory testings or natural analogs, or both).	Dilution of radionuclides in soil is evaluated in CRWMS M&O 2000d and CRWMS M&O 2000h. Evaluation of soil processes for dilution of radionuclides is based to the extent practical on analogue processes. Section 3.2.4.1.2. discusses soil parameters pertinent to the biosphere model. Abstraction of BDCF distributions for irrigation periods couples the soil erosion processes with irrigation period build-up or radionuclides as discussed in Section 3.3.1.1.
Criterion T5 - Important site features, physical phenomena and couplings, and consistent and appropriate assumptions are incorporated into the dilution of radionuclides in soil due to surface processes abstraction.	Abstraction of BDCF distributions for irrigation periods couples the soil erosion processes with irrigation period build-up or radionuclides as discussed in Section 3.3.1.1. Consistent and appropriate assumptions have been applied to analysis of soil process for calculation of BDCFs for use in TSPA.
Critical Group for Subissue 3	
Criterion T1 - Sufficient data (field, laboratory, or natural analog data) are available to adequately define relevant parameters and conceptual models as necessary for developing the lifestyle of critical group abstraction in TSPA. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the TSPA.	Section 3.1.2.1 describes the data used to identify the critical group to support TSPA. The 1997 dietary survey data is used to characterize consumption for the critical group (CRWMS M&O 2000b). Bureau of Census data is used to characterize other lifestyle characteristics of the critical group (CRWMS M&O 2000b). These data are sufficient to adequately quantify parameters for the critical group. Characteristics of the human receptor related to the key exposure pathways are discussed in section 3.2.4.2.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Critical Group for Subissue 3 (continued)	
Criterion T2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the lifestyle of critical group abstraction such as consumption rates, plant and animal uptake factors, mass loading factors, and BDCFs are technically defensible and reasonably account for uncertainties and variability.	DOE 's development of parameter values, assumed ranges, probability distributions and bounding assumptions is controlled by implementing procedures compliant with the QARD. Section 3.2.4 discusses parameters pertaining to the environmental transport of radionuclides and characteristics of the human receptor. Supporting AMRs (CRWMS M&O 2000c, CRWMS M&O 2000b, CRWMS M&O 1999a, CRWMS M&O 2000s, and CRWMS M&O 2000t) provide detailed description of parameter value for determination of critical group. Parameter values and associated ranges and distributions considered in the lifestyle of critical group abstractions are defensible and reasonable.
Criterion T3 - Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations appropriately factored into the lifestyle of critical group abstractions.	The PMR conceptual approach to the critical group is qualitative. The development of the critical group is discussed in section 3.1.2. Uncertainties in the critical group model are discussed in CRWMS M&O 2000b.
Criterion T4 – Dose calculation output pertaining to lifestyle of the critical group is justified through comparison to output of detailed process models, and/or empirical observations (field data, laboratory data, or natural analogs).	Dose calculations are not discussed in this document. Dose calculations based on the lifestyle and behavioral characteristics of the critical group are discussed in TSPA. Section 3.3 describes the development of the biosphere dose conversion factors for input to the TSPA code for calculation of expected annual doses.

Table 4-2. Issue Resolution Status Reports, Subissues, Technical Acceptance Criteria, and PMR Approach

NRC Technical Acceptance Criteria	PMR Approach and Section Reference
IRSR: TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION	
Critical Group for Subissue 3 (continued)	
Criterion T5 - Important site features, physical phenomena and couplings, and consistent and appropriate assumptions are incorporated into the lifestyle of the critical group abstraction.	The AMRs that document assumptions, features, physical phenomena and couplings have been subjected to thorough interdisciplinary reviews to help ensure consistency among documented values. In addition, the PMRs that summarize and integrate the results of the AMRs have been subjected to a review by a single review team, one of whose main objectives is to identify inconsistencies among PMRs. Finally, the TSPA will document the couplings from the AMRs supporting performance assessment. These measures provide confidence that consistency is maintained as appropriate among the various TSPA models.
IRSR: Total System Performance Assessment and Integration	
Subissue 4—Total System Performance Assessment and Integration: Demonstration of Overall Performance Objectives	
The final requirements for the overall performance objective will be established after the rule is published in final form, and the acceptance criteria will be modified (as needed) to be consistent with the final regulations.	The Biosphere PMR addresses the link between the geosphere and dose calculation in the TSPA code that forecasts the expected annual average dose to the average member of the critical group. TSPA addresses the overall expected performance of the potential repository at Yucca Mountain.
IRSR: Total System Performance Assessment and Integration	
Programmatic Acceptance Criteria	
Criterion P1 - The collection, documentation, and development of data, models, and/or computer codes have been performed under acceptable QA procedures, or if the data, models and/or computer codes were not subject to an acceptable QA procedure, they have been appropriately qualified.	Activities associated with development of this PMR and its related AMRs were determined to be subject to the QA program as described in the QARD (DOE 2000) document. As such, collection of related data, development of analyses and models, and use and validation of software is subject to the requirements of procedures developed to implement QA program requirements.
Criterion P2 - Formal expert elicitations can be used to support data synthesis and model development for DOE's TSPA, provided that the elicitations are conducted and documented under acceptable procedures	No expert elicitation were conducted for the Biosphere PMR. No further discussion of this acceptance criterion is provided.

5. SUMMARY AND CONCLUSIONS

A potential repository for spent nuclear fuel and high-level radioactive waste is being studied at Yucca Mountain, Nevada. As part of that work, assessments are being developed of repository performance, that is, of possible impacts on people and the environment. The impacts associated with hypothesized release of radioactive material from the potential repository are being evaluated in the TSPA.

The biosphere model summarizes the biosphere-related technical bases for the TSPA model. This biosphere work, in combination with the models developed and reported in other PMRs, permits careful evaluation of potential repository performance. The objective of the Biosphere PMR is to recapitulate the development of the biosphere model and the BDCFs developed for use in TSPA. The *Biosphere PMR* does not present estimates of potential radiation doses to human receptors. Dose calculations are performed as part of TSPA and will be presented in the TSPA documentation.

This section provides a concise, high-level discussion summarizing the biosphere effort and listing the major conclusions relative to the objectives. Greater detail and discussion is presented in other sections of this PMR.

5.1 SUMMARY

The biosphere model has evolved in TSPA work performed in 1991, 1993, 1995, and most recently in 1998 for the Viability Assessment. The current model stands on the previous work, but includes a number of modifications and enhancements, which are detailed in Chapter 2 of this document.

Generally, biosphere modeling includes the migration and accumulation of radionuclides in the biosphere and evaluation of potential radiological impacts on a human receptor. The biosphere model for the potential repository described in this PMR considers radionuclide transport and uptake resulting from a unit of radioactivity concentration present at the contamination source, i.e., groundwater, or volcanic ash deposit on surface soil. The results of biosphere modeling are expressed in terms of BDCFs.

To develop the biosphere model, the relationships between the important environmental transport processes and processes leading to radionuclide uptake by humans were conceptualized. These processes are numerically implemented in the GENII-S computer code, which was selected to support BDCF calculations. Parameters used by the numerical model include attributes of the human receptor as well as characteristics of radionuclide transport in the biosphere. To be pertinent for Yucca Mountain, these attributes and characteristics must be specific to the biosphere in the general vicinity of the mountain. Proposed NRC and EPA rules prescribe characteristics of both the reference biosphere and the human receptor, an "average member of the critical group" or the "reasonably maximally exposed individual" (RMEI).

The principal results of the biosphere model work are BDCFs that quantify the annual radiation dose that potentially would be received by the receptor for a unit of radioactivity concentration in the source entering the biosphere, for example, groundwater. These BDCFs are used in the

TSPA model as multipliers to convert any concentration of a specific radioactive isotope in the source to annual radiation dose incurred by a specified human receptor. The BDCFs are developed based on currently available information defining the characteristics of the human receptors prescribed in the proposed regulations. Results from the TSPA modeling as well as changes in the regulatory requirements and guidance will be examined to ensure this assessment and identification of the critical group remains appropriate for its intended use.

The two potential exposure scenarios analyzed for an average member of the critical group are based on the sources of contamination, groundwater and volcanic ash. The groundwater contamination scenario was used to evaluate the BDCFs for undisturbed performance of the potential repository, and for consideration of consequences of some disruptive seismic events and human intrusion. The disruptive volcanic event scenario was used to develop BDCFs for the biosphere in which contaminated volcanic ash becomes deposited on the surface. A reasonable conservative analysis was performed for each exposure scenario for each radionuclide of interest. For the groundwater contamination scenario, BDCFs were calculated for six time periods of assumed continual irrigation of a plot of land. These calculations were performed in order to determine if potential buildup of radioactivity in soil would change the estimated values of the BDCFs.

The Biosphere effort also assessed the annual volume of water used by the community specified in NRC's proposed regulation, and the buildup and loss of radionuclides in soil. State of Nevada water usage data for Amargosa Valley and Bureau of Census data were used in the water analysis. Soil dynamics were developed using values reported in the technical literature for conditions similar to those in the vicinity of Yucca Mountain.

This report includes discussion of this assessment in the context of other Project work, the conceptual biosphere model, exposure scenarios, mathematical model of the biosphere, input parameter values, and calculation of BDCFs. Quantitative evaluation of uncertainty in BDCF values due to uncertainties in input parameters is expressed as distributions of potential BDCF values. This report also includes conclusions regarding the relevant features of the existing biosphere in the vicinity of Yucca Mountain, a discussion of the regulations applicable to a potential repository at Yucca Mountain, and a discussion of the methods used to assign and evaluate site-specific characteristics of potential human receptors.

5.2 CONCLUSIONS

This section provides the principal conclusions of the Biosphere PMR. Conclusions and results are provided throughout the PMR as it discusses portions of the biosphere model, selection of input parameters, and use of the model to calculate BDCFs. This section presents the conclusions and results by progressing through these subjects in a similar manner.

The objectives of the Biosphere PMR have been satisfied. The work performed and the report's development provide the biosphere model, and BDCFs for use in TSPA. DOE guidance and proposed regulations pertinent to the biosphere model were studied and the work was performed to assure satisfaction of these expectations.

The biosphere model describes processes required to evaluate the movement of radionuclides through the environment to humans, and the resulting uptake by human receptor. The model consists of a conceptual model, and its numerical implementation, a generalized mathematical tool including inputs that represent specific conditions in the biosphere.

One result of the biosphere work reported in the Biosphere PMR is development of the conceptual portion of the model. This includes definitions of human receptors, around which the model must be designed. The selection of FEPs potentially important to modeling the biosphere was performed. The portions of the report on the conceptual biosphere model discuss the methods and process used to evaluate and screen potential FEPs for inclusion in the biosphere model. The hypothesized exposure scenarios are also described in the PMR (Section 3.1.5). One of these is a groundwater contamination scenario to evaluate BDCFs for undisturbed performance of the potential repository and for some disruptive events, such as seismic events and human intrusion. The second scenario addresses contamination of soil with volcanic ash and is referred to as the disruptive volcanic event scenario.

The section on the mathematical representation of the biosphere model discusses relationships among model components and mathematical algorithms. Consideration of model needs and comparison of available model mathematical representations was previously conducted. The conclusion reached was that the existing computer code, GENII-S, provides an appropriate representation. The PMR summarizes the justification for selecting this computer code (Section 3.2.1). GENII-S meets all eight of the computer code selection criteria used, and was found to be the most comprehensive code available for biosphere modeling. It is capable of addressing the FEPs applicable to the Yucca Mountain biosphere, and has been used by the principal regulatory agencies involved in waste isolation.

Model validation work was performed. It concluded that the combination of the conceptual model, appropriately selected input parameters, and the mathematical expressions of the model are valid for use in evaluating the reference biosphere. The report provides the criteria used and judgments made that conclude confidence exists that the model is appropriate and adequate for the intended purpose.

Input parameter values were developed for the GENII-S code to permit prediction of radiation exposures to persons living in the vicinity of the potential repository. These inputs were developed in the biosphere AMRs. These input parameters are numerical values that express those behaviors of the people that are important to radiation exposure. For example, one AMR was prepared to define the characteristics of the receptors of interest. This included dietary consumption of locally produced food. Another AMR was developed to define typical external and inhalation exposure characteristics. There are two receptors of interest. One is an average member of the critical group, constructed based DOE guidance that is consistent with the NRC's proposed rule for the potential repository. The second receptor is the RMEI based on EPA's proposed regulation.

The process to identify the critical group involved identifying screening groups, using dietary characteristics and behaviors data, and examining additional lifestyle and land use data to select the critical group that exhibits behaviors and characteristics that result in the highest expected annual doses. This group is concluded to be the residential farmer. The RMEI is conservatively presumed to be a member of the critical group because that group represents the component of the Amargosa Valley population expected to experience the highest potential exposures to radiation.

The model also incorporates components of the environment around these people that are significant to radiation exposure. For example, AMRs were developed to quantify the amounts of potentially radioactive chemical elements in soil that are transferred to various food plants. These input parameter values are part of the biosphere model, and are inserted in GENII-S to permit the prediction of radiation exposures. The detailed process for development and review of AMRs supports the validity of the conclusions made regarding input parameter selections.

One of the primary results of the biosphere modeling effort is the calculation of radionuclide-specific BDCFs. This biosphere report does not present estimates of human dose. A discussion in the report also presents conclusions of the degree to which chosen pathways and parameter values influence the estimated BDCF values (sensitivity analysis) (Section 3.3.1 and 3.3.2). For the groundwater contamination scenario, the inhalation and external exposure pathways are not significant, and the ingestion pathway accounts for essentially all of the BDCF. The most important parameters for all radionuclides of interest, except Carbon-14 and Cesium-137, is ingestion of drinking water, followed by ingestion of leafy vegetables. For Carbon-14, consumption of fish, assumed raised in ponds filled from groundwater sources, is the greatest contributor (more than 90%). Fish consumption is the leading contributor to the BDCF for Cesium-137, followed by drinking water, leafy vegetables and meat.

Results for the disruptive volcanic event scenario are more variable among the radionuclides of interest than is the case for the groundwater contamination scenario. For the disruptive volcanic event scenario, soil ingestion is the dominant pathway and inhalation is an important contributor to the BDCF for isotopes of actinium, americium, protactinium, and plutonium. The inhalation and soil ingestion pathways are approximately of equal importance for Thorium-229, with lesser contributions from external exposure and food ingestion. For Strontium-90 and isotopes of uranium, ingestion of vegetables and fruit is the dominant pathway. Soil ingestion and inhalation are also significant contributors for uranium. External exposure is the dominant pathway for Cesium-137, with minor contributions from ingesting fruit, vegetables and meat.

The sensitivity analysis for the disruptive volcanic event scenario provided additional attention to possible variations in the amount of dust (referred to as mass loading) in the breathing air. This was done to ensure understanding of the effect on the BDCFs if the mass loading, and consequently the inhalation of radioactivity, were hypothesized to vary greatly from that used to calculate the BDCFs. Hypotheses that could result in increased mass loading include thicker volcanic ash deposits, ash particle size that is more respirable, changes in particle size over time, redistribution of ash relative to the receptors of interest, and assumptions about surface-disturbing activities.

Rather than pursuing predictions for these physical parameters that help determine the amount of inhalable dust in the breathing air, measured values following the eruption of Mount St. Helens were used. Two higher levels of mass loading were hypothesized based on these reported measurements. One level corresponds to the higher of the measurements taken in non-occupational settings during the post-eruption period, and the other level corresponds to the highest measured values for all but the most extreme occupational conditions. The increase in the inhalation pathway component of the BDCFs was calculated for these two levels using conservative assumptions.

The conclusion for levels associated with non-occupational settings is that the originally calculated BDCFs would need to be multiplied by a factor of approximately 2 to 4, depending on the radionuclide selected. For levels associated with occupational settings, the multiplier is about 13 to 38 depending on the radionuclide. The exception for both mass loading levels is that the BDCF is unchanged (the factor is approximately 1) for Strontium-90 and Cesium-137.

Conclusions have also been developed regarding the uncertainty in the BDCF values calculated due to uncertainties in the input values used in the calculations. These are discussed in Sections 3.3.1 and 3.3.2 of the PMR.

For the disruptive volcanic event scenario the uncertainty is fairly small. Using the normal distribution assumption again, there is a 95 percent confidence that the true mean of the population of BDCF values will fall within 4 to 22 percent of the observed mean for 11 of the radionuclides of interest. For the remaining radionuclide, Strontium-90, the range is about 36 percent.

Abstraction was performed on the information developed in modeling and analysis for the average member of the critical group. This abstraction condenses and captures the salient features of the BDCFs for each radionuclide into a simple mathematical form that can be further analyzed, and integrated in the TSPA model. The conclusions of these abstraction efforts are presented in Section 3.3.2 of the PMR.

The Biosphere effort derived the annual volume of water used by the community and the buildup and loss of contaminants in soil. The conclusions are provided in Section 3.3.2 and 3.4 of this PMR. The values developed are used in calculations performed as part of TSPA. Water usage was estimated to be approximately 97 acre-feet per year for each farm. The specific number of farms on which to base annual groundwater withdrawal is uncertain, but is in the range 15 to 25. The associated expected water usage value is in the range 1454 to 2423 acre-feet per year. Additionally, water usage for domestic purposes was found to be less than a half percent of the agricultural usage.

The report contains a discussion of the relationship of the biosphere model to KTIs addressed in the NRC's Issue and Resolution Status Reports (Section 4). Resolution of acceptance criteria applicable to the biosphere effort is provided.

The biosphere work undertaken and reported in this PMR and the values it has produced will facilitate TSPA calculations to assess performance of a potential repository. This will support preparation of the SR.

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APPENDIX A

GLOSSARY

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GLOSSARY

Abstraction	Distillation of the essential components of a process model into a suitable form for use in a total system performance assessment. The distillation must retain the basic intrinsic form of the process model but does not usually require its original complexity. Model abstraction is usually necessary to maximize the use of limited computational resources while allowing a sufficient range of sensitivity and uncertainty analyses.
Activity	The number of nuclear transformations occurring in a given quantity of material per unit time. See Radioactivity.
Algorithm	(1) The set of well-defined rules that governs the solution of a problem in a finite number of steps. (2) A mathematical formulation of a model of a physical process.
Ambient	(1) Undisturbed, natural conditions such as ambient temperature caused by climate or natural subsurface thermal gradients. (2) Surrounding conditions.
Annual Dose	For human exposure scenarios, a measure of an individual's exposure to ionizing radiation in a year, calculated as either total effective dose equivalent or committed effective dose equivalent.
Aquifer	A subsurface, saturated rock unit (formation, group of formations, or part of a formation) of sufficient permeability to transmit groundwater and yield usable quantities of water to wells and springs.
Average Individual	An individual representative of the life style in the Amargosa Valley with regard to eating, drinking, and other activities that may be relevant in a human exposure scenario as determined by a survey of Amargosa Valley residents by TSPA researchers.
Biosphere	The ecosystem of the earth and the living organisms inhabiting it.
Biosphere Dose Conversion Factor	A multiplier used in converting a radionuclide concentration at the geosphere/biosphere interface into a dose that a human would experience for all pathways considered, with units expressed in terms of annual dose (i.e., the effective dose equivalent) per unit concentration. Depends on the radionuclide(s), pathway(s), climate, and other factors. A key assumption is that the dose is a linear function of concentration at the geosphere/biosphere interface.

Climate	Weather conditions, including temperature, wind velocity, precipitation, and other factors, that prevail in a region.
Code	The set of commands used to solve a mathematical model on a computer.
Committed Effective Dose Equivalent	The total effective dose equivalent received by an individual from radionuclides internal to the individual following a one-year intake of those radionuclides.
Conceptual Model	A set of qualitative assumptions used to describe a system or subsystem for a given purpose. Assumptions for the model should be compatible with one another and fit the existing data within the context of the given purpose of the model.
Confidence	In statistics, a measure of how close the estimated value of a random variable is to its true value.
Confidence Interval	An interval that is believed, with a preassigned degree of confidence, to include the particular value of the random variable that is estimated.
Critical Group	With regard to annual dose, the maximally exposed individuals. A group of members of the public whose exposure is reasonably homogeneous and includes individuals receiving the highest dose. The individuals making up the critical group may change with changes in source term and pathway.
Curie (Ci)	A unit of radioactivity equal to 37 billion (3.7×10^{10}) disintegrations per second.
Data	Facts or figures measured or derived from site characteristics or standard references from which conclusions may be drawn Parameters that have been derived from raw data are sometimes, themselves, considered to be data.
Decay	See Radioactive Decay.
Deep Dose Equivalent	In relation to external whole-body exposure, it is the dose equivalent at a tissue depth of 1 cm (1000 mg/cm^2)
Deep Percolation	Precipitation moving downward, below the plant-root zone, toward storage in subsurface strata.
Deterministic	A single calculation using only a single value for each of the model parameters. A deterministic system is governed by definite rules of evolution leading to cause and effect relationships and predictability. Deterministic calculations do not account for uncertainty in the physical

relationships or parameter values.

Distribution	The overall scatter of values for a set of observed data. A term used synonymously with frequency distribution. Distributions have probability structures that are the probability that a given value occurs in the set.
Distribution Function	A function whose values are the probabilities that a random variable assumes a value less than or equal to a specified value. Synonymous with cumulative distribution.
Disruptive Event	An unexpected event that, in the case of the repository, includes human intrusion, volcanic activity, seismic activity, and nuclear criticality. Disruptive events have two possible effects: (1) direct release of radioactivity to the surface or (2) alteration of the nominal behavior or the system.
Dose	The amount of radioactive energy that passes the exchange boundaries of an organism (e.g., skin and mucous membranes) and is taken into living tissues. Dose arises from a combination of the energy imparted by the radiation and the absorption efficiency of the affected organism or tissues. It is expressed in terms of units of the radiation taken in, the body weight or mass impacted.
Dose Conversion Factor	(1) Any factor used to change an environmental measurement to dose in the appropriate units. (2) The multipliers that convert an amount of radionuclides ingested or inhaled to an estimate of dose.
Dose Equivalent	The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. See also Effective Dose Equivalent and Total Effective Dose Equivalent.
Dosimetric	An adjective of dosimetry, which is defined as the measurement or calculation of energy aborted by matter in the health physics field.
Ecosystem	The complex of a community and its environment functioning as an ecological unit in nature.
Effective Dose Equivalent	The sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.
Expected Value	A variable's mean, or average, outcome. The weighted average of the number of possible outcomes, with each outcome being weighted by its probability of occurrence. The mean of a probability distribution of a random variable that one would expect to find in a very large, random sample. The sum of the possible values, each weighted by its

	probability the center of the random variable's histogram (frequency distribution).
Features	Physical, chemical, thermal, or temporal characteristics of the site or repository system.
Function (Mathematics)	A quantity that is variable and whose value depends on and varies with the value of another quantity or quantities. Functions show the mathematical relationship between dependent variables and the independent variables upon which the value of the dependent variables depend.
GENII	A deterministic computer software code that evaluates dose from the migration of radionuclides introduced into the accessible environment, or biosphere, that may eventually affect humans through ingestion, inhalation, or direct radiation. It is used to develop biosphere dose conversion factors.
GENII-S	A quasi-stochastic computer software code that can create distributions and sample them and is run in conjunction with GENII for biosphere modeling.
Geometric Mean	The geometric mean of a set of positive numbers is the exponential of the arithmetic mean of their logarithms. The geometric mean of a lognormal distribution is the exponential mean of the associated normal distribution.
Geometric Standard Deviation	The geometric standard deviation of a lognormal distribution is the exponential of the standard deviation of the associated normal distribution.
Geosphere	The combination of the earth's rock, water, and air layers (spheres).
Groundwater	Water contained in pores or fractures in either the unsaturated or saturated zones below ground level.
High-Level Radioactive Waste	(1) The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing, and any solid material derived from such liquid waste that contains fission products in sufficient concentrations. (2) Other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.
Human Intrusion	The inadvertent disturbance of a disposal system by humans that could result in release of radioactive waste. Subpart B of 40 CFR 191 requires that performance assessments consider the possibility of human intrusion.

Ionizing Radiation	(1) Alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. (2) Any radiation capable of displacing electrons from an atom or molecule, thereby producing ions.
Isotope	One of two or more atomic nuclei with the same number of protons (i.e., the same atomic number) but with a different number of neutrons (i.e., a different atomic weight). For example, uranium-235 and uranium-238 are both isotopes of uranium.
Latin Hypercube Sampling	A sampling technique that divides the cumulative distribution function into intervals of equal probability and then samples from each interval.
Linear Regression	A regression where the relationship between the (conditional) mean of a random variable and one or more independent variables can be expressed by the mathematical equation that describes a line. A relationship between two variables such that the dependence of one variable on the other can be described by (the equation of) a straight line.
Lognormal Distribution	A distribution of a random variable X such that the natural logarithm of X is normally distributed.
Loguniform	A distribution of a random variable X such that the natural logarithm of X is uniformly distributed.
Mathematical Model	A mathematical description of a conceptual model.
Mean (Arithmetic)	For a statistical data set, the sum of the values divided by the number of items in the set. The arithmetic average.
Meteorological	Of, or relating to meteorology, or to weather and other atmospheric phenomena.
Millirem (mrem)	A one thousandth (10^{-3}) part of a rem.
Model	A depiction of a system, phenomenon, or process including any hypotheses required to describe the system or explain the phenomenon or process.
Order of Magnitude	A range of numbers extending from some value to ten times that value.
Parameter	Scientific data generally represented by a value or range of values.

Pathway	A potential route by which radionuclides might reach the accessible environment and pose a threat to humans.
Partition Coefficient (K_d)	Parameter describing sorbing properties of soil in terms of relationship between geochemical aqueous solution and the sorbent (soil).
Percentile	For a large data set where specific values are not repeated extensively, used to indicate where a value lies in relation to the entire group of values. For example, the 25th percentile indicates that about 25 percent of the items are smaller than this value and about 75 percent are larger than this value.
Performance Assessment	An analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling. See TSPA.
Picocurie (p Ci)	A one trillionth (10^{-12}) part of a Curie or 0.037 nuclear transformations per second.
Plume	A measurable discharge of a contaminant, such as radionuclides, from a point of origin. The contaminants are usually moving in groundwater, and the plume may be defined by chemical concentration gradients.
Precipitation	(1) The process of depositing a substance from a solution, by the action of gravity or by a chemical reaction. (2) Any form of water particles, such as frozen water in snow or ice crystals, or liquid water in raindrops or drizzle, that fall from clouds in the atmosphere and reaches the earth's surface. (3) An amount of water that has fallen at a given point over a specified period of time, measured by a rain gauge.
Probability	The relative frequency with which an event occurs in the long run. Statistical probability is about what really happens in the real world and can be verified by observation or sampling. Knowing the exact probability of an event is usually limited by the inability to know, or compile the complete set of, all possible outcomes over time or space.
Probability Distribution	See Distribution Function
Process Model	A depiction or representation of a process along with any hypotheses required to describe or to explain the process.
Processes	Phenomena and activities that have gradual, continuous interactions with the system being modeled.

Quantitative	A variable that is expressed numerically.
Radiation	Ionizing radiation.
Radioactive Decay	The process in which one radionuclide spontaneously transforms into one or more different radionuclides, which are called daughter radionuclides.
Radioactivity	The property possessed by some elements (i.e., uranium) of spontaneously emitting alpha, beta, or gamma rays by the disintegration of atomic nuclei.
Radionuclide	Radioactive type of atom with an unstable nucleus that spontaneously decays, usually emitting ionizing radiation in the process. Radioactive elements characterized by their atomic mass and number.
Random Variable (Statistics)	The numerical difference between the highest and lowest value in any series.
Realization	A complete calculation using a randomly selected value. Many of these calculations are done in Latin Hypercube Sampling in GENII-S. See also simulation.
Reasonable Representation Analysis	A method for producing a conservative best estimate of a BDCF together with a quantitative assessment of its uncertainty. Most parameters used in the Reasonable Representation calculation are described by distributions that are subsequently sampled to arrive at a stochastic representation (mean value and standard deviation) of the BDCF.
Reasonably Maximally Exposed Individual	A hypothetical individual who would be representative of the most highly exposed individuals.
Reference Person	With regard to dose, a hypothetical collection of human physical and physiological characteristics arrived at by international consensus. This collection may be used by researchers to relate biological damage to a stimulus such as radiation exposure. The reference adult person lives 20 km (12 miles) from Yucca Mountain and will be defined using a survey of the existing population.
Regression	The relationship between the (conditional) mean of a random variable and one or more independent variables.
Regression Analysis	The analysis of paired data such that one member of the pair is a constant and the other is a random variable. The analysis of a paired dependent variable and the independent variable upon which it depends.

For example, the term was first used in a study of the heights of fathers and sons where a regression (or turning back) was observed toward the mean height of the population in the heights of sons whose fathers were taller or shorter than the mean.

Regression Coefficient — In expressing the relationship between two or more variables, the regression coefficient associated with an independent variable indicates the weight or influence that variable has in predicting the value of the dependent variable. In the equation $Y = AX_1 + BX_2 + C$, A and B are regression coefficients of the independent variables X_1 and X_2 respectively. When regression coefficients are standardized, their absolute values directly indicate the relative importance of the corresponding independent variables in predicting the value of the dependent variable.

rem — The unit of a dose equivalent from ionizing radiation to the human body. It is used to measure the amount of radiation to which a person has been exposed) (rem means roentgen equivalent man).

Risk — The probability that an undesirable event will occur multiplied by the consequences of the undesirable event.

Saturated Zone — The region below the water table where rock pores and fractures are completely saturated with groundwater.

Scenario — A well-defined, connected sequence of features, events and processes that can be thought of as an outline of a possible future condition of the repository system. Scenarios can be undisturbed, in which case the performance would be expected, or nominal, behavior for the system. The scenario can also be disturbed, if altered by disruptive events such as human intrusion, natural phenomena such as volcanism, or nuclear criticality.

Sensitivity (Analysis) — An analytic or numerical technique for examining the effects of varying specified parameters when a model run is performed. Shows the effects that changes in various parameters have on model outcomes and can illustrate which parameters have a greater impact on the predicted behavior of the system being modeled. Also, called sensitivity analysis because it shows the sensitivity of the consequences (e.g., radionuclide release) to uncertain parameters (e.g., the infiltration rate that results from precipitation).

Shifted Lognormal — A shifted lognormal distribution occurs when $ln(x-s)$ is distributed normally (with a defined mean and standard distribution), where x is the random variable and s is a constant.

Simulation — The generation of a sample set by selecting a parameter value from each input distribution and calculating the consequences for the sample set. See also Realization.

Site Recommendation — A recommendation by the Secretary of Energy to the President that the Yucca Mountain site be approved for development as the nation's first high-level radioactive waste repository. If the site is determined to be suitable, this recommendation is expected in fiscal year 2001.

Source Term — Types and amounts of radionuclides that are the source of a potential release from the repository.

Standard Deviation — (1) For a set of observations or a frequency distribution, the square root of the average of the squared deviations from the mean divided by n-1 (where n is the sample size). (2) The square root of the variance.

Statistical Approach — Assessment approach that quantifies uncertainties in the model parameters and predicts the likelihood of the scenarios used for the model.

Stepwise Linear Regression — An analysis designed to determine variables that have the greatest influence on an output value (e.g., peak dose) when there are many variables whose input values go into the calculation. In simple terms, a linear regression is performed for a line in a multidimensional space, and the correlation of the values of different variables to the line are examined by performing the calculation multiple times and varying the value of one variable at a time while holding the others constant. This is a stepwise process in which one variable at a time is examined to determine the impact of its influence on the final outcome (peak dose, for instance).

Stochastic — Involving a variable (e.g., temperature and porosity) that may take on values of a specified set with a certain probability. Data from a stochastic process is an ordered set of observations, each of which is one item from a probability distribution. Random.

Stochastic Model — A model whose outputs are predictable only in a statistical sense. A given set of model inputs produces outputs that are not the same, but follow statistical patterns.

Total Effective Dose Equivalent — The sum of the deep dose equivalent, for external exposures, and the committed effective dose equivalent, for internal exposures.

Total System Performance Assessment — A risk assessment that quantitatively estimates how the proposed Yucca Mountain repository system will perform in the future under the influence of specific features, events, and processes, incorporating uncertainty in the models and data. Its purposes follow:

	(1) provide the basis for predicting system behavior and testing that behavior against safety measures in the form of regulatory standards (2) provide the results of TSPA analyses and sensitivity studies (3) provide guidance to site characterization and repository design activities (4) help prioritize testing and selection of the most effective design options.
Uncertainty	A measure of how much a calculated or estimated value that is used as a reasonable guess or prediction may vary from the unknown true value.
Undisturbed Performance	Refers to the expected or nominal behavior of the system as perturbed only by the presence of the repository. This is as used in description of scenarios, or features, events, or processes making up scenarios.
Uptake	Quality of a radionuclide taken up by the systemic circulation, e.g., by injection into the blood, by respiratory or gastronintestinal tracts, or by absorption through the skin or through wounds in the skin.
Unsaturated Zone	The zone of soil or rock below the ground surface and above the water table in which the pore spaces contain water, air, and other gases. Generally, the water saturation is below 100 percent in this zone, although really limited perched water bodies (having 100 percent water saturation) may exist in the unsaturated zone. Also called the vadose zone.
Variable	A nonunique property or attribute.
Variance	(1) The square of the standard deviation. (2) The expected squared distance from the population mean of a random variable, sometimes called the population variance.
Waste Package	The waste form and any containers (i.e., disposal container barriers and other canisters), spacing structures or baskets, shielding integral to the container, packing contained within the container, and other absorbent materials immediately surrounding an individual waste container placed internally to the container or attached to the outer surface of the disposal container. The waste package begins its existence when the outer lid welds are complete and accepted.
Water Table	The upper surface of a zone of saturation above which the majority of pore spaces and fracture openings are less than 100 percent saturated with water most of the time (unsaturated zone), and below which the opposite is true (saturated zone).

APPENDIX B

SUMMARY OF SCREENING DECISIONS FOR PRIMARY BIOSPHERE-RELATED FEATURES, EVENTS AND PROCESSES

APPENDIX B

SUMMARY OF SCREENING DECISIONS FOR PRIMARY BIOSPHERE-RELATED FEATURES, EVENTS AND PROCESSES

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
1.2.07.01.00	Erosion/denudation	EXCLUDE	Inconsistent with section 115(a)(1) of the RIG which limits the Reference Biosphere to current conditions. This FEP relates to significant changes in present-day topography; therefore, this FEP is excluded.	
1.2.07.02.00	Deposition	EXCLUDE	Inconsistent with section 115(a)(1) of the RIG which limits the Reference Biosphere to current conditions. This FEP relates to significant changes in present-day topography; therefore, it is excluded.	
1.3.01.00.00	Climate change, global	EXCLUDE	Inconsistent with section 115(a)(1) of the RIG which limits the Reference Biosphere to current conditions; therefore, this FEP is excluded.	
1.3.04.00.00	Periglacial effects	EXCLUDE	Inconsistent with section 115(a)(1) and (2) of the RIG, which limits the Reference Biosphere to current arid/semi-arid conditions. This FEP relates to cold environments; therefore, this FEP is excluded.	
1.3.05.00.00	Glacial and ice sheet effects, local	EXCLUDE	Inconsistent with section 115(a)(1) and (2) of the RIG, which limits the Reference Biosphere to current arid/semi-arid conditions. This FEP relates to the effects of glaciers and ice-sheets; therefore, it is excluded.	

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
1.4.01.00.00	Human influences on climate	EXCLUDE	Inconsistent with Sections 115(a) and (b) of the RIG which require that the Reference Biosphere be consistent with current conditions. This FEP relates to the impact of future human actions on the environment. As a result, this FEP is excluded.	
1.4.01.02.00	Greenhouse gas effects	EXCLUDE	Inconsistent with Sections 115(a) and (b) of the RIG which require that the Reference Biosphere be consistent with current conditions; including current greenhouse gas effects and current climatic conditions. The effect of changing the greenhouse effect gas is therefore excluded.	
1.4.01.03.00	Acid rain	EXCLUDE	Section 115(a)(1) and (2) of the RIG, limits the Reference Biosphere to current arid/semi-arid conditions, which includes any existing acid rain. Human actions, which change acid rain characteristics, are therefore excluded.	
1.4.01.04.00	Ozone layer failure	EXCLUDE	Inconsistent with section 115(a)(1) of the RIG, which limits the Reference Biosphere to current conditions; therefore, the processes in this FEP, which consider changes to the ozone layer as a result of future human actions, are excluded.	
1.4.06.01.00	Altered soil or surface water chemistry	EXCLUDE	Section 115(b)(1) specifies the location of the critical group as 20 km south of Yucca Mountain. As a result, this FEP which deals with impacts on the repository is excluded.	

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
1.4.07.01.00	Water management activities	EXCLUDE	Section 115(b) of the RIG specifies that the behavior and characteristics of the critical group be consistent with current conditions. Figure 2-2 of LaPlante and Poor (1997) indicates that there are no major water retention facilities within 20 km. of the location of the critical group specified in Section 115(b). As a result, this FEP is excluded	
1.4.07.02.00	Wells	INCLUDE / EXCLUDE	Section 115(b) specifies the location of the critical group as approximately 20 km. south of the repository. Wells at other locations are excluded.	This FEP is considered as the source of radionuclides entering the environment under the Non-disruptive scenario. See AMR entitled: *Groundwater Usage by the Proposed Farming Community* (CRWMS M&O 2000l), and *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e).
1.4.08.00.00	Social and institutional developments	EXCLUDE	Inconsistent with section 115(b)(2) of the RIG, which specifies that the behavior and characteristics of the critical group be consistent with current conditions. Changes are not to be considered.	
1.4.09.00.00	Technological developments	EXCLUDE	Inconsistent with section 115(b)(2) of the RIG, which specifies that the behavior and characteristics of the critical group be consistent with current conditions. Change is, therefore, not to be considered.	
1.5.02.00.00	Species evolution	EXCLUDE	Inconsistent with section 115(b)(2) of the RIG, which specifies that the behavior and characteristics of the critical group be consistent with current conditions. Consideration of non-human receptors is precluded by the performance objective specified in Section 113 (b).	

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
2.2.07.03.00	Capillary rise	EXCLUDE	Section 115(b) (1) specifies the location of the critical group; approximately 20 km south of the facility. Since depth to water in that area is in excess of 50 meters (LaPlante and Poor 1997), this FEP is excluded.	
2.3.02.01.00	Soil type	INCLUDE / EXCLUDE	Section 115 of the RIG limits reference biosphere to current conditions. Therefore, formation and development of soils are excluded.	This FEP is considered in the transfer of radionuclides from well water to the food chain. It is also considered in the build-up radionuclides as a function of previous irrigation. See AMR entitled *Non-Disruptive Event Biosphere Dose Conversion Factors Analysis* (CRWMS M&O 2000e), *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j), and *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000d)
2.3.02.02.00	Radionuclide accumulation in soils	INCLUDE / EXCLUDE	Section 115(b) of the RIG specifies the location of the critical group as 20 km south of repository. Therefore, consideration of upwelling/ discharging at other locations is excluded.	Disposition of radionuclides in soil as a result of continuous irrigation is considered. See AMRs entitled: *Non-Disruptive Event Biosphere Dose Conversion Factors Analysis* (CRWMS M&O 2000e), and *Abstraction of BDCF Distributions for Irrigation Periods* (CRWMS M&O 2000h)
2.3.02.03.00	Soil and sediment transport	INCLUDE / EXCLUDE	Section 115(a) of the RIG specifies that the Reference Biosphere be consistent with current conditions. As there are no fluvial or glacial processes currently at work in the area, this FEP is excluded.	Removal of potentially contaminated soil is considered. Aeolian processes for current conditions are addressed in AMR entitled *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000d)

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
2.3.04.01.00	Surface water transport and mixing	EXCLUDE	Sections 115(a) and (b) of the RIG specifies that the Reference Biosphere be consistent with current conditions. Figure 2-2 of LaPlante and Poor (1997) indicates there are no lakes and rivers within 20 km of the location of the critical group.	
2.3.06.00.00	Marine features	EXCLUDE	Section 115(a) of the RIG specifies that the Reference Biosphere be consistent with current conditions. Figure 2-2 of LaPlante and Poor (1997) indicates there are no marine or coastal features within 20 km of the location of the critical group.	
2.3.09.01.00	Animal burrowing/intrusion	EXCLUDE	Section 115 of the RIG specifies the location of the critical group and the reference biosphere. As a result, events involving the repository are excluded on the basis of inconsistency with the RIG. Ingestion or contact of burrowing animals with contaminated soil is excluded from consideration by the performance objectives in Section 114 which set one of the objectives as a dose to a human, not an animal.	
2.3.11.01.00	Precipitation	INCLUDE / EXCLUDE	Section 115(a) and (b) of the RIG specify that the reference biosphere must be consistent with current conditions and that the location of the critical group is 20 km south of the repository. Therefore, portions of the FEP that relate to recharge and climate change are excluded.	Precipitation is considered a part of the overall water balance and is empirically considered in the amount of water used to support agricultural activities that may lead to an exposure. See AMRs entitled *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e), and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j).

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
2.3.11.02.00	Surface runoff and flooding	INCLUDE / EXCLUDE	Section 115(a) and (b) of the RIG specify that the reference biosphere must be consistent with current conditions and that the location of the critical group is 20 km south of the repository.	Dispersion of contaminants through erosion and leaching is addressed in AMR entitled *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2000d).
2.3.13.01.00	Biosphere characteristics	INCLUDE / EXCLUDE	Changes in current biosphere characteristics over time are precluded from consideration by Sections 115(a)(1) & (2) of the RIG.	Biosphere characteristics are considered, in support of the calculations of dose conversion factors, as part of the reference biosphere in the following AMRs: 1) *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000b), 2) *Groundwater Usage by the Proposed Farming Community* (CRWMS M&O 2000l), 3) *Input Parameter Values for External and Inhalation Radiation Exposure Analysis.* (CRWMS M&O 2000t), 4) *Identification of Ingestion Exposure Parameters* (CRWMS M&O 2000c), 5) *Environmental Transport Parameter Analysis* (CRWMS M&O 1999a), and 6) *Transfer Coefficient Analysis* (CRWMS M&O 2000s).

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
2.3.13.02.00	Biosphere transport	INCLUDE / EXCLUDE	Radionuclides in gaseous form are assumed to be dispersed as a result of irrigation. Dispersion will reduce the radionuclide concentration in air and as a result will have a low consequence on the projected dose. Therefore they are excluded from consideration. Since Section 115 limits the reference biosphere to current conditions, the impacts of both time-dependent and chemical-dependent environments, sedimentary transport and water bodies are excluded.	Transport and transfer of radionuclides, entering the biosphere via a groundwater well and a volcanic eruption through various biosphere compartments are summarized in AMRs entitled *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j)
2.4.01.00.00	Human characteristics (physiology, metabolism)	INCLUDE / EXCLUDE	Section 115(b)(5) specifies that the average member of the critical group is an adult. Non-adult receptors are excluded.	The human receptor of interest is an adult as specified in the RIG. See AMR entitled *Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods.* (CRWMS M&O 1999d).
2.4.03.00.00	Diet and fluid intake	INCLUDE / EXCLUDE	Effects of filtration and food preparation techniques are excluded on the basis of low consequence since these processes would tend to reduce the amount of radionuclides available for ingestion. Consumption of drugs (locally produced) for medicinal purposes is inconsistent with current behaviors and is contrary to the requirements of Section 115 of the RIG..	Applicable portions of this FEP are considered in the identification of the behavior of the critical group and its average member. See AMRs entitled *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000b), and *Identification of Ingestion Exposure Parameters* (CRWMS M&O 2000c).

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
2.4.04.01.00	Human lifestyle	INCLUDE / EXCLUDE	Section 115(b) of the RIG specifies that the critical group is part of a farming community. Hunter gathering lifestyle is inconsistent with the behavior of a farming community and is therefore excluded.	Lifestyle characteristics are considered in the development of the behavior and characteristics of the critical group. See AMRs entitled *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000b), *Identification of Ingestion Exposure Parameters* (CRWMS M&O 2000c), and *Input Parameter Values for External and Inhalation Radiation Exposure Analysis.* (CRWMS M&O 2000t).
2.4.07.00.00	Dwellings	INCLUDE / EXCLUDE	Effects of different locations are excluded from consideration since the location is specified in Section 115 of the RIG. Building material, gas and water leakage into basements and space are inconsistent with current conditions as required in Section 115 of the RIG and are excluded. Based on U.S. census Bureau (1999) data, dwellings in Amargosa Valley are predominately of a single type with no basements, and use of non-locally produced heating materials is very common. As a result these FEPs are excluded.	The effects of dwellings and household activities are implicitly considered in AMRs entitled *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j), and *Input Parameter Values for External and Inhalation Radiation Exposure Analysis.* (CRWMS M&O 2000t).
2.4.08.00.00	Wild and natural land and water use	EXCLUDE	Section 115(a) and (b) of the RIG specify that the critical group resides within a farming community. Since use of wild and natural lands would remove the members of the critical group from the area of potential contamination, and thereby lower exposure, this FEP is excluded on the basis of low consequence.	

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
2.4.09.01.00	Agricultural land use and irrigation	INCLUDE / EXCLUDE	Section 115(a) and (b) require consistency with current lifestyle and environmental conditions. Hydoponic gardening, peat and leaf harvesting, use of ashes and sewage sludge are excluded from consideration inconsistent with assumed current conditions.	Traditional farming and gardening, as they support calculation of the dose conversion factors, are considered. See AMRs entitled *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000b), and *Identification of Ingestion Exposure Parameters* (CRWMS M&O 2000c), and *Input Parameter Values for External and Inhalation Radiation Exposure Analysis.* (CRWMS M&O 2000t).
2.4.09.02.00	Animal farms and fisheries	INCLUDE		This FEP is considered in the calculation of the dose conversion factors. See AMRs entitled *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000b), *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j), and *Transfer Coefficient Analysis* (CRWMS M&O 2000s).
2.4.10.00.00	Urban and industrial land and water use.	EXCLUDE	Inconsistent with section 115(a) and (b) of the RIG, which specifies that, the critical group resides within a farming community. Therefore this FEP is excluded.	

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
3.3.01.00.00	Drinking water, foodstuffs and drugs, contaminant concentrations in	INCLUDE / EXCLUDE	Consideration of use of locally produced drugs is inconsistent with current conditions as required by Section 115 of the RIG. As a result of this, a portion of the FEP is excluded. Given the depth to groundwater as presented in LaPlante and Poor (1997), well water is considered the most probable source of drinking water. Therefore, non-well water sources are excluded on the basis of inconsistency with current conditions. Use of locally produced drugs for medical purposes is inconsistent with assumed current conditions.	Applicable portions of these FEPs are considered in the calculation of biosphere dose conversion factors. See AMRs entitled *Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water)* (CRWMS M&O 2000b), *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j).
3.3.02.01.00	Plant uptake	INCLUDE/ / EXCLUDE	Section 115 of the RIG specifies the location of the critical group. Based on the depth to groundwater presented in Figure 2-2 of LaPlante and Poor (1997) there are no natural outfalls in that area. Therefore, consideration of natural outfalls is excluded from consideration.	Plant uptake as a factor in the movement of radionuclides through biosphere compartments is considered in the calculation of biosphere dose conversion factors. Plant uptake is considered in AMR entitled *Transfer Coefficient Analysis* (CRWMS M&O 2000s)
3.3.02.02.00	Animal uptake	INCLUDE / EXCLUDE	Animal grooming and fighting are excluded on the basis of low consequence since these are relatively short-term activities. Consumption of carcasses and scavengers and predators is not consistent with the behavior of a farming community as is required by Section 115.	Applicable portions of this FEP are considered in the calculation of biosphere dose conversion factors. See AMR entitled *Transfer Coefficient Analysis* (CRWMS M&O 2000s).
3.3.02.03.00	Bioaccumulation	INCLUDE		This FEP is considered as applicable, in the calculation of biosphere dose conversion factors. See AMR entitled *Transfer Coefficient Analysis* (CRWMS M&O 2000s).

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
3.3.03.01.00	Contaminated non-food products and exposure	EXCLUDE	Section 115(b)(2) specifies that the behavior and characteristics of the critical group shall be consistent with current conditions. The data regarding employment in Amargosa Valley (U.S. Census Bureau 1999) shows that relatively few local residents are employed in manufacturing industries. These data suggest that manufacturing of durable and non-durable goods for use by local residents is not a significant source of potential contamination. Therefore, this FEP is excluded.	
3.3.04.01.00	Ingestion	INCLUDE / EXCLUDE	Production of charcoal, treesap consumption, and smoking of locally grown tobacco are activities that are in consistent with assumed current conditions.	Applicable portions of these FEPs are considered as an input for the calculation of biosphere dose conversion factors. See AMRs entitled *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j).
3.3.04.02.00	Inhalation	INCLUDE		See AMRs entitled *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j)
3.3.04.03.00	External exposure	INCLUDE / EXCLUDE	Dermal sorption of tritium and non-tritium radionuclides are excluded since dermal sorption is considered to be of low consequence relative to ingestion & inhalation. Similarly, injection is considered to be low consequence considering other pathways.	See AMRs entitled *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j).

YMP FEP NO.	YMP FEP NAME	SCREENING DECISION	SCREENING ARGUMENT	TSPA DISPOSITION
3.3.05.01.00	Radiation doses	INCLUDE / EXCLUDE	The RIG is specific to Yucca Mountain. Therefore WIPP-specific FEP are excluded	See AMRs entitled *Non-Disruptive Event Biosphere Dose Conversion Factors* (CRWMS M&O 2000e) and *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2000j)
3.3.06.00.00	Radiological toxicity/effects	EXCLUDE	Section 113(b) of the RIG establishes a performance objective that is based on radiation dose	
3.3.06.02.00	Sensitization to radiation	EXCLUDE	Section 115(b)(2) of the RIG precludes consideration of changes in physiology or metabolics.	
3.3.07.00.00	Non-radiological toxicity/effects	EXCLUDE	Section 113(b) of the RIG establishes a performance objective that is based on radiation dose	
3.3.08.00.00	Radon and radon daughter exposure	EXCLUDE	Based on the inventory data provided in CRWMS M&O (2000m), precursor Ra-226 radionuclide, Th-230 does not appear in the saturated zone within the first 10,000 years. As a result, generation of Rn-222 is precluded.	

APPENDIX C

MATHEMATICAL MODELS USED BY GENII-S

APPENDIX C

MATHEMATICAL MODELS USED BY GENII-S

This appendix describes selected mathematical models used in the GENII-S computer code, which are important for the biosphere modeling effort. Some components of the models, such as radionuclide decay, are omitted in order to maintain focus on the main model features.

C.1 ENVIRONMENTAL TRANSPORT OF RADIONUCLIDES

The exposure scenarios under consideration are discussed in Section 3.1.5 Exposure Scenarios. In the case of groundwater contamination scenario, radionuclide migration in the biosphere, and following human exposure, is initiated when contaminated water is used for domestic and agricultural needs. In the case of the disruptive volcanic event scenario, radionuclides become deposited with volcanic ash on the soil surface following volcanic eruption. The subsequent use of contaminated land, combined with the natural processes, causes radionuclide migration through the environment. As a result, radionuclides become redistributed from the initial source of contamination (groundwater or volcanic ash) to other components of the biosphere, such as soil, air, plants, animals, and, eventually, humans.

C.1.1 Radionuclide Concentration in Soil

The soil model used in GENII-S is relatively simple. Although the code considers two soil strata: surface soil and deep soil, only contamination present in the surface soil layer is subject to resuspension and transfer to food products. The radionuclide concentration in the top layer of soil is governed by a conservation equation, where the rate of change in radionuclide concentration in a volume of soil is equal to the rate of activity addition (from either irrigation or ash fall) minus the rate of activity removal. GENII-S considers three mechanisms of potential radionuclide removal from the soil: radioactive decay, plant uptake, and leaching into the deeper soil layer where activity becomes unavailable to plants. A fourth mechanism of potential radionuclide removal, not incorporated into the GENII-S computer code, is physical loss of soil (i.e., erosion by wind and water). This process is modeled outside of the GENII-S code.

Primary calculations of radionuclide concentration in soil in GENII-S are based on an irrigation period of one year. It is assumed that radioactivity is initially distributed throughout the upper soil layer, which is where the plants' roots are assumed to be located. Radionuclide activity in soil per unit area, C_s, following irrigation with contaminated water is calculated using the following relationship (adapted from Napier et al. 1988, p. 4.57-4.58):

$$C_s = \frac{25.4\, C_w\, I}{\lambda_l}\left(1 - e^{-\lambda_l t}\right) \qquad \text{(Eq. C-1)}$$

where

C_s	– radionuclide activity concentration in soil per unit area (pCi m^{-2})
C_w	– activity concentration of radionuclide in water (pCi L^{-1})
I	– irrigation rate (in y^{-1})
λ_l	– leaching rate (y^{-1})
t	– exposure time (equal to one year)
25.4	– unit conversion factor (L in^{-1} m^{-2}), (number of liters in one inch of water applied over one m^2 of soil surface)

For irrigation periods longer than one year, GENII-S factors in removal of radionuclides from soil by harvest. Harvest removal calculations are based on radionuclide concentration in a plant and the plant's yield and are carried out cyclically for the assumed duration of prior irrigation use of contaminated water.

C.1.2 Radionuclide Concentration in Air

The concentration of radionuclides in air, C_a, resulting from soil resuspension is calculated, from the definition of the resuspension factor, using the following equation (Napier et al. 1988, p. 4.63):

$$C_a = C_s \times M \quad \text{(Eq. C-2)}$$

where

C_a	– radionuclide concentration in air (pCi m^{-3})
C_s	– radionuclide activity concentration in soil per unit area (pCi m^{-2})
M	– resuspension factor (m^{-1})

C.1.3 Radionuclide Concentration in Plants

Four categories of edible plants are considered in GENII-S: leafy vegetables, other (root) vegetables, fruit, and grain. There are two main mechanisms of radionuclide transfer to a plant: direct deposition on plant surfaces and the root uptake. Deposition on plant surfaces may result from irrigation with contaminated water and from resuspension of contaminated soil.

In order to evaluate radionuclide deposition onto leaf surfaces, the deposition rates for irrigation and soil resuspension have to be calculated separately. The leaf deposition rate from irrigation, DR_{ir}, is calculated as follows (adapted from Napier et al. 1988, p. 4.57):

$$DR_{ir} = \frac{25.4 \times 12\, C_w\, I}{ID} \quad \text{(Eq. C-3)}$$

where

DR_{ir}	– leaf deposition rate from irrigation (pCi m^{-2} y^{-1})
ID	– irrigation duration (months)
25.4	– unit conversion factor (L in^{-1} m^{-2})
12	– unit conversion factor (months y^{-1})

The leaf deposition rate from resuspension, DR_{rs}, is calculated as follows (adapted from Napier et al. 1988, p. 4.57):

$$DR_{rs} = 3.154 \times 10^7 \; C_a \; v_d \qquad \text{(Eq. C-4)}$$

where

DR_{rs}	– leaf deposition rate from resuspension (pCi m^{-2} y^{-1})
v_d	– deposition velocity (m s^{-1})
3.154×10^7	– unit conversion factor (s y^{-1})

Activity concentration in a plant, following leaf deposition of airborne radionuclides, $C_{p,d}$, is calculated as follows (adapted from Napier et al. 1988, p. 4.67):

$$C_{p,d} = \frac{(DR_{ir}\, r_w + DR_{rs}\, r_a)\, T}{365\, \lambda_w\, B} \left(1 - e^{-\lambda_w t_g}\right) \qquad \text{(Eq. C-5)}$$

where

$C_{p,d}$	– activity concentration in a plant (pCi kg^{-1})
λ_w	– weathering constant (d^{-1})
t_g	– growing time (days)
r_w	– irrigation interception fraction (dimensionless)
r_a	– air interception fraction (dimensionless)
T	– translocation factor (dimensionless)
365	– unit conversion factor (d y^{-1})

Translocation factor, T, describes the fraction of radionuclide transferred from plant surfaces to edible parts of the plant. The irrigation interception fraction, r_w, and the air interception fraction, r_a represent the fraction of initial deposition retained on the plant.

The air interception fraction, r_a, was calculated as follows (adapted from Napier et al. 1988, p. 4.69):

$$r_a = 1.0 - e^{-a\, B\, DW} \qquad \text{(Eq. C-6)}$$

where

a	– empirical factor ($m^2\, kg^{-1}_{\text{dry mass}}$)
B	– biomass ($kg_{\text{wet mass}}\, m^{-2}$)
DW	– plant dry-to-wet weight ratio ($kg_{\text{dry mass}}\, kg^{-1}_{\text{wet mass}}$)

Empirical factor, a, is equal to 3.6 for root vegetables and fruit and 2.9 for leafy vegetables, grain and grasses (Napier et al. 1988, p. 4.69).

Activity concentration in a plant which results from radionuclide uptake by a plant root system, $C_{p,r}$, is calculated using the following equation (adapted from Napier et al. 1988, p. 4.67):

$$C_{p,r} = \frac{C_s}{\rho_s} F_{s \to p} DW \qquad \text{(Eq. C-7)}$$

where

$C_{p,r}$	– activity concentration in a plant from root uptake (pCi kg^{-1})
ρ_s	– surface soil density (kg m^{-2})
$F_{s \to p}$	– radionuclide soil-to-plant transfer factor (pCi kg$^{-1}_{\text{dry plant}}$ per pCi kg$^{-1}_{\text{dry soil}}$)

Total activity concentration in a plant, C_p, is the sum of deposition on plant surfaces and root uptake contributions (adapted from Napier et al. 1988, p. 4.68):

$$C_p = C_{p,d} + C_{p,r} \qquad \text{(Eq. C-8)}$$

where

C_p	– total activity concentration in a plant (pCi kg^{-1})

Activity concentration of Carbon-14 in plants was calculated using a different method (Napier et al. 1988, p. 4.86). It was assumed that the specific activity of Carbon-14 in an environmental medium, such as a plant, was the same as that of the contaminating medium. The fractional content of carbon in a plant was then used to compute the concentration of Carbon-14 in the food product under consideration. The following equation was used to determine Carbon-14 activity concentration in plants (Napier et al. 1988, p. 4.86):

$$C_p = \frac{25.4 \times 12\, C_w I}{ID\ \lambda_l\ \rho_s} \times \frac{0.1}{0.01} \times FC_p \qquad \text{(Eq. C-9)}$$

where

0.1	– the assumed uptake of 10 percent of plant carbon from soil
0.01	– the average fraction of soil that is carbon
FC_p	– fraction of carbon in a plant

The assumption of uptake of 10 percent of plant carbon from the soil is conservative because plants acquire almost all of their carbon from the air (Napier et al. 1988, p. 4.86).

Calculation of activity concentration in plants following radionuclide deposition onto the soil due to a volcanic event is calculated using a similar set of equations, except that radionuclide activity concentration in soil per unit area, calculated for irrigation with contaminated water using Equation C-2, is a given quantity (source term).

C.1.4 Radionuclide Concentration in Animal Products

Radionuclide transfer to animal products results from the ingestion of contaminated feed and contaminated water by the animal. Animal products considered include meat (beef and pork), milk, poultry, and eggs. Determination of radionuclide concentrations in animal products begins with the calculation of radionuclide concentrations in fresh forage and stored feed, C_f, using formulas similar to those described in Section 5.2.1.2, but with parameter values characteristic of crops grown for animal consumption. Once the concentrations of radionuclides in fresh forage and stored feed were determined, the daily radionuclide intake by the animal is calculated which is then converted to the radionuclide concentration in animal product, C_{ap}, using the following formula (adapted from Napier et al. 1988, p. 4.70-4.72):

$$C_{ap} = \left(C_w \; CR_{a,w} + C_f \; CR_{a,f}\right) F_{ad \to ap} \qquad \text{(Eq. C-10)}$$

where

C_{ap}	– radionuclide concentration in animal product (pCi kg^{-1} or pCi L^{-1})
$CR_{a,w}$	– animal consumption rate of water (L d^{-1})
C_f	– activity concentration in fresh forage or stored feed (pCi kg^{-1})
$CR_{a,f}$	– animal consumption rate of fresh forage or stored feed (kg d^{-1})
$F_{ad \to ap}$	– radionuclide transfer factor from animal diet to animal product (d kg^{-1} or d L^{-1})

The concentration of carbon-14 in animal products is calculated using the following formula (Napier et al. 1988, p. 4.89):

$$C_{ap} = \frac{C_f \; CR_{a,f} + C_w \, CR_{a,w}}{FC_f \; CR_{a,f} + FC_w \, CR_{a,w}} \; FC_{ap} \qquad \text{(Eq. C-11)}$$

where

FC_{ap}	– fraction of carbon in animal product
FC_f	– fraction of carbon in animal feed

C.1.5 Radionuclide concentration in aquatic food

The concentration of radionuclides in fish, C_f, is calculated using the following formula:

$$C_f = C_w \; BF \qquad \text{(Eq. C-12)}$$

where

BF – bioaccumulation factor in fish (pCi kg^{-1} per pCi L^{-1})

C.2 DOSE ASSESSMENT

Radiation doses to humans may result from internal intake of radionuclides by inhalation or ingestion or from external exposure to radionuclides present in the environment. Dose assessment in GENII-S is carried out by considering radionuclide concentrations in environmental media, factoring in human exposure conditions, and performing the conversion of exposure to dose. For internal exposure, radionuclide activity intake is calculated by combining the radioactivity concentration in environmental media (e.g., food, soil, air, and water) with the amount of environmental medium taken into the body. Then, using dosimetric models, radionuclide intake is converted into dose. To assess exposure from external sources, GENII-S uses dose coefficients that convert radionuclide concentrations in environmental media to doses for the duration of exposure.

Dose calculations performed by GENII-S are based on methods developed in ICRP-30 (ICRP 1979; ICRP 1980; ICRP 1981). The code calculates incremental organ dose equivalents for each year following an initial radionuclide intake. Committed dose equivalent (50-year organ dose following an intake) is then assembled from incremental dose equivalents to each organ over the commitment period. Committed effective dose equivalent (CEDE) (see Glossary in Attachment A) is then calculated by producing a sum of the organ dose equivalents weighted by organ/tissue weighting factors.

Conceptually, calculation of doses from internally deposited radionuclides, D_{int}, can be considered as if the following relationship were used (adapted from Napier et al. 1988, pp. 4.63, 4.69, 4.72):

$$D_{\text{int}} = IN \times DCF \qquad \text{(Eq. C-13)}$$

where

D_{int}	– dose from annual radionuclide intake (rem)
IN	– annual radionuclide intake by inhalation or by ingestion (pCi).
DCF_{int}	– dose conversion factor for internal radionuclide intake by inhalation or ingestion (rem pCi^{-1})

Dose calculated in Eq. C-13 is expressed in terms of CEDE.

Annual intake, *IN*, is a product of activity concentration in a medium and the amount of this medium taken internally over one year. For annual intake with food, activity concentration in a food product is multiplied by the annual consumption rate for this food; for annual intake with water, activity concentration in water gets combined with the annual consumption rate of water; for inadvertent soil ingestion, activity concentration in soil is multiplied by the amount of soil ingested annually. To calculate intake by inhalation, the activity concentration in air is multiplied by the breathing rate and the amount of time a person is exposed to a given activity concentration in air.

GENII-S calculates the radiation doses from external exposures by considering radionuclide concentrations in soil or air and the duration of exposure to soil and air and combining them with dose coefficients to calculate radiation doses. For example, annual doses from external exposure, D_{ext}, to radionuclides in soil were calculated using the following relationship (adapted from Napier et al. 1988, pp. 4.84):

$$D_{ext} = C_{s,v}\ T_{ext}\ DCF_{soil} \quad \text{(Eq. C-14)}$$

where

D_{ext}	– annual dose from external exposure (rem)
$C_{s,v}$	– activity concentration in soil per unit volume (pCi m^{-3})
T_{ext}	– duration of external exposure to contaminated soil (h)
DCF_{soil}	– dose coefficient for exposure to soil contaminated to a depth of 15 cm from FGR 12 (Eckerman and Ryman 1993) (mrem h^{-1} per pCi m^{-3}).

Dose calculated in Eq. C-14 is expressed in terms of effective dose equivalent (EDE) (see Glossary in Attachment A).

Doses from exposure to internally deposited radionuclides are combined with doses from external irradiation to produce total all-pathway doses.

$$D_{tot} = D_{\text{int}} + D_{ext} \quad \text{(Eq. C-15)}$$

where

D_{tot}	– total dose (rem)

Total dose, calculated using Eq. C-15 is expressed in terms of total effective dose equivalent (TEDE) (see Glossary in Appendix A).

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