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BECHTEL SAIC COMPANY LLC

Soil-Related Input Parameters for the Biosphere Model

Prepared for:
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12. Revision/ICN No.	13. Description of Change
Rev. 00	Initial Issue
Rev. 00 ICN 01	Inclusion of discussion of (1) potential effects of future climate change on calculated soil loss estimates and leaching coefficients, (2) applicable FEPs and how these were addressed in the analysis, and (3) to satisfy one of the issues addressed in CAT 10 (i.e., acknowledgement of the use of an existing soil leaching model for calculating leaching coefficients).
Rev. 01	Provide soil-related product output to be used with the Biosphere Model (ERMYN). Parameters and, where appropriate, distributions are given for soil bulk density, partition coefficients, soil erosion rate, enhancement factor for resuspension, soil water capacity at field capacity, and ash bulk density.
Rev. 02	Revised in accordance with current AP-SIII.9Q. Improve traceability and transparency for analysis documentation by addressing comments from the review by the Repository Integration Project. Made editorial changes. The entire documentation of the scientific analysis was revised and thus change bars were not used.

CONTENTS

CONTENTS (Continued)

Page

FIGURE

Page

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TABLES

Page

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ACRONYMS AND ABBREVIATIONS

BDCF	biosphere dose conversion factor
CR	concentration ratio
ERMYN	Environmental Radiation Model for Yucca Mountain Nevada
FAO	Food and Agriculture Organization of the United Nations
FEPs	features, events, and processes
GM	geometric mean
GSD	geometric standard deviation
LA	license application
NCRP	National Council on Radiation Protection and Measurements
NRCS	Natural Resources Conservation Service
SD	standard deviation
SR	site recommendation
TSPA	total system performance assessment
TWP	technical work plan
USDA	U. S. Department of Agriculture

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1. PURPOSE

This report presents one of the analyses that support the Environmental Radiation Model for Yucca Mountain Nevada (ERMYN). The *Biosphere Model Report* (BSC 2004 [DIRS 169460]) describes the details of the conceptual model as well as the mathematical model and the required input parameters. The biosphere model is one of a series of process models supporting the postclosure Total System Performance Assessment (TSPA) for the Yucca Mountain repository. A schematic representation of the documentation flow for the Biosphere input to TSPA is presented in Figure 1-1. This figure shows the evolutionary relationships among the products (i.e., analysis and model reports) developed for biosphere modeling, and the biosphere abstraction products for TSPA, as identified in the *Technical Work Plan for Biosphere Modeling and Expert Support* (TWP) (BSC 2004 [DIRS 169573]). This figure is included to provide an understanding of how this analysis report contributes to biosphere modeling in support of the license application, and is not intended to imply that access to the listed documents is required to understand the contents of this report.

This report, *Soil-Related Input Parameters for the Biosphere Model*, is one of the five analysis reports that develop input parameters for use in the ERMYN model. This report is the source documentation for the six biosphere parameters identified in Table 1-1. The purpose of this analysis was to develop the biosphere model parameters associated with the accumulation and depletion of radionuclides in the soil. These parameters support the calculation of radionuclide concentrations in soil from on-going irrigation or ash deposition and, as a direct consequence, radionuclide concentration in other environmental media that are affected by radionuclide concentrations in soil.

The analysis was performed in accordance with the TWP (BSC 2004 [DIRS 169573]) where the governing procedure was defined as AP-SIII.9Q, *Scientific Analyses*. This analysis revises the previous version with the same name (BSC 2003 [DIRS 161239]), which was itself a revision of one titled *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [DIRS 152517]). In Revision 00 of this report, the data generated were fixed values (i.e., taking no account of uncertainty and variability). Revision 01 (BSC 2003 [DIRS 161239]) incorporated uncertainty and variability into the values for the bulk density, elemental partition coefficients, average annual loss of soil from erosion, resuspension enhancement factor, and field capacity water content. The current revision of this document improves the transparency and traceability of the products without changing the details of the analysis.

This analysis report supports the treatment of six of the features, events, and processes (FEPs) applicable to the Yucca Mountain reference biosphere (DTN: MO0407SEPFEPLA.000 [DIRS 170760]). The use of the more recent FEP list in DTN: MO0407SEPFEPLA.000 [DIRS 170760] represents a deviation from the detail provided in the TWP (BSC 2004 [DIRS 169573]), which referenced a previous version of the FEP list. The parameters developed in this report support treatment of these six FEPs addressed in the biosphere model that are listed in Table 1-1. Inclusion and treatment of FEPs in the biosphere model is described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.2).

The data developed for the six parameters addressed in this analysis are subsequently used as applicable for inputs to the calculations of the biosphere dose conversion factors (BDCFs) for the biosphere groundwater exposure scenario in the *Nominal Performance Biosphere Dose Conversion Factor Analysis*, and for the volcanic ash exposure scenario in the *Disruptive Event Biosphere Dose Conversion Factor Analysis* as illustrated in Figure 1-1.

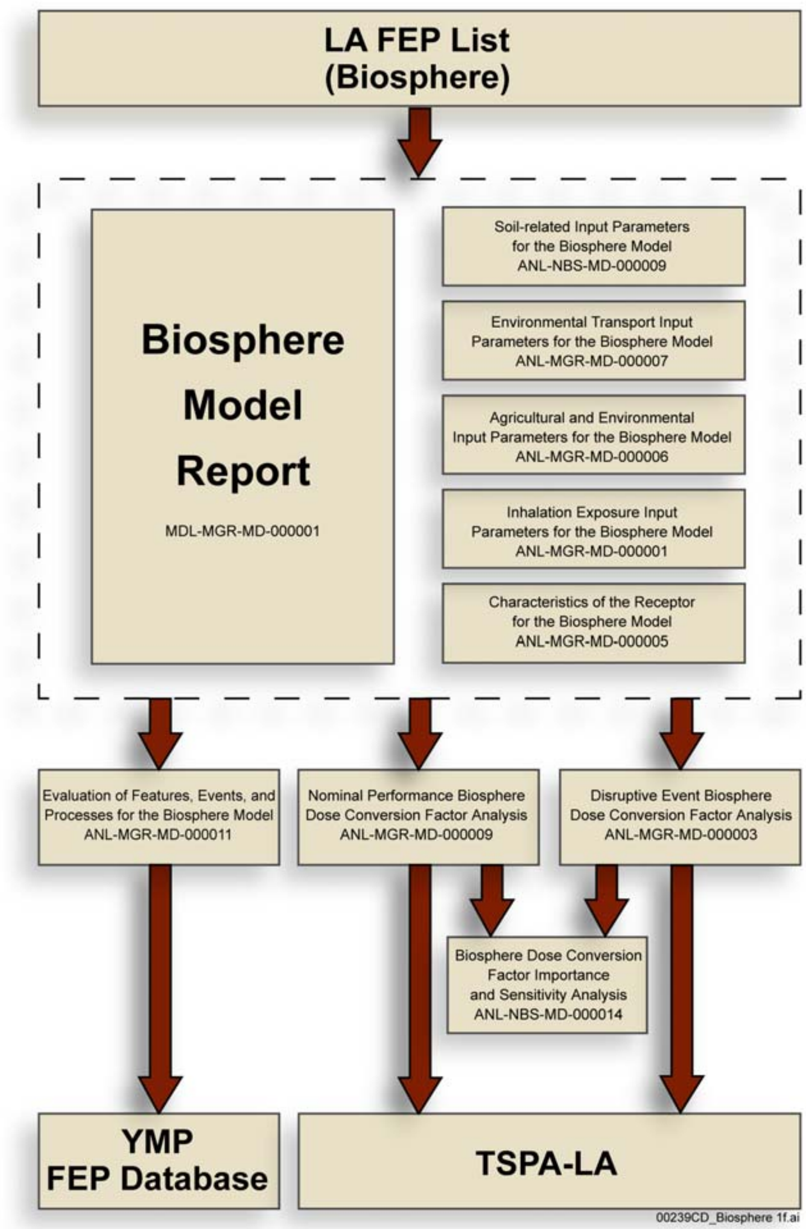

Figure 1-1. Documentation Hierarchy for the Environmental Radiation Model for Yucca Mountain, Nevada

Table 1-1. Parameters and Related Features, Events, and Processes

Parameter(s)	Related FEP [a]	YMP FEP Number	Associated Submodel(s)	Summary of Disposition in TSPA[b]
Soil bulk density	Soil type	2.3.02.01.0A	Soil Air Carbon-14	The treatment of this parameter is described in Sections 4.1.1 and 6.1 and summarized in Section 7.1.1
	Radionuclide accumulation in soils	2.3.02.02.0A		
	Atmospheric transport of contaminants	3.2.10.00.0A		
	Soil and sediment transport in the biosphere	2.3.02.03.0A		
	Plant uptake	3.3.02.01.0A		
Partition coefficient	Radionuclide accumulation in soils	2.3.02.02.0A	Soil	The treatment of this parameter is described in Sections 4.1.2 and 6.2 and summarized in Section 7.1.2
Soil erosion rate	Soil type	2.3.02.01.0A	Soil	The treatment of this parameter is described in Sections 4.1.3 and 6.3 and summarized in Section 7.1.3
	Radionuclide accumulation in soils	2.3.02.02.0A		
	Soil and sediment transport in the biosphere	2.3.02.03.0A		
Enhancement factor for resuspension	Atmospheric transport of contaminants	3.2.10.00.0A	Air	The treatment of this parameter is described in Sections 4.1.4 and 6.4 and summarized in Section 7.1.4
Soil water content at field capacity	Soil type	2.3.02.01.0A	Soil	The treatment of this parameter is described in Sections 4.1.5 and 6.5 and summarized in Section 7.1.5
	Radionuclide accumulation in soils	2.3.02.02.0A		
Ash bulk density	Ashfall	1.2.04.07.0A	Soil Air	The treatment of this parameter is described in Sections 4.1.6 and 6.6 and summarized in Section 7.1.6
	Soil type	2.3.02.01.0A		
	Radionuclide accumulation in soils	2.3.02.02.0A		
	Atmospheric transport of contaminants	3.2.10.00.0A		
	Soil and sediment transport in the biosphere	2.3.02.03.0A		
	Plant uptake	3.3.02.01.0A		

[a] DTN MO0407SEPFEPLA.000 [DIRS 170760].
[b] The effects of the related FEPs are included in the TSPA through the BDCFs. See BSC 2004 [DIRS 169460], Section 6.2 for a complete description of the inclusion and treatment of FEPs in the biosphere model.

Two climate states are considered in this analysis. The present-day conditions, referred to as the present-day climate, are characteristic of the interglacial climate (BSC 2004 [DIRS 170002], Section 6.2) and are characterized by hot, dry summers; warm winters; and low precipitation. The future climate states are represented in this analysis by the upper bound of the glacial transition climate. The glacial transition climate is predicted to persist for the majority of the 10,000-year compliance period (BSC 2004 [DIRS 170002], Table 6-1). The glacial transition climate, referred to as the future climate, is predicted to have cooler, wetter winters and to have warm-to-cool, dry summers relative to current conditions (BSC 2004 [DIRS 170002], Section 6.6.2).

The biosphere model (BSC 2004 [DIRS 169460], Section 6.3.5) was constructed for 28 radionuclides screened in for the TSPA-LA. Consequently, this analysis developed partition coefficient distributions for the 17 elements represented by the 28 radionuclides. The radionuclides considered by the post-closure TSPA for the LA (TSPA-LA) were identified in *Radionuclide Screening* (BSC 2002 [DIRS 160059], Table 13). The screening analysis considered two periods. The first period was from 100 years to 20,000 years and had 13 elements defined. The second period was from 20,000 years to 1,000,000 years for which four additional elements were identified. The time separating these periods is consistent with the intent of TSPA-LA to limit calculations to 20,000 years as defined in the *Total System Performance Assessment-License Application Methods and Approach*, (BSC 2003 [DIRS 166296], Sections 1.3, 8.1, and D.2). Twenty thousand years is the time-period to be used in TSPA-LA to demonstrate performance over and beyond the 10,000 years required for regulatory compliance (BSC 2003 [DIRS 166296], Section 1.3). Only data for those elements defined to be of concern in the initial period of 20,000 years will be used for regulatory compliance and need to be developed under the criteria defined in Section 4.2 of this report.

2. QUALITY ASSURANCE

Development of this report involves analysis of data to support performance assessment as identified in the TWP (BSC 2004 [DIRS 169573]) and thus is a quality affecting activity in accordance with AP-2.27Q, *Planning for Science Activities*. Approved quality assurance procedures identified in the TWP (BSC 2004 [DIRS 169573], Section 4) have been used to conduct and document the activities described in this report. Electronic data used in this analysis were controlled in accordance with the methods specified in the TWP (BSC 2004 [DIRS 169573], Section 8).

The natural barriers and items identified in the *Q-List* (BSC 2004 [DIRS 168361]) are not pertinent to this analysis and a Safety Category per AP-2.22Q, *Classification Analyses and Maintenance of the Q-List* is not applicable.

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3. USE OF SOFTWARE

The only software used during this analysis was the commercial off-the-shelf product Microsoft Excel (Version 97 SR-2). This software was used to confirm calculations performed using a hand calculator and to generate the exponential function values used in the lognormal distributions. The standard functions (logarithm and exponential, average, and standard deviation [SD]) were used to calculate values presented in tables as noted in Section 6.

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4. INPUTS

4.1 DIRECT INPUTS

The list of biosphere model parameters addressed in this analysis, and the sources of direct input used to develop the parameter values, are shown in Table 4.1-1. Descriptions of the direct inputs follow the same order in which the parameters appear in Table 4.1-1.

Table 4.1-1. Sources of Parameter Information Used to Develop the Biosphere Model Input Parameters

Biosphere Model Parameter	Source of Parameter or Data Used to Develop Parameter	Description and Justification
Soil bulk density	Soil bulk density by location - DTN: SN9912USDASOIL.000 [DIRS 142440] This DTN contains three data set discussed in the document. These data sets are: Dollarhide 1999 [DIRS 159253] Hipple 2000 [DIRS 163474] Scheffe 2000 [DIRS 163473]	Section 4.1.1
Partition coefficient	Elemental partition coefficients for four soil types - Sheppard and Thibault 1990 [DIRS 109991], Tables A-1, A-2, A-3, and A-4 Soil texture by local soil series - USDA 1993 [DIRS 160546], pp. 137 to 139	Section 4.1.2
Soil erosion rate	Soil erosion data by type and by state - USDA 2000 [DIRS 160548] Soil loss tolerance indices by location - DTN: SN9912USDASOIL.000 [DIRS 142440] See entry on soil bulk density for components of this DTN Dry deposition velocity - DTN: MO0406SPAETPBM.002 [DIRS 170150] Particle distribution parameters - NCRP (1999 [DIRS 155894], p. 68). Deposition velocity as a function of particle diameter - Sehmel (1984 [DIRS 158693], p. 559) Atmospheric mass loading distributions - DTN: MO0407SPAINEXI.002 [DIRS 170597]	Section 4.1.3
Enhancement factor for resuspension	Enhancement factor for various soil conditions - NCRP 1999 [DIRS 155894], Section 4.2.2	Section 4.1.4
Soil water content at field capacity	Soil water content at field capacity - Allen et al. 1998 [DIRS 157311], Table 19	Section 4.1.5
Ash bulk density	Ash bulk density - DTN: LA0407DK831811.001 [DIRS 170768]	Section 4.1.6

4.1.1 Soil Bulk Density

The data associated with the soils in Amargosa Valley were taken from a database maintained by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (Dollarhide 1999 [DIRS 159253]). To consider climate change in the future, two locations (Hobbs, NM and Spokane, WA) defined in the *Future Climate Analysis* (BSC 2004

[DIRS 170002]) were used because they have present-day climates that are expected to be analogous to the future climate at Yucca Mountain. The data on soils for the analog sites for future climatic conditions were also obtained from the NRCS (Scheffe 2000 [DIRS 163473]; Hipple 2000 [DIRS 163474]). The data from the above three references is included in the qualified DTN: SN9912USDASOIL.000 [DIRS 142440] and is considered established fact.

NRCS is the federal authority on soil surveys in the United States and has held this authority since 1896. As such it can be considered to be the source of established fact data. The mission of the NRCS is to provide leadership to help people conserve and improve the nation's natural resources and environment. Part of this mission is to collect and disseminate agricultural land use data, including physical and chemical data for soils. These data are gathered under stringent standards and serve as a basis for land use management decisions that will lead to "best-use" practices. The soil characterization process by the NRCS is ongoing to reflect advances in soil science, new and more specific soil taxonomy, and the increasing importance of soil use and conservation. The information provided by the NRCS is judged to be technically adequate for the purposes for which it is used in this analysis.

The data for soil characteristics referenced in Table 4.1-1 are suitable for the intended use, i.e., to develop distributions of the soil characteristics for the biosphere model representative of Amargosa Valley and analog sites for future climatic conditions considered in the biosphere model. The data for the Amargosa Valley are site-specific while the data for the analog sites are representative of the future climates predicted to occur in the Yucca Mountain region during the compliance period. The data are presented, discussed, and used in Section 6.1.

4.1.2 Partition Coefficients

By definition, the partition coefficient (K_d) is the ratio of the mass of the solute on the solid phase per unit mass of the solid phase to the concentration of the solute in the solution at equilibrium (Freeze and Cherry 1979 [DIRS 101173], Section 9.2). Synonyms for K_d with this definition include sorption coefficient and distribution coefficient. The dimensions of the K_d are volume per mass, with units typically given in L kg^{-1}. The K_d values are required by the biosphere model to determine the rate of leaching of radionuclides from the surface soil (see discussion in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.4.1.3)).

A review of the literature was conducted in an attempt to find suitable K_d values for the sandy loam-textures soils found in the Amargosa Valley. This data search did not yield values specific to any of the six major soils identified in the region or for similar soils in the vicinity of Yucca Mountain or southern Nevada. However, the distributions of K_ds recommended by Sheppard and Thibault (1990 [DIRS 109991], Table 3) following their extensive literature review are appropriate for the intended use because the recommendations include the generic soil types identified in Section 4.1.1 to be present in the vicinity of Lathrop Wells, Amargosa Valley.

A qualitative description of soil texture was taken from the *National Soil Data Access Facility: Official Soil Series Description* (NSSC 1998 [DIRS 146306]). The quantitative definitions of sands and sandy loams came from the USDA *Soil Survey Manual* (USDA 1993 [DIRS 160546], pp. 137 to 139). Because the NRCS is the organization responsible for the contents of this manual within the USDA, this publication can also be considered the source of established fact data (see discussion of NRCS in Section 4.1.1). This information on soil texture is presented in Section 6.1. The fractional clay content of soils found in the Amargosa Valley came from the same source as the density information provided in Section 4.1.1 (DTN: SN9912USDASOIL.000 [DIRS 142440]). The following factors were considered in the following sections to evaluate the data regarding their suitability and qualify the data for their intended use.

- Reliability of data source and qualification of personnel or organizations generating the data
- Extent to which the data demonstrate the properties of interest
- Prior uses of the data
- Availability of corroborating data

4.1.2.1 Reliability of Data Source and Qualification of the Data Originator

Sheppard and Thibault 1990 [DIRS 109991] – The review report, *Default Soil Solid/Liquid Partition Coefficients, Kds, for Four Major Soil Types: A Compendium*, is an article presenting the results of a review and synthesis of previously published element K_d data for radionuclides of importance in nuclear waste management. The article was published in *Health Physics*, a scientific journal with international distribution. Prior to acceptance for publication, the article was subjected to rigorous scientific/technical peer review. Information extracted from the SciSearch Database of the Institute for Scientific Information revealed that the Sheppard and Thibault (1990 [DIRS 109991]) article had been cited 26 times by other published scientific works by the end of 1999 (Andrews 1999 [DIRS 169528]).

4.1.2.2 Extent to Which the Data Demonstrate the Properties of Interest

The K_d data developed by Sheppard and Thibault (1990 [DIRS 109991]), based on a comprehensive review of previously published data, are considered adequate for representing variability and uncertainty in determining leaching rates. The data included in the source described in Section 4.1.2.1 were used to define the values and distributions of K_ds representative of Amargosa Valley soils. All the relevant data from the reference were used as a basis for the values and distributions of the K_ds. Such a method ensures that the property of interest is adequately represented.

4.1.2.3 Prior Uses of the Data

Sheppard and Thibault (1990 [DIRS 109991]) developed these data for use in the Canadian nuclear waste program. The use of these data in this program is documented in *The Disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment* (Davis et al. 1993 [DIRS 103767], Section 6.5.3).

Other researchers including those at the Nuclear Regulatory Commission's Center for Nuclear Waste Regulatory Analysis, San Antonio, Texas, have used these values for their calculations of leaching coefficients in biosphere modeling for the Yucca Mountain Repository (LaPlante and Poor 1997 [DIRS 101079], p. 2-22).

4.1.2.4 Availability of Corroborating Data

The authors of the cited reference, Sheppard and Thibault (1990 [DIRS 109991]), reviewed and synthesized a comprehensive set of published reports describing K_ds. While this reference was the sole source of input, the parameters characterizing the distributions were developed based on all the applicable data reviewed and included in this report, as described in detail in Section 6.2. This method ensured that all relevant data were included or at least considered.

Based on the ranges of K_ds values presented by Sheppard and Thibault (1990 [DIRS 109991], Tables A-1 through A-4), this parameter exhibits large uncertainty for any nuclide. While some portion of the variability between the results of independent measurements for a given element can be attributed to variation in soil characteristics between the locations of the experimental sites, there is also known to be a significant variability between measurements conducted at specific sites. Local variability of K_ds has been reported in the BIOMASS meetings (BIOMASS 2001 [DIRS 159468], Theme 1, Working Document No. BIOMASS/T1/WD04, Item 36 on page 9), "*It has been shown that measurements of soil K_ds on a single 100 × 150 m^2 field plot produced values ranging up to one order of magnitude for some radionuclides such as zinc, cobalt, cadmium, cerium and ruthenium, and a factor of 3 for critical ones such as caesium* (sic) *and iodine*." Thus, even if the precise location of the receptor were known, it would be expected that any measured K_d would be subject to significant variability over the lands that the receptor may use for agricultural purposes. This variability should be taken into account when modeling the biosphere. The non-location-specific data used here incorporate this variability as they are being synthesized from multiple measurements at multiple locations.

The data presented by Sheppard and Thibault (1990 [DIRS 109991]) are considered qualified for intended use. They are used in Section 6.2.

In addition, equations from *GoldSim, Graphical Simulation Environment, User's Guide* (Golder Associates 2000 [DIRS 146973], p. B-3) for calculation of geometric mean (GM) and geometric standard deviation (GSD) for the lognormal distribution were used to develop distributions of K_ds. These equations describe standard relationships between statistics of the lognormal distribution and can be considered established fact.

4.1.3 Soil Erosion Rate

Soil erosion rate is the parameter that quantifies mass removal of surface soil from a unit surface area per unit time. The distribution of soil erosion rate values for the biosphere model was based on several sources of data described below.

4.1.3.1 Lower Limit of Erosion Rate

The lower limit of erosion rate was estimated in Section 6.3.2 based on a number of direct inputs. The following inputs were used.

The values of atmospheric mass loading were taken from DTN: MO0407SPAINEXI.002. [DIRS 170597]. These values were developed specifically for use in the biosphere model and were appropriate for the development of the erosion rates because they ensured internal consistency between the approaches and parameters used in the biosphere modeling.

The values of the dry deposition velocity were taken from DTN: MO0406SPAETPBM.002 [DIRS 170150]. These values were also developed specifically for the use in the biosphere model with consideration of site specific meteorological and land cover (terrain roughness) conditions and are, therefore, appropriate for the use in development of erosion rates.

The estimate of the GSD of airborne soil particles was obtained from the National Council on Radiation Protection and Measurements (NCRP) Report No. 129 (1999 [DIRS 155894], p. 68).

NCRP 1999 [DIRS 155894] – This NCRP report, *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies*, provides screening approaches, that can be applied to sites where the surface soil is contaminated with radionuclides, to assist with impact evaluation and with making decisions regarding any necessary remediation. The report includes a description of the methods that were used to arrive at the values of screening factors. These methods were chosen such that they are conservative under most conditions, which is consistent with a screening approach. The description of the methods and the pertinent parameters are useful for developing parameter values for the ERMYN biosphere model.

The NCRP is an organization that seeks to formulate and widely disseminate information, guidance and recommendations on radiation protection and measurements and its publications represent the consensus of leading scientific thinking on the topics presented. The NCRP was chartered by the U.S. Congress in 1964 as the National Council on Radiation Protection and Measurements. The Charter of the Council (Public Law 88-376) states that some of its objectives are to:

1. collect, analyze, develop and disseminate in the public interest information and recommendations about (a) protection against radiation (referred to herein as radiation protection) and (b) radiation measurements, quantities and units, particularly those concerned with radiation protection;

2. develop basic concepts about radiation quantities, units and measurements, about the application of these concepts, and about radiation protection;

3. cooperate with the International Commission on Radiological Protection, the Federal Radiation Council, the International Commission on Radiation Units and Measurements, and other national and international organizations, governmental and private, concerned with radiation quantities, units and measurements and with radiation protection.

The NCRP is a non-governmental, not-for-profit, public service organization and has status as an educational and scientific body. The main output of the NCRP are scientific reports with a distribution well exceeding a million copies. The recommendations promulgated by the Council provide the scientific basis for radiation protection efforts throughout the country. Therefore, the NCRP reports can be considered as sources of established fact data.

The data on deposition velocity as a function of particle diameter were taken from a review article titled *Deposition and Resuspension* (Sehmel 1984 [DIRS 158693], pp. 558 to 559). The following factors were considered in the following sections to evaluate the data regarding their suitability and qualify the data for their intended use.

Reliability of data source and qualification of personnel or organizations generating the data–Sehmel wrote a chapter in the book *Atmospheric Science and Power Production* (Randerson 1984 [DIRS 109153]), which is a collection of review articles written by experts on many subjects related to atmospheric science. This publication was prepared for the DOE and provides fundamentals of atmospheric transport, dispersion, chemistry, and removal processes. The book is recommended as a textbook, a handbook, and a guide for university professors and students, as well as for professionals involved in disciplines related to power production and air-quality analysis. It can be considered a reference source. Information from this book used in this analysis report concerns the behavior of aerosols in the outdoor environment with emphasis on dry deposition of particulates.

Extent to which the data demonstrate the properties of interest–Graphical representations of predicted deposition velocities (Sehmel 1984 [DIRS 158693], pp. 558 to 559) were used to develop the distribution function of deposition velocity for the biosphere model. These graphs represent deposition velocity as a function of particle diameter for different values of friction velocity, terrain roughness, and particle density. Roughness height depends on the type of surface. Because the deposition velocity is used in the biosphere model to calculate contaminant deposition on crop surfaces, the values of surface roughness representative of the fully grown crops, equal to 9 cm to 14 cm (long grass, fully grown crops) (NCRP 1984 [DIRS 103784], p. 48) is adequate for the intended purpose. The friction velocity depends on the surface cover and the wind speed.

4.1.3.2 Upper Limit of Erosion Rate

The tolerable soil loss rate provided by Dollarhide (1999 [DIRS 159253]) for Amargosa Valley soils established the upper limit of erosion rates for sustainable agricultural production. These data were supplemented by the USDA data taken from the *Summary Report 1997 National Resources Inventory* (*Revised December 2000)* (USDA 2000 [DIRS 160548], Tables 10 and 11), which were used to confirm upper limits of annual erosion rate. This reference provides the annual average rates for (a) wind and (b) sheet and rill erosion for different types of cropland and for pastureland for the States of Nevada, New Mexico, and Washington. Values from New Mexico and Washington are appropriate because the future climate analog sites, Hobbs and Spokane, respectively, are located in those states (BSC 2004 [DIRS 170002], Table 6-1). The erosion values of interest to this work are those averaged over long periods and several generations of farmers. Thus, it is considered that the published state-averaged data are sufficiently accurate for the purpose in which they are used in this analysis.

The USDA *National Resources Inventory* (USDA 2000 [DIRS 160548]), being controlled by the NRCS can, for the reasons outlined in Section 4.1.1, be considered a source of established fact data.

The values of state-average wind, as well as sheet and rill, erosion rates are presented, and their application for calculation of the upper limit of erosion rate is described, in Section 6.3.3.

4.1.4 Enhancement Factor for Resuspension

The values of the enhancement factor were developed based on the data from the NCRP (NCRP 1999 [DIRS 155894]). The reports of NCRP can be considered as sources of established fact data, as described in the previous section. The data on the enhancement factor are presented, described, and used in Section 6.4.

Some of the data on resuspension reported by the NCRP were obtained at the Nevada Test Site and as such can be considered site specific. These data were supplemented with data from other locations. While not site-specific, these data were collected on cultivated lands and are therefore considered more use-specific. The stated intent of this report (NCRP 1999 [DIRS 155894]), a screening analysis, is to provide limits that can be applied to sites where the surface soil is contaminated with radionuclides. The screening limits are calculated using methods that are chosen to be conservative under most conditions to allow the performance of site assessments to determine the significance of any radionuclide contamination. In the absence of more detailed and specific data, the use of the recommended data will allow reasonable estimates to be made regarding regulatory compliance. Thus, these data are considered adequate for the intended purpose, i.e., to develop parameter values for the biosphere model. The data are used in Section 6.4.

4.1.5 Soil Water Content at Field Capacity

The distribution of the water content at field capacity values was estimated using the data from *Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements* (Allen et al. 1998 [DIRS 157311], Table 19). The description of this reference and the factors considered in determining the appropriateness of these data for development of parameter values for the biosphere model are presented below.

4.1.5.1 Reliability of Data Source and Qualification of the Data Originator

Allen et al. 1998 [DIRS 157311] – *Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements* is a publication by the Food and Agriculture Organization of the United Nations (FAO). The FAO is one of the largest specialized agencies in the United Nations system and the lead agency for agriculture and rural development. It is considered a source of established fact data. Included in its many functions are collection, analysis, interpretation, and dissemination of information relating to nutrition, food, agriculture, forestry, and fisheries. The FAO serves as a clearing-house, providing farmers, scientists, government planners, traders and non-governmental organizations with the information they need to make rational decisions on planning, investment, marketing, research, and training. A series of *Irrigation and Drainage Papers* was written by experts in the various related fields of study and published by the FAO.

Crop Evapotranspiration (Allen et al. 1998 [DIRS 157311], FAO Irrigation and Drainage Paper 56) describes comprehensive guidelines for determining crop water requirements.

4.1.5.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included by Allen et al. (1998 [DIRS 157311], Table 19) were used to define the values and distributions of soil water content at field capacity in four soil types, including the type (sandy loam) that is representative of Amargosa Valley. All the relevant data from this reference was used as a basis for the values and distributions of the soil water content. Such a method ensures that the property of interest is adequately represented.

4.1.5.3 Availability of Corroborating Data

Baes and Sharp (1983 [DIRS 109606], p. 20) made recommendations on the soil water content at field capacity. This recommendation for sandy loam (mid-point value of 0.23) is the same as the mid-point value given in the reference described in the preceding sections (Allen et al. 1998 [DIRS 157311], Table 19) and used in this analysis.

The site specific data provided in the *United States Department of Agriculture Soil Survey Data - Lathrop Wells Area* (Dollarhide 1999 [DIRS 159253]) include values of the available water capacity by soil type. The range of values for this parameter that can be used to corroborate the values used for the soil water content at field capacity. The available water capacity is defined as the quantity of water that the soil can store for use by plants. It should be noted that because of physical forces that bind water to soil, not all the water present in soil is available for use by plants. Allen et al. (1998 [DIRS 157311], Eq. 82, p. 162) give the relationship between the available water capacity and field capacity. The available water content is the water content at field capacity less the water content at the plant wilting point. This latter parameter is a measure of the soil water content that the plant is unable to avail itself of.

The range of values of site specific available water content for the soils of interest is given by Dollarhide (1999 [DIRS 159253]) as embracing a range of 0.04 to 0.13. Allen et al. (1998 [DIRS 157311], Table 19) provide the expected generic range of soil water capacity at wilting point (crop dependent) of 0.06 to 0.16 for sandy loams. The site specific related data is consistent with the data for the water content at field capacity used in this analysis.

The data are used in Section 6.5.

4.1.6 Ash Bulk Density

The bulk density of ash is taken from DTN: LA0407DK831811.001 [DIRS 170768]. In this data set, the bulk density of settled ash is 1,000 kg m^{-3} (1.0 g cm^{-3}). This value was used in the calculations related to waste-form concentrations in ash released from a vent and deposited at the location of the receptor. It is also appropriate for its intended use in the biosphere model. The data are further described in Section 6.6.

4.1.7 Units

Data presented in reports issued by U.S. Government Departments, including the USDA, are generally given in Imperial units. As an aid to the reader, Imperial to SI conversion factors used in the agricultural area are presented in Table 4.1-2.

Table 4.1-2. Imperial to Metric Conversion Factors

To convert		
From	**To**	**Multiply by**
Acres	Hectares (10^4 m^2)	0.405
Tons	Metric tons (10^3 kg)	0.907
Tons per acre	Metric tons per hectare	2.24

Source: USDA 2000 [DIRS 160548], p. 8.

4.2 CRITERIA

Applicable requirements from the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 2-3) are presented in Table 4.2-1. These project requirements are for compliance with applicable portions of 10 CFR 63 [DIRS 156605].

Table 4.2-1. Requirements Applicable to this Analysis

Requirement Number	Requirement Title	Related Regulation
PRD-002/T-015	Requirements for Performance Assessment	10 CFR 63.114
PRD-002/T-026	Required Characteristics of the Reference Biosphere	10 CFR 63.305
PRD-002/T-028	Required Characteristics of the Reasonably Maximally Exposed Individual	10 CFR 63.312

Source: Canori and Leitner (2003 [DIRS 163275], Table 2-3).

Listed below are the acceptance criteria from the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) that are applicable to this analysis. The list is based on meeting the requirements of 10 CFR 63.114, 10 CFR 63.305, and 10 CFR 63.312 [DIRS 156605], that relate in whole or in part to this analysis.

<u>Acceptance Criteria from Section 2.2.1.3.13: Redistribution of Radionuclides in Soil</u>

Acceptance Criterion 2: Data are Sufficient for Model Justification

(1) Behavioral, hydrological, and geochemical values used in the license application are adequately justified (e.g., irrigation and precipitation rates, erosion rates, radionuclide solubility values, etc.). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

(2) Sufficient data (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of redistribution of radionuclides in soil in the total system performance assessment.

Acceptance Criterion 3: Data Uncertainty is Characterized and Propagated Through the Model Abstraction

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, do not result in an under-representation of the risk estimate, and are consistent with the characteristics of the reasonably maximally exposed individual in 10 CFR Part 63.

(2) The technical bases for the parameter values and ranges in the total system performance assessment abstraction are consistent with data from the Yucca Mountain region, e.g., Amargosa Valley survey studies of surface processes in the Fortymile Wash drainage basin; applicable laboratory testings; natural analogs; or other valid sources of data. For example, soil types, crop types, plow depths, and irrigation rates should be consistent with current farming practices, and data on the airborne particulate concentration should be based on the resuspension of appropriate material in a climate and level of disturbance similar to that which is expected to be found at the location of the reasonably maximally exposed individual, during the compliance time period.

(3) Uncertainty is adequately represented in parameters for conceptual models, process models, and alternative conceptual models considered in developing the total system performance assessment abstraction of redistribution of radionuclides in soil, either through sensitivity analyses, conservative limits, or bounding values supported by data, as necessary. Correlations between input values are appropriately established in the total system performance assessment.

<u>Acceptance Criteria from Section 2.2.1.3.14: Biosphere Characteristics</u>

Acceptance Criterion 1: System Description and Model Integration are Adequate

(3) Assumptions are consistent between the biosphere characteristics modeling and other abstractions. For example, the U.S. Department of Energy should ensure that the modeling of features, events, and processes, such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumption in other total system performance assessment abstractions.

Acceptance Criterion 2: Data are Sufficient for Model Justification

(1) The parameter values used in the license application are adequately justified (e.g., behaviors and characteristics of the residents of the Town of Amargosa Valley, Nevada, characteristics of the reference biosphere, etc.) and consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

(2) Data are sufficient to assess the degree to which features, events, and processes related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63, the U.S. Department of Energy should demonstrate that features, events, and processes, which describe the biosphere, are consistent with present knowledge of conditions in the region, surrounding Yucca Mountain. As appropriate, the U.S. Department of Energy sensitivity and uncertainty analyses (including consideration of alternative conceptual models) are adequate for determining additional data needs, and evaluating whether additional

data would provide new information that could invalidate prior modeling results and affect the sensitivity of the performance of the system to the parameter value or model.

Acceptance Criterion 3: Data Uncertainty is Characterized and Propagated Through the Model Abstraction

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, do not result in an under-representation of the risk estimate, and are consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63.

(2) The technical bases for the parameter values and ranges in the abstraction, such as consumption rates, plant and animal uptake factors, mass-loading factors, and biosphere dose conversion factors, are consistent with site characterization data, and are technically defensible.

(4) Uncertainty is adequately represented in parameter development for conceptual models and process-level models considered in developing the biosphere characteristics modeling, either through sensitivity analyses, conservative limits, or bounding values supported by data, as necessary. Correlations between input values are appropriately established in the total system performance assessment, and the implementation of the abstraction does not inappropriately bias results to a significant degree.

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulations other than those identified in the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 2-3) and determined to be applicable (Table 4.2-1) were used in this analysis.

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5. ASSUMPTIONS

5.1 UNDEFINED STANDARD DEVIATIONS FOR THE PARTITION COEFFICIENT DISTRIBUTIONS

The data defining the parameters for the lognormal distribution of the K_ds are from Sheppard and Thibault (1990 [DIRS 109991], Tables 3, A-1, A-2, A-3, and A-4). For some soil types (sandy or loamy) and some elements of interest for the compliance period (carbon, actinium, protactinium, and thorium) there were insufficient data available for the authors to define a SD of the logarithm of the K_d. In those cases where the SD is not provided, the mean value of the logarithm of the K_d still provides an estimate for the K_d value. However, the use of a single value for a given K_d would not meet the requirement to incorporate the necessary variability and uncertainty. In these cases it was assumed that the SD of the logarithm of the K_d could be approximated by the mean of the SDs of the logarithm of the K_ds for elements where data are available. This assumption is used in Section 6.2 to generate the parameters required to define the lognormal distribution representing the variability and uncertainty of the K_ds.

This assumption is reasonable as it attributes an average uncertainty about a measured mean of the logarithm of the K_d. Using an average value for this SD allows reasonable uncertainty and variability associated with this parameter to be propagated through the biosphere model. This is a more realistic approach than using a fixed value while not attributing too little or excessive uncertainty to the parameter.

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6. SCIENTIFIC ANALYSIS DISCUSSION

The processes within the ERMYN biosphere model that are supported by this analysis are those representing radionuclide transport mechanisms associated with soil. To capture uncertainty within ERMYN, this analysis develops the distributions of numerical values for parameters related to soil. After identifying specific elements of interest for the biosphere model, the subsequent sections develop soil-related parameter distributions and define parameters for various environmental transport pathways related to radionuclide transport in soil. The distributions for soil bulk density, element-specific soil solid/liquid partition coefficients (K_ds), erosion rate, enhancement factors, and soil water content at field capacity are developed in Sections 6.1, 6.2, 6.3, 6.4, and 6.5, respectively. Section 6.6 identifies the source of, and presents the value of, ash bulk density that is recommended for use in TSPA-LA in the context of its impact on soil properties, but does not develop this parameter. Equations indicating where these soil-related parameters are used as inputs to environmental transport models were taken from the *Biosphere Model Report* (BSC 2004 [DIRS 169460]).

The K_ds are the only element specific parameters developed in this analysis. The biosphere model was constructed for radionuclides screened in for the TSPA-LA (BSC 2004 [DIRS 169460], Section 6.3.5). This list of radionuclides is used in the analysis to identify the elements for which K_ds are required. Elements identified as being potentially important to TSPA for time up to 20,000 years are: actinium (Ac), americium (Am), carbon (C), cesium (Cs), iodine (I), neptunium (Np), protactinium (Pa), plutonium (Pu), radium (Ra), strontium (Sr), technetium (Tc), thorium (Th), and uranium (U). Additional elements identified as also being potentially important to TSPA for times beyond 20,000 years are chlorine (Cl), lead (Pb), selenium (Se), and tin (Sn). To avoid placing artificial constraints on TSPA calculations, K_d distributions were generated for all of these elements.

The analysis considers two human exposure scenarios: groundwater and volcanic ash. The distributions for the five soil-related parameters developed in this report are representative of environmental conditions expected under present-day and future climates for the Amargosa Valley. In this analysis it is assumed that climate changes predicted for the Yucca Mountain region (BSC 2004 [DIRS 170002]) will not affect the soil types for predicting the soil behavior. The rationale for this assumption is as follows.

The climates to be considered are defined to be either arid or semi-arid (10 CFR 63.305(d) [DIRS 156605]). Temperatures are predicted to be lower for the glacial transition period, and therefore thermally activated processes of soil generation will be retarded. Also, the fraction of organic matter in coarse textured soil at the analog sites (DTN: SN9912USDASOIL.000 [DIRS 142440]; Scheffe 2000 [DIRS 163473]; Hipple 2000 [DIRS 163474]) is generally in the range 0 to 3 percent for Hobbs, and up to 4 percent for Spokane. These values are representative of the sandy and sandy-loam K_d data given in Section 6.2 (i.e., much less than the 30 percent organic matter required for classification of organic soils). In addition, clay contents of the representative soils (3 to 18 percent for Amargosa Valley, less than 35 percent for Hobbs, and generally less than 20 percent for Spokane) (DTN: SN9912USDASOIL.000 [DIRS 142440]; Scheffe 2000 [DIRS 163473]; Hipple 2000 [DIRS 163474]) are within the loam category used for the K_ds grouping. The expected variability of soil parameters, especially K_ds where variability can readily extend over an order of magnitude, are considered to adequately incorporate changes in parameter values arising from soil evolution processes.

6.1 SOIL BULK DENSITY

The soil bulk density, ρ, is one of the parameters that describes the physical characteristics of the surface soil. This parameter is used in several parts of the surface soil submodel of the biosphere model. It is used to calculate the areal density of surface soil, a parameter used in calculating atmospheric activity concentrations from soil resuspension. The areal density is calculated by using the following relation (BSC 2004 [DIRS 169460], Equation 6.4.1-6):

$$\rho_s = \rho \times d \qquad \text{(Eq. 6-1)}$$

where

ρ_s = areal density of surface soil (kg m^{-2})
ρ = bulk density of surface soil (kg m^{-3})
d = depth of surface soil (m).

Soil bulk density is also required to determine the leaching removal constant, λ_l, of radionuclides from surface soil as a result of overwatering. The relationship used in the biosphere model for this process is (BSC 2004 [DIRS 169460], Equation 6.4.1-10):

$$\lambda_l = \frac{OW}{d \times \theta \left(1 + \frac{\rho \times K_d}{\theta}\right)} \qquad \text{(Eq. 6-2)}$$

where

OW = the crop overwatering rate (m y^{-1})
θ = the water content of soil at field capacity (dimensionless)
K_d = the solid/liquid partition coefficient for the radionuclide in surface soil (m^3_{liquid} kg_{solid}^{-1}).

The third use of the bulk density parameter is in determining the surface soil erosion removal constant, λ_e, as discussed in Section 6.4.1.4 of the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Equation 6.4.1-11).

$$\lambda_e = \frac{ER}{\rho \times d} \qquad \text{(Eq. 6-3)}$$

where

ER = Annual average erosion rate per unit area for surface soil (kg m^{-2} y^{-1})

The NRCS soil data (DTN: SN9912USDASOIL.000 [DIRS 142440]) identified nine soil series as being present in the Amargosa Valley region. The location of the regulatory receptor is specified as being the accessible environment above the highest concentration of radionuclides in the plume of contamination (10 CFR 63.312(a) [DIRS 156605]). Due to the stochastic nature of the TSPA-LA calculations, there will always be some uncertainty associated with location of the receptor and, therefore, of the soil characteristics that are applicable. To allow for this uncertainty, a set of possible soil series was considered from the list provided by the NRCS. The series used for the analysis were identified by the map symbol provided in the soil map of the Amargosa Valley (CRWMS M&O 1999 [DIRS 107736], Figure 1, pp. 2 to 3) as being approximately south of the repository. Table 6.1-1 provides a summary of soil types and thickness of soil layers of interest to agriculture and horticulture (for each soil series the values are given for the thicknesses of the two uppermost soil layers). Table 6.1-2 provides the particle-size class and texture of the surface horizon for the soil series included in Table 6.1-1. Table 6.1-3 summarizes the bulk density and other characteristics of the soil type of interest. It should be noted that density is given as the *moist bulk density*, which is defined by Dollarhide (1999 [DIRS 159253], p. 3 of 5) as being the oven dry weight of soil per unit volume sampled at field capacity of moisture. Thus the parameter represents the actual soil content (i.e., solids excluding water) measured under conditions prevailing in irrigated fields and, as such, is the appropriate parameter to represent soil density.

The densities of the two uppermost layers of interest to agriculture of each soil type considered are provided in Table 6.1-3. Values in Table 6.1-1 and identified above as being appropriate soil candidates indicate these two layers extend from a depth of approximately 0.35 m (14 inches for Commski) up to 1.5 m (60 inches for Arizo and Yermo). From the report *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673], Table 7.1-1), this minimum thickness is greater than the maximum tillage depth considered. Therefore, the density data in Table 6.1-3 can form the basis to estimate the moist bulk density of the soil.

Table 6.1-1. Soil Types and Depths

Map Symbol	Soil Name	Depth (in)	
		Upper	Lower
2054	Yermo	0	6
		6	60
	Arizo	0	8
		8	60
2070	Shamock	0	4
		4	37
2030	Corbilt	0	4
		4	32
2451	Sanwell	0	9
		9	16
	Yermo	0	6
		6	60
2153	Arizo	0	8
		8	60
	Corbilt	0	4
		4	32
	Commski	0	5
		5	14

Sources: DTN: SN9912USDASOIL.000 [DIRS 142440]; Dollarhide (1999 [DIRS 159253]); CRWMS M&O (1999 [DIRS 107736], Figure 1, pp. 2 to 3).

Table 6.1-2. Soil Texture by Soil Type

Soil Series	Soil Texture
Arizo	Very gravelly fine sand [a]
Corbilt	Gravelly fine sandy loam [b]
Shamock	Gravelly fine sandy loam [b]
Yermo	Cobbly sandy loam [b]
Commski	Very gravelly fine sandy loam [b]
Sanwell	Gravelly fine sandy loam [b]

Source: Soil textures from NSSC (1998 [DIRS 146306]); soil texture definitions from the *Soil Survey Manual* (USDA 1993 [DIRS 160546], pp. 137 to 139).

[a] Sands – More than 85% sand, the percentage of silt plus 1.5 times the percentage of clay is less than 15.
[b] Sandy loams – 7 to 20% clay, more than 52% sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7% clay, less than 50% silt, and more than 43% sand.

Table 6.1-3. Soil Characteristics by Soil Type

	Clay Content Range [a]		Moist Bulk Density Range [a]		Organic Matter		
	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Max	T Factor [b]	Wind Erodibility Group
Soil Name	(%)		($g\ cm^{-3}$)		(%)	tons $acre^{-1}yr^{-1}$	
Arizo	5	12	1.40	1.55	0.5	5	5
	0	5	1.45	1.65			
Corbilt	5	10	1.35	1.50	0.5	4	4
	5	10	1.35	1.55			
Shamock	3	8	1.50	1.70	0.8	2	4
	5	10	1.55	1.70			
Yermo	8	18	1.40	1.60	0.5	5	5
	8	18	1.40	1.60			
Commski	10	18	1.40	1.60	0.5	5	5
	5	15	1.40	1.60			
Sanwell	5	10	1.40	1.60	0.5	5	4
	5	10	1.30	1.50			

Sources: DTN: SN9912USDASOIL.000 [DIRS 142440]; Dollarhide (1999 [DIRS 159253]).

[a] The values are given for the two uppermost layers of interest to agriculture where the thicknesses are given in Table 6.1-1.

[b] T Factor is an estimate of the maximum average annual rate of soil erosion by wind or water that can occur without affecting crop productivity over a sustained period (Troeh et al. 1980 [DIRS 110012], Section 6-1). The rate is in tons per acre per year. This parameter is only applicable to the surface layer that is available for erosion.

From inspection of the density values in Table 6.1-3, the lower and upper values of soil density were 1.3 $g\ cm^{-3}$ and 1.7 $g\ cm^{-3}$ respectively. For stochastic modeling, it is recommended that the distribution of density be triangular over this range with a mode at the mid-point 1.5 $g\ cm^{-3}$. However, if a deterministic value is required, then the moist soil density can be taken as 1.5 $g\ cm^{-3}$ (the mid-point of the range).

It should be noted that the bulk density ranges for the soils provided by Dollarhide (1999 [DIRS 159253]; DTN: SN9912USDASOIL.000 [DIRS 142440]) but not used in Table 6.1-3 are consistent with the data used. This indicates that the moist bulk density ranges for Amargosa Valley soils are not sensitive to actual texture. The use of all data supplied by Dollarhide (1999 [DIRS 159253]) would not change the estimates of the range or distribution of the moist bulk density parameter.

The distribution of the soil bulk density values for the future climate is the same as that for the present-day climate, as discussed in the beginning of Section 6. The data for the future analog sites support the use of the same range of density values (DTN: SN9912USDASOIL.000 [DIRS 142440]; Scheffe 2000 [DIRS 163473]).

6.2 PARTITION COEFFICIENT

Information on the soils near the expected location of the receptor is presented in Section 6.1. The objective of this section is to identify appropriate distributions with their parameters for the elemental K_ds for the range of soils found in the Amargosa Valley. Partition coefficients are used in the biosphere model for the groundwater exposure scenario (BSC 2004 [DIRS 169460], Equation 6.4.1-10) to calculate the leaching rate as given in equation 6-2.

The element specific K_ds used in this analysis are those recommended by Sheppard and Thibault (1990 [DIRS 109991]) and presented in their Tables A-1, A-2, A-3, and A-4 for sandy soil, loamy soil, clayey soil, and organic soil respectively.

It should be noted that the biosphere model does not use K_d data that were used in analyses conducted for either the unsaturated zone or the saturated zone. The K_ds used to calculate BDCFs are applicable to surface soils and differ from the coefficients used to model the transport of radionuclides through the saturated and unsaturated zones. This was done because the sorptive properties of the media in the geosphere (e.g., tuffaceous rocks and alluvium) and the geochemical environment differ from those of the surface soil in the biosphere.

Tables 6.2-1 through 6.2-4 provide K_d data for the four soil textures as given by Sheppard and Thibault (1990 [DIRS 109991]) and the 17 elements defined to be of interest to TSPA in the beginning of Section 6.

Table 6.2-1. Element Specific Partition Coefficients for Sandy Soil

Element	Number of Observations	λ [a]	ζ [b]	Measured Range	
				Minimum	Maximum
		ln(L kg^{-1})	ln(L kg^{-1})	(L kg^{-1})	(L kg^{-1})
Actinium (Ac)	0	6.1 [c]			
Americium (Am)	29	7.6	2.6	8.2	300000
Carbon (C)	3	1.1	0.8	1.7	7.1
Chlorine (Cl)	0				
Cesium (Cs)	81	5.6	2.5	0.2	10000
Iodine (I)	22	0.04	2.2	0.04	81
Neptunium (Np)	16	1.4	1.7	0.5	390

Table 6.2-1. Element Specific Partition Coefficients for Sandy Soil (Continued)

Element	Number of Observations	λ [a]	ζ [b]	Measured Range	
				Minimum	Maximum
		ln(L kg^{-1})	ln(L kg^{-1})	(L kg^{-1})	(L kg^{-1})
Protactinium (Pa)	0	6.3 [c]			
Lead (Pb)	3	5.6	2.3	19	1405
Plutonium (Pu)	39	6.3	1.7	27	36000
Radium (Ra)	3	6.2	3.2	57	21000
Selenium (Se)	3	4.0	0.4	36	70
Tin (Sn)	0	4.9 [c]			
Strontium (Sr)	81	2.6	1.6	0.05	190
Technetium (Tc)	19	-2.0	1.8	0.01	16
Thorium (Th)	10	8.0	2.1	207	150000
Uranium (U)	24	3.5	3.2	0.03	2200

Source: Sheppard and Thibault (1990 [DIRS 109991], Table A-1).

[a] λ is the mean of the natural logarithms of the observed values.
[b] ζ is the standard deviation (SD) of the natural logarithms of the observed values.
[c] Default values for λ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported as detailed by Sheppard and Thibault (1990 [DIRS 109991], p. 472).

Table 6.2-2. Element Specific Partition Coefficients for Loamy Soil

Element	Number of Observations	λ [a]	ζ [b]	Measured Range	
				Minimum	Maximum
		ln(L kg^{-1})	ln(L kg^{-1})	(L kg^{-1})	(L kg^{-1})
Actinium (Ac)	0	7.3 [c]			
Americium (Am)	20	9.2	1.4	400	48309
Carbon (C)	0	2.9 [c]			
Chlorine (Cl)	0				
Cesium (Cs)	54	8.4	1.3	560	61287
Iodine (I)	33	1.5	2.0	0.1	43
Neptunium (Np)	11	3.2	1.2	1.3	79
Protactinium (Pa)	0	7.5 [c]			
Lead (Pb)	3	9.7	1.4	3500	59000
Plutonium (Pu)	21	7.1	1.2	100	5933
Radium (Ra)	3	10.5	3.1	1262	530000
Selenium (Se)	1	5.0			
Tin (Sn)	0	6.1 [c]			
Strontium (Sr)	43	3.0	1.7	0.01	300
Technetium (Tc)	10	-2.3	1.1	0.01	0.4
Thorium (Th)	0	8.1 [c]			
Uranium (U)	8	2.5	3.3	0.2	4500

Source: Sheppard and Thibault (1990 [DIRS 109991], Table A-2).

[a] λ is the mean of the natural logarithms of the observed values.
[b] ζ is the standard deviation (SD) of the natural logarithms of the observed values.
[c] Default values for λ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported as detailed by Sheppard and Thibault (1990 [DIRS 109991], p. 472).

Table 6.2-3. Element Specific Partition Coefficients for Clayey Soil

Element	Number of Observations	λ [a]	ζ [b]	Measured Range	
				Minimum	Maximum
		ln(L kg^{-1})	ln(L kg^{-1})	(L kg^{-1})	(L kg^{-1})
Actinium (Ac)	0	7.8 [c]			
Americium (Am)	11	9.0	2.6	25	400000
Carbon (C)	0	0.8 [c]			
Chlorine (Cl)	0				
Cesium (Cs)	28	7.5	1.6	37	31500
Iodine (I)	8	0.5	1.5	0.2	29
Neptunium (Np)	4	4.0	3.8	0.4	2575
Protactinium (Pa)	0	7.9 [c]			
Lead (Pb)	0	6.3 [c]			
Plutonium (Pu)	18	8.5	2.1	316	190000
Radium (Ra)	8	9.1	1.3	696	56000
Selenium (Se)	14	4.7	0.5	36	246
Tin (Sn)	0	6.5 [c]			
Strontium (Sr)	24	4.7	2.0	3.6	32000
Technetium (Tc)	4	0.2	0.06	1.16	1.32
Thorium (Th)	5	8.6	2.6	244	160000
Uranium (U)	7	7.3	2.9	46	3951000

Source: Sheppard and Thibault (1990 [DIRS 109991], Table A-3).

[a] λ is the mean of the natural logarithms of the observed values.
[b] ζ is the standard deviation (SD) of the natural logarithms of the observed values.
[c] Default values for λ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported as detailed by Sheppard and Thibault (1990 [DIRS 109991], p. 472).

Table 6.2-4. Element Specific Partition Coefficients for Organic Soil

Element	Number of Observations	λ [a]	ζ [b]	Measured Range	
				Minimum	Maximum
		ln(L kg^{-1})	ln(L kg^{-1})	(L kg^{-1})	(L kg^{-1})
Actinium (Ac)	0	8.6 [c]			
Americium (Am)	5	11.6	1.7	6398	450000
Carbon (C)	0	4.2 [c]			
Chlorine (Cl)	0				
Cesium (Cs)	9	5.6	3.6	0.4	145000
Iodine (I)	9	3.3	2.0	1.4	368
Neptunium (Np)	3	7.1	0.4	857	1900
Protactinium (Pa)	0	8.8 [c]			
Lead (Pb)	6	10.0	0.5	9000	31590
Plutonium (Pu)	7	7.5	2.6	60	62000
Radium (Ra)	0	7.8 [c]			
Selenium (Se)	4	5.1	0.5	105	310
Tin (Sn)	0	7.4 [c]			

Table 6.2-4. Element Specific Partition Coefficients for Organic Soil (Continued)

Element	Number of Observations	λ [a]	ζ [b]	Measured Range	
				Minimum	Maximum
		ln(L kg^{-1})	ln(L kg^{-1})	(L kg^{-1})	(L kg^{-1})
Strontium (Sr)	12	5.0	1.8	8	4800
Technetium (Tc)	24	0.4	1.8	0.02	340
Thorium (Th)	3	11.4	4.6	1579	1.30E+07
Uranium (U)	6	6.0	2.5	33	7350

Source: Sheppard and Thibault (1990 [DIRS 109991], Table A-4).

[a] λ is the mean of the natural logarithms of the observed values.

[b] ζ is the standard deviation (SD) of the natural logarithms of the observed values.

[c] Default values for λ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported as detailed by Sheppard and Thibault (1990 [DIRS 109991], p. 472).

Sheppard and Thibault (1990 [DIRS 109991], p. 471) defined their texture categories of soil as follows.

> "The mineral soils were categorized by texture into sand, clay, and loam. The soils that contained ≥ 70 percent sand-sized particles were classified as sand soils, and those containing ≥ 35 percent clay-sized particles were classified as clay soils. Loam soils had an even distribution of sand-, clay-, and silt-sized particles or consisted of up to 80 percent silt-sized particles. Organic soils contained > 30 percent organic matter and were either classic peat or muck soils, or the litter horizon of a mineral soil."

Inspection of Tables 6.2-1 through 6.2-4 indicates that, for a given element and a given soil, the measured range of the K_d is large, in many cases spanning several orders of magnitude. While a large portion of the variability between the results of independent measurements can be attributed to soil variation between the experimental locations, there is also known to be appreciable variability at specific sites, as discussed in Section 4.1.2.4. Thus even if the precise location of the receptor were known, it would be expected that any measured K_d would be subject to significant variability over an irrigated field. This variability should be taken into account when assessing biosphere modeling. The use a broad distribution for the K_ds ensures this variability is taken into account

The authors of the review article from which the values were obtained (Sheppard and Thibault 1990 [DIRS 109991], p. 472) indicated that K_ds are lognormally distributed. Therefore, they elected to derive the mean and standard deviation of the logarithm of the parameter. Thus, in the absence of site-specific data, it was assumed that the lognormal distribution is appropriate for the K_d. In other words, for given elements and soils, the uncertainty and variability in K_d distributions can be represented by lognormal distributions.

As noted previously, for a given element and soil, the measured range of the K_d is large, in many cases spanning several orders of magnitude (Tables 6.2-1 to 6.2-4). The use of the lognormal distribution can only be considered an approximation because no statistical justification was provided for universally using this distribution, other than that such a distribution can embrace a wide range of non-negative values. Justification of a particular distribution is a potential concern especially for elements with few reported measurements of the K_d. The lognormal distribution is consistent with observations and captures the large degree of variability known to exist in K_d values.

No attempt was made in this analysis to derive any time dependency of the K_ds. Instead, it was assumed that for a given radionuclide and soil type, the K_d is not a function of time. Sheppard and Thibault (1990 [DIRS 109991]) stated that if a researcher reported a time series of K_d values, they used only the K_d values for the longest time because those values would most closely approximate equilibrium (i.e., late time) conditions (Sheppard and Thibault 1990 [DIRS 109991], p. 472). The use of the K_d for the longest time period is the best representation of the long periods of continuing irrigation to be modeled. Furthermore the mathematical model of the leaching process used in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.4.1.3) is consistent with the use of a constant leaching removal rate, which implies that a time independent K_d is appropriate.

The maximum organic matter content for Amargosa Valley soils is less than 0.8 percent (Table 6.1-3), and therefore the native soils are not classified as organic in texture (i.e., they do not contain more than 30 percent organic matter). As a result the data in Table 6.2-4 are not applicable to the Amargosa Valley. The upper limit of the fractional clay content for Amargosa Valley soils is 18 percent (Table 6.1-3), and therefore the native soils are not classified as clay in texture (i.e., they do not contain 35 percent or more of clay-sized particles). As a consequence the data in Table 6.2-3 are not used in this analysis.

For the Arizo series, the soil texture is fine sand (Table 6.1-2). The qualifiers of gravely, very gravely, and cobbly refer to the size and fraction of rock fragments within the soil, see the *Soil Survey Manual* (USDA 1993 [DIRS 160546], pp. 32 to 35 and 141 to 144, including Table 3-11). These qualifiers do not affect the soil properties but impact tillage and possibly restrict crop types. Being composed of more than 85 percent sand, the Arizo series is captured by the sand soils used for the classification of K_ds.

The other soil series of interest in the Amargosa Valley are classified as sandy loam (Table 6.1-2). The *Soil Survey Manual* (USDA 1993 [DIRS 160546], pp. 137 to 140) presents a soil texture scale that starts at sand and transitions sequentially through loamy sand, sandy loam, loam, clay loam, and silty clay loam before embracing clay combinations. Thus, with the exception of the Arizo series, the textures of Amargosa Valley soils are between sand and loam with, if anything, a tendency to be more like loam than sand.

Sheppard and Thibault (1990 [DIRS 109991], p. 477) reported examining the effect of pH on K_ds for the elements studied. Although they expected to see some dependence, no such effect was observed. The natural soils in and around the Amargosa Valley are alkaline (Dollarhide 1999 [DIRS 159253], table titled *Chemical Properties of Soils*). However, continuous farming with soil augmentation, fertilizer use, and raising alfalfa (legumes) can change pH. The variations implicit in the K_d distributions are considered sufficiently broad to accommodate pH uncertainty and variability over time.

The K_d values used for radionuclides in the soil in Amargosa Valley should reasonably account for uncertainty and variability, and not result in an under-representation of the dose estimate for the defined receptor. The soil types present at the possible location of the receptor fall between the categories of soil types (i.e., sand and loam) for which K_d data are available. Therefore, the K_ds presented in Tables 6.2-1 and 6.2-2 are considered reasonable to represent Amargosa Valley soils. To select between the two data sets so that risk is not underestimated requires further consideration. An increase in the value of the K_d causes a greater increase in radionuclide concentration in the soil (if there is sufficient elapsed time for the build-up process to attain near equilibrium conditions). The additional activity resident in the soil can only increase predicted dose. To ensure that the dose risk is not underestimated, the K_d data for a given element will be taken from the data set (sand or loam) that has the higher expected value (i.e., mean) for the K_d using the lognormal distribution. This can be intuitively justified as a lower K_d value results in a smaller radionuclide build-up in soils and results in a small increase in dose. At the other end of the range, a higher K_d results in a larger radionuclide build-up in soil and higher dose.

It is not immediately apparent from inspection of the parameters of the lognormal distribution based on the mean and SD of the logarithms of the variable (i.e., K_d) which of two distributions have the greater expected value (mean). For a lognormal distribution of variable x, where λ is the mean value of the natural logarithm of the variable, ln(x), and ζ is the SD of ln(x), then the arithmetic mean, μ, of the variable x is being given by (Golder Associates 2000 [DIRS 146973], p. B-3)

$$\mu = \exp\left(\lambda + 0.5\varsigma^2\right) \quad \text{(Eq. 6-4)}$$

Using Equation 6-4 and the values for the logarithmic mean and SDs in Tables 6.2-1 and 6.2-2, Table 6.2-5 was constructed showing the arithmetic mean for the individual elemental K_ds. Table 6.2-5 also shows which soil type has the larger arithmetic mean and provides the logarithmic parameters for that lognormal distribution.

The value of SD was not available for all elements. One option for the analysis would be to use a fixed value for the K_d. In light of the data and discussion presented earlier in this section, this approach is not considered justifiable, nor would it be responsive to comments from earlier work that the variability of the K_ds should be included in TSPA. It was therefore assumed (Section 5.1) that, for elements without information on K_d variability, it is reasonable to express the variability using an average of the SDs for all other elements for the same soil type. This assumption is only required for actinium, carbon, and protactinium before 20,000 years and selenium and tin after 20,000 years. Using an average value, based on other elements for which values are available, as a surrogate for those radionuclides for which data are not available is considered reasonable to incorporate variability and uncertainty.

In Table 6.2-5, the cases where there are no data for the SD of the logarithm of the K_d (i.e., for elements Ac, C, Pa, Se, and Sn) the selection of soil texture as discussed above (the soil type having the greater arithmetic mean K_d) results in the selection of data for loam soils. The arithmetic mean of the column titled SD ln(K_d) for loam soils is 1.77 (hand calculation). This value is rounded up to 1.8 and is used to estimate the SD for those elements where a value is not provided.

Table 6.2-5. Logarithmic Parameters and the Associated Arithmetic Means of the Partition Coefficients for the Elements of Concern

Element	Sand			Loam			Conservative Case		
	Mean $\ln(K_d)$[a]	SD $\ln(K_d)$[a]	Arithmetic Mean K_d	Mean $\ln(K_d)$[b]	SD $\ln(K_d)$[b]	Arithmetic Mean K_d	Soil Type	Mean $\ln(K_d)$	SD $\ln(K_d)$
	K_d units L kg^{-1}			K_d units L kg^{-1}			K_d units L kg^{-1}		
Elements required for initial 20,000 years (required for TSPA-LA)									
Actinium (Ac)	6.1		4.46×10^{2}	7.3		1.48×10^{3}	loam	7.3	
Americium (Am)	7.6	2.6	5.87×10^{4}	9.2	1.4	2.64×10^{4}	sand	7.6	2.6
Carbon (C)	1.1	0.8	4.14	2.9		1.82×10^{1}	loam	2.9	
Cesium (Cs)	5.6	2.5	6.15×10^{3}	8.4	1.3	1.04×10^{4}	loam	8.4	1.3
Iodine (I)	0.04	2.2	1.17×10^{1}	1.5	2.0	3.31×10^{1}	loam	1.5	2.0
Neptunium (Np)	1.4	1.7	1.72×10^{1}	3.2	1.2	5.04×10^{1}	loam	3.2	1.2
Protactinium (Pa)	6.3		5.45×10^{2}	7.5		1.81×10^{3}	loam	7.5	
Plutonium (Pu)	6.3	1.7	2.31×10^{3}	7.1	1.2	2.49×10^{3}	loam	7.1	1.2
Radium (Ra)	6.2	3.2	8.25×10^{4}	10.5	3.1	4.43×10^{6}	loam	10.5	3.1
Strontium (Sr)	2.6	1.6	4.84×10^{1}	3	1.7	8.52×10^{1}	loam	3.0	1.7
Technetium (Tc)	-2	1.8	6.84×10^{-1}	-2.3	1.1	1.84×10^{-1}	sand	-2.0	1.8
Thorium (Th)	8.0	2.1	2.70×10^{4}	8.1		3.29×10^{3}	sand	8.0	2.1
Uranium (U)	3.5	3.2	5.54×10^{3}	2.5	3.3	2.82×10^{3}	sand	3.5	3.2
Additional elements required after 20,000 years (not required for TSPA-LA)									
Chlorine (Cl)	No Data			No Data			No Data		
Lead (Pb)	5.6	2.3	3.81×10^{3}	9.7	1.4	4.35×10^{4}	loam	9.7	1.4
Selenium (Se)	4.0	0.4	5.91×10^{1}	5.0		1.48×10^{2}	loam	5.0	
Tin (Sn)	4.9		1.34×10^{2}	6.1		4.46×10^{2}	loam	6.1	

[a] Data taken from Table 6.2-1.
[b] Data taken from Table 6.2-2.

The data for the lognormal distributions presented in Table 6.2-5 are in terms of the mean, λ, and SD, ζ, of the natural logarithm of the reported K_d. This convention was followed here as it was the one used by the author of the paper presenting the data (Sheppard and Thibault 1990 [DIRS 109991], p. 472). However, an alternative way to define the parameters of a lognormal distribution is to use the GM and GSD (Golder Associates 2000 [DIRS 146973], p. B-3). The relationships between the GM and the GSD and λ and ζ are

$$GM = \exp(\lambda) \quad \text{(Eq. 6-5)}$$

$$GSD = \exp(\zeta) \quad \text{(Eq. 6-6)}$$

The values of the parameters used to specify the lognormal distributions representing the uncertainty and variability of the elemental K_ds to be used in the biosphere model are summarized Table 6.2-6. The parameter values in Table 6.2-6 are provided in terms of λ and ζ and also GM and GSD. The 95 percent confidence interval for a lognormal distribution is approximately two (1.96) SDs logarithmically above and below the GM, i.e., GM × GSD$^{\pm2}$.

Because the TSPA does not require K_d values for the elements that are assessed only to be important after 20,000 years, the absence of K_d information for chlorine is of no consequence. However, if it were necessary to run the TSPA model for simulations beyond 20,000 years, K_d data for chlorine would be needed. The K_d data for chlorine can be estimated because there is an inverse correlation between K_d values and soil-to-plant concentration ratios, CR (Sheppard and Thibault 1990 [DIRS 109991], p. 472) i.e., a large value for the K_d implies a low value for the soil-to-plant concentration ratio. In *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides Through Agriculture*, Baes et al. (1984 [DIRS 103766]) reported the (dimensionless) soil-to-plant transfer concentration ratios (called transfer factors in the biosphere model) for vegetative portions of food crops for many elements. Included were values for chlorine (transfer factor = 70) and technetium (transfer factor = 9.5) (Baes et al. 1984 [DIRS 103766], p. 10). The soil-to-plant transfer concentration ratios for these two elements are larger than the values for most of the other elements thereby indicating a small value for the K_d. The K_d distribution for technetium was used as a surrogate of that of chlorine.

Sheppard and Thibault (1990 [DIRS 109991], p. 472) state that there is an inverse relationship between the two parameters of approximate form $CR \propto K_d^{-2}$. The correlation coefficient between the K_d and the soil-to-plant transfer factor is evaluated and reported in *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672], Section 6.2.1.5) where it was determined to be –0.8. This topic will not be discussed further here.

Table 6.2-6. Lognormal Distribution Parameters for Partition Coefficients

Element	Parameter values for a lognormal distribution			
	λ mean of $\ln(K_d)$ [a]	ζ SD of $\ln(K_d)$ [a]	GM	GSD
	K_d units L kg^{-1}		K_d units L kg^{-1}	
Elements required for initial 20,000 years (required for TSPA-LA)				
Actinium (Ac)	7.3	1.8	1.5×10^3	6.0
Americium (Am)	7.6	2.6	2.0×10^3	1.3×10^1
Carbon (C)	2.9	1.8	1.8×10^1	6.0
Cesium (Cs)	8.4	1.3	4.4×10^3	3.7
Iodine (I)	1.5	2.0	4.5	7.4
Neptunium (Np)	3.2	1.2	2.5×10^1	3.3
Protactinium (Pa)	7.5	1.8	1.8×10^3	6.0
Plutonium (Pu)	7.1	1.2	1.2×10^3	3.3
Radium (Ra)	10.5	3.1	3.6×10^4	2.2×10^1
Strontium (Sr)	3.0	1.7	2.0×10^1	5.5
Technetium (Tc)	-2.0	1.8	0.14	6.0
Thorium (Th)	8.0	2.1	3.0×10^3	8.2
Uranium (U)	3.5	3.2	3.3×10^1	2.5×10^1
Additional elements required after 20,000 years (not required for TSPA-LA)				
Chlorine (Cl)	No K_d Data			
Lead (Pb)	9.7	1.4	1.6×10^4	4.1
Selenium (Se)	5.0	1.8	1.5×10^2	6.0
Tin (Sn)	6.1	1.8	4.5×10^2	6.0

[a] ln(x) is the natural logarithm of x.

6.3 EROSION RATE

The erosion removal constant, required by the biosphere model (BSC 2004 [DIRS 169460], Equation 6.4.1-11) to calculate the surface soil erosion removal constant, is given by Equation 6-3.

Erosion is one of the mechanisms of radionuclide removal from surface soil that is considered in the biosphere model for the groundwater exposure scenario and influences the level of equilibrium radionuclide concentration in surface soil, especially for those radionuclides that do not get effectively removed from the surface soil via other mechanisms.

6.3.1 Background of the Soil Removal Process

For the Amargosa Valley, where farming and gardening practices rely on irrigation with potentially contaminated water, any dose assessment must consider processes that occur in the soil compartment of the biosphere. For some elements, the soil has a high affinity for atoms of that element. This attachment of atoms to soil particles is described by the K_d as defined in Section 4.1.2. If water contaminated with an element in solution is mixed with uncontaminated soil, some of the atoms of that element are removed from the water and become attached to the soil particles. The K_d is a simple linear representation of this reversible process.

Where an element has a large K_d, prolonged irrigation with contaminated water can lead to relatively high concentrations of the element on particles of soil. This is especially so in the arid to semi-arid conditions around Yucca Mountain, where evapotranspiration rather than percolation is the major water removal mechanism. Such a loss of water to the atmosphere leaves any radionuclides introduced by the irrigation water behind in the soil. If these radionuclides now resident in the soil can be transported to the receptor, predicted doses could be increased. Possible mechanisms for this transport include resuspended soil particles containing radionuclides attaching to the leaves of edible plants and thereby allowing radionuclides to get into the food chain, and by direct inhalation of the resuspended soil particles.

Radionuclide buildup due to continuing irrigation is limited by competing processes that remove radioactivity from the soil. Baes and Sharp (1983 [DIRS 109606], p. 18) identify radioactive decay, harvesting, and leaching as examples of such processes. Another transport mechanism that can result in removal is erosion of the soil by wind and water. To put the accumulation process into perspective some information generated for TSPA-SR (BSC 2001 [DIRS 154659]) can be used. These data were generated using fixed values for K_ds and did not consider a distribution to reflect uncertainty. The values for the K_ds used in support of TSPA-SR (BSC 2001 [DIRS 154659]) were based on those data presented in Table 6.2-1 for sand soils. The actual data used for some elements in TSPA-SR (BSC 2001 [DIRS 154659]) are reproduced in Table 6.3-1. Also included in Table 6.3-1 is the time required for the soil build-up to reach 50 percent of its asymptotic value for the radionuclide.

Table 6.3-1. Values of Elemental Partition Coefficients and the Associated Time to Achieve 50 Percent Accumulation in Soil

Element	Partition Coefficient [a] (Lkg^{-1})	Leaching Coefficient [b] (y^{-1})	Time to 50% Build-up [c] (y)
Iodine (I)	1.0	5.92×10^{-1}	3
Neptunium (Np)	5.0	1.32×10^{-1}	5
Protactinium (Pa)	5.5×10^{2}	1.23×10^{-3}	554
Plutonium (Pu)	5.5×10^{2}	1.23×10^{-3}	563
Technetium (Tc)	1.0×10^{-1}	2.77	3
Thorium (Th)	3.2×10^{3}	2.12×10^{-4}	3136
Uranium (U)	3.5×10^{1}	1.93×10^{-2}	36

[a] CRWMS M&O (2001 [DIRS 152517], Table 4, Best Estimate Value).

[b] CRWMS M&O (2001 [DIRS 152517], Table 7, Best Estimate Value).

[c] CRWMS M&O (2001 [DIRS 152539], Table 3, column labeled Prior Irrigation Period 4). Where multiple radionuclides are given in cited table the data presented here represent the one with the highest time period.

For erosion to have an effect comparable with leaching on radionuclide accumulation in soil, a reasonable fraction of the top soil would have to be removed in the time required for the 50 percent build-up as shown in Table 6.3-1. Revision 01 of this analysis (CRWMS M&O 2001 [DIRS 152517], p. 20) gives the thickness of soil used in the analysis as 15 cm with a density of 1.5 g cm^{-3}. Taking the product of these two parameters gives a topsoil areal density of 22.5 g cm^{-2} (or 225 kg m^{-2}) for TSPA-SR.

To continue the discussion of the erosion process, the values of average annual sheet and rill erosion as well as the annual average wind erosion are introduced. Table 6.3-2 provides the estimated sheet and rill erosion on non-federal land in Nevada, New Mexico and Washington states. The term sheet and rill erosion is defined in Appendix 3 of the *Summary Report 1997 National Resources Inventory (revised December 2000)* (USDA 2000 [DIRS 160548]) as the removal of layers of soil from the land surface by the action of rainfall and runoff. It is the first stage in water erosion. The values for wind erosion are given in Table 6.3-3.

Table 6.3-2. Estimated Average Annual Sheet and Rill Erosion on Non-federal Land by State by Year

State	Year	Cultivated Cropland	Non-cultivated Cropland	Total Cropland	Pastureland
Nevada	1982	0.2	0.0	0.1	0.0
	1987	0.2	0.0	0.1	0.0
	1992	0.2	0.0	0.1	0.1
	1997	0.2	0.0	0.1	0.1
New Mexico	1982	1.2	0.1	1.0	0.1
	1987	0.9	0.1	0.7	0.1
	1992	1.0	0.2	0.8	0.1
	1997	0.9	0.1	0.7	0.1
Washington	1982	6.1	0.5	5.5	0.2
	1987	7.0	0.4	6.2	0.4
	1992	5.0	0.5	4.4	0.4
	1997	4.7	0.6	4.0	0.3

Source: USDA (2000 [DIRS 160548], Table 10).

[a] All units in ton $acre^{-1}$ y^{-1}.

Table 6.3-3. Estimated Average Annual Wind Erosion on Non-federal Land by State by Year

State	Year	Cultivated Cropland	Non-cultivated Cropland	Total Cropland	Pastureland
Nevada	1982	11.4	1.0	5.2	1.2
	1987	24.5	0.9	5.2	1.3
	1992	19.3	1.1	6.1	1.2
	1997	20.8	1.0	4.4	1.3
New Mexico	1982	15.1	4.0	13.2	4.1
	1987	16.0	4.1	13.4	3.9
	1992	16.7	3.0	13.6	5.1
	1997	12.1	3.4	9.9	5.3
Washington	1982	3.9	0.6	3.5	0.2
	1987	3.9	1.0	3.5	0.4
	1992	5.6	0.5	4.9	0.2
	1997	5.0	0.8	4.3	0.0

Source: USDA (2000 [DIRS 160548], Table 11)
[a] All units in ton acre^{-1} y^{-1}.

The data presented in Tables 6.3-2 and 6.3-3 suggest that 1 ton acre^{-1} y^{-1} (2.24 metric ton hectare^{-1} y^{-1} from Table 4.1-2) of soil loss is not unreasonable for non-cultivated land. This value will be used to put the erosion process into perspective with the competing process of leaching. As one metric ton is 10^3 kg and one hectare is 10^4 m^2, one ton acre^{-1} y^{-1} is equivalent to 2.24×10^{-1} kg m^{-2} y^{-1}. Thus, if soil were to be eroded at an annual rate of one ton per acre, this would correspond to a radionuclide fractional removal rate of 1.0×10^{-3} per year (i.e., 2.24×10^{-1} kg m^{-2} y^{-1} per 225 kg m^{-2}). At this rate of removal, erosion losses would be insignificant compared to leaching losses for iodine, neptunium, technetium, strontium, and uranium (approximately $K_d \leq 50$ L kg^{-1}) in Table 6.2-6. For thorium, however, this erosion loss rate is about a factor of five above the loss from leaching. Therefore, erosion would be the more dominant removal mechanism.

The purpose of developing distributions for the K_ds and erosion rates is to take into account the coupling of the uncertainties in these parameters and the propagation of that uncertainty to the BDCFs.

The textbook, *Soil and Water Conservation for Productivity and Environmental Protection* (Troeh et al. 1980 [DIRS 110012], Section 6-1), states that erosion cannot be prevented but that it is possible and necessary to reduce erosion losses to tolerable rates. The book then develops the concept of the tolerable soil loss, T. This factor is an estimate of the maximum average annual rate of soil erosion (by wind, water, or both) that can occur without affecting crop productivity over a sustained period. The units of the values given in Table 6.1-3 are ton acre^{-1} y^{-1}. Dollarhide (1999 [DIRS 159253] and (DTN: SN9912USDASOIL.000 [DIRS 142440]) provides the tolerable soil loss for the Amargosa Valley as given in Table 6.1-3. With the exception of the Shamock soil (T factor of 2 ton acre^{-1} y^{-1}), it is reasonable to say that the typical soils in the Amargosa Valley area could tolerate annual erosion losses of about four to five tons per acre before production would be affected. It is conceivable that some future users, using bad conservation practices, would tolerate losses at a higher rate for many years before production is impacted. Such use is considered non-representative of a farmer who has to work in an arid (or in the future semi-arid) climate where irrigation presents a significant expense and requires attention to watering needs. In the absence of an alternative upper limit for soil removal, the highest T value of 5 ton $acre^{-1}$ y^{-1} will be taken as the limit.

There are two sources of soil erosion: water and wind. On farmland, the water erosion mode is sheet and rill erosion where soil is removed in an almost uniform manner over the surface. Both fluvial and eolian mechanisms are complex and are dependent on soil characteristics, crop type, slope, vegetation cover, and erosion control practices in addition to the prevailing meteorological conditions. Troeh (1980 [DIRS 110012], Section 1-2.1) indicates that erosion from either process is generally very intermittent with the possibility of months or years passing without much soil being lost. During unfavorable meteorological conditions, especially when the soil is in a vulnerable condition such as when plant cover is at a minimum, a significant fraction of the annual loss can be removed in only a few days.

Inspection of the values given in Tables 6.3-2 and 6.3-3 indicates that for the present-day climate, wind erosion dominates the soil removal process. For the glacial transition climate analog of Spokane, Washington (BSC 2004 [DIRS 170002]; defined in Section 1), wind erosion contributes approximately half of the total soil loss (Tables 6.3-2 and 6.3-3).

6.3.2 Estimate of Lower Loss Limit for Erosion

A lower limit for the rate of contaminated soil loss can be established for wind erosion for agricultural land under both climate conditions (both are dry and require irrigation). Consider an irrigated field where the average atmospheric mass loading of particles above the field is known (S, kg m^{-3}). The effective settling velocity of these particles is V_d (m sec^{-1}). If the field is considered to have zero net loss over a period of time, then the deposition of particles from remote non-contaminated areas is equal to the resuspension (and removal) of contaminated dirt from the point of interest. From the wind erosion data in Table 6.3-3, this state of equilibrium is unlikely, but conservative, as cultivated land loses more soil than non-cultivated land. The rate of contaminated soil loss, ER, can be estimated as

$$ER = 3.2\times10^{7} \times V_d \times S \qquad \text{(Eq. 6-7)}$$

where

ER	=	annual average erosion rate for the surface soil (kg m^{-2} y^{-1})
V_d	=	deposition velocity (m sec^{-1})
S	=	atmospheric mass loading (kg m^{-3})
3.2×10^{7}	=	approximate number of seconds in a year

The modal value for atmospheric mass loading for the inactive outdoors environment is 6.0×10^{-8} kg m^{-3} (DTN: MO0305SPAINEXI.001). An estimate of the deposition velocity is required before a soil loss can be estimated. The deposition velocity value that is needed is the one that represents not simply an average-sized particle but one that gives a reasonable representation of the way the total suspended mass of the particulate matter settles.

An approximation for the median diameter of particulate matter is 4 μm (NCRP 1999 [DIRS 155894], p. 68). By using the reported GSD of 5 (NCRP 1999 [DIRS 155894], p. 68) the distribution of particle sizes can be generated. Sixty-eight percent of particles would fall within the range from 0.8 to 20 μm (4 μm/5 to 4 μm×5), and 99 percent of particles would be in the range from 0.06 to 250 μm (4 μm/$5^{2.58}$ to 4 μm×$5^{2.58}$). The individual points are set at diameters that are expected to be at the 0.5-percentile point, the 16-percentile point, the 50-percentile point (the median), the 84-percentile point and the 99.5-percentile point of the distribution respectively. The corresponding diameters are 0.06 μm, 0.8 μm, 4.0 μm, 20 μm, and 250 μm.

To estimate an approximate deposition velocity, a measure of the effective particle diameter is required. The particle diameter can be estimated in the following manner. Mass is proportional to the third power of the linear dimension of particles of a given density, so the larger particles although small in number dominate the mass transport. If there are N particles in total, then there are $0.005 \times N$ particles (i.e., 0.5 percent of the total number) with a mass of $A \times 250^3$, where A is a constant. The next smaller particle size considered has a diameter of 20 μm and represents approximately 32 percent of the total number of particles. To estimate an average mass in a conservative manner, consider only the largest particle group and take it that the remaining 99.5 percent of the particles have no mass. Then the total mass of the assembly of particles is $0.005 \times N \times A \times 250^3$. Define d_{eff} (μm) as the effective diameter of the assembly of particles (i.e., the mass weighted average diameter), then from a simple mass balance approach where the total mass of the particles is attributed to an assembly of average particles each with an effective diameter,

$$N \times A \times d_{eff}^3 = 0.005 \times N \times A \times 250^3 \qquad \text{(Eq. 6-8)}$$

Cancellation of factors common to both sides and taking the cube root, gives

$$d_{eff} = 0.005^{1/3} \times 250 \ \mu\text{m} \qquad \text{(Eq. 6-9)}$$

which results in

$$d_{eff} = 42.7 \ \mu\text{m} \qquad \text{(Eq. 6-10)}$$

If the right hand side of Equation 6-8 is modified to include the 20 μm particles (i.e., $0.32 \times N \times A \times 20^3$ is added), the net effect is to increase the effective diameter to 43.2 μm. Such a small change is of no consequence.

Referring to the source of the deposition velocity, Sehmel (1984 [DIRS 158693], p. 559) indicates that an approximate dry deposition velocity for this sized particle is about 0.1 m s^{-1}, a value consistent with the values used in the biosphere model (see Table 4.1-1).

The above estimates for the parameters when substituted in Equation 6-7 give an estimated soil loss rate (ER) of 0.19 kg m^{-2} y^{-1} (or 0.87 ton $acre^{-1}$ y^{-1}). This value is consistent with the state-average estimated values presented in Table 6.3-3 for wind erosion on non-cultivated cropland. If the surface soil areal density were 225 kg m^{-2}, then the fractional annual loss would be 8.4×10^{-4} y^{-1}.

6.3.3 Estimate of Upper Loss Limit for Erosion

The upper limit of soil erosion rate was calculated based on the average values of sheet, rill, and wind erosion for different types of cropland and for pastureland for the States of Nevada, New Mexico, and Washington (Tables 6.3-2 and 6.3-3). Upper limit of erosion rate is only of any concern for elements that have high K_ds and, therefore, for which leaching is not a very effective removal mechanism. Using an average erosion rate based on statewide data to estimate an upper limit value for Amargosa Valley will provide a degree of conservatism in predicting the dose component from the soil pathway. Even as an upper limit, the rate of erosion is sufficiently low that the characteristic time is of the order of a few hundred years. As discussed in Section 6.3.1, the process of erosion is erratic over time and is dependent on agricultural practices and land stewardship.

The estimated erosion values are tabulated by land usage. The categories of land use are defined in the *Summary Report 1997 National Resources Inventory (revised December 2000)* (USDA 2000 [DIRS 160548], Appendix 3) and are as follows.

Cropland. A land cover/use category that includes areas used for the production of adapted crops for harvest. Two subcategories of cropland are recognized: cultivated and noncultivated. Cultivated cropland comprises land in row crops or close-grown crops and also other cultivated cropland, for example, hayland or pastureland that is in a rotation with row or close-grown crops. Noncultivated cropland includes permanent hayland and horticultural cropland.

Pastureland. A land cover/use category of land managed primarily for the production of introduced forage plants for livestock grazing. Pastureland cover may consist of a single species in a pure stand, a grass mixture, or a grass-legume mixture. Management usually consists of cultural treatments: fertilization, weed control, reseeding or renovation, and control of grazing. For the National Resources Inventory, this category includes land that has a vegetative cover of grasses, legumes, and/or forbs, regardless of whether or not it is being grazed by livestock.

Summary Report, 1997 National Resources Inventory (USDA 2000 [DIRS 160548], Appendix Table 2, p. 78) provides the estimated average annual sheet and rill erosion in Nevada for 1997 cultivated cropland as being 0.2 ton $acre^{-1}$ y^{-1} with estimated margins of error of 0.05 ton $acre^{-1}$ y^{-1}. It is stated in this report (USDA (2000 [DIRS 160548], p. 76) that "The margin of error is approximately twice the estimated standard error, and can be used to construct a 95 percent confidence interval for the estimate."

As shown by the data presented in Tables 6.3-2 and 6.3-3, the annual average erosion rate depends on land use, with higher erosion rates being present on cultivated land (i.e., lands subject to regular disturbance such as plowing) than uncultivated land. Thus, the upper limit of annual soil loss requires some knowledge of land use.

The major crop in the Amargosa Valley is alfalfa hay, a perennial crop that does not need annual soil disturbing activities (Table 6.3-4). In addition, other hay contributes from approximately 3 percent to 30 percent of the alfalfa area. Thus, the most appropriate data are those for non-cultivated croplands, with some consideration being given to the cultivated category (Tables 6.3-2 and 6.3-3). Note that no credit is taken for the replanting of the alfalfa crop, which occurs about once every seven years. For the glacial transition analog site (Washington), the primary crops are winter and spring wheat, barley, and peas; alfalfa and grasses are secondary in importance. Thus, erosion rates for cultivated croplands are thought reasonable for estimates of soil loss (Tables 6.3-2 and 6.3-3) for the future climate.

As discussed above, soil removal is the only dose alleviation mechanism for radionuclides that have a large K_d and then only if long times are involved. For this section, attention will be paid to the glacial transition climate and the defined analog site. Adding the statewide loss rates for Washington for water and wind erosion for cultivated croplands gives an estimate of annual loss of between 9 and 11 ton acre^{-1} y^{-1}. This is in excess of the tolerance factor for the soils as given in Table 6.1-3 under the T Factor column. Therefore, the tolerance factor of 5 ton acre^{-1} y^{-1} will be used as a conservative upper limit for the future climate. This reduction of the upper limit allows for possible inaccuracies from using statewide estimates for specific locations. The T Factor is an upper limit of sustainable soil loss, and therefore any sampled value will be lower.

Table 6.3-4. Acres Planted in Amargosa Valley

Crop [a]	Year			
	1996[b]	1997[b]	1998[c]	1999[c]
Alfalfa Hay	1747	1822	1278	1360
Other Hay	51	68	634	313
Barley	17	32	34	
Oats	45			
Pistachios	92	80	98	98
Fruit Trees	2	8	18	16
Grapes	8	10	10	11
Garlic	5	5	0.3	0.3
Onions	5			

[a] Commercial agricultural crop production during spring in Radiological Monitoring Program Grid cells 408, 409, 508, and 509.
[b] Source: CRWMS M&O (1997 [DIRS 101090], Tables 3-12 and 3-13).
[c] Source: YMP (1999 [DIRS 158212] Tables 10 and 11).

For the present-day conditions in Nevada, only wind erosion has any significant effect. Taking the average rate of loss from Table 6.3-3 for both cultivated land (≈ 20 ton acre^{-1} year^{-1}) and non-cultivated land (≈1 ton acre^{-1} y^{-1}), and weighting with the mid-point of the percentages of crop in each category, gives approximately 4 ton acre^{-1} y^{-1}. This is in reasonable agreement with value estimated above (5 ton acre^{-1} y^{-1}) for the glacial transition period for cultivated land. Furthermore the surface soil model, as developed in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.4.1), considers that the surface soil is mixed over the root zone. This mixing implies frequent (annual) tillage, where the estimated soil loss rate is that for cultivated land.

6.3.4 Recommended Distribution and Parameters for the Annual Rate of Soil Erosion

The recommended distribution for the annual erosion rate is triangular with a lower limit at 0.19 kg m^{-2} y^{-1}, and an upper limit at 1.1 kg m^{-2} y^{-1}. Because of the lack for detailed site-and climate-specific information, the mode will be conservatively taken to be coincident with the lower limit. If a single deterministic value is required to estimate the erosion rate, then the mean value of the distribution should be used; which, from geometric considerations shows the mean value is equal to one third of the sum of the lower value, the upper value, and the mode (Golder Associates (2000 [DIRS 146973], p. B-5)), which in this case is 0.49 kg m^{-2} y^{-1}.

6.4 ENHANCEMENT FACTOR FOR RESUSPENSION

Resuspension of contaminated soil is potentially important for the groundwater and volcanic ash exposure scenarios. In the case of contaminants introduced into the soil from groundwater used in agriculture, BDCFs are generated for each radionuclide of interest in terms of annual dose for unit radioactivity in each liter of groundwater. It is implicitly assumed in this approach that each liter of groundwater has the same activity concentration, and that within each liter the activity is uniformly dispersed. When used for irrigation, the radioactive contaminants in this water will give rise to uniform contamination over the soil surface.

The activity per unit mass on resuspended particles is not necessarily identical to the activity per unit mass on the surface layer of soil. The NCRP discussed resuspension models in Report No. 129 (NCRP 1999 [DIRS 155894], Section 4.2.2) and introduced an enhancement factor defined as the ratio of airborne particle activity concentration (Bq kg^{-1}) to total surface soil activity concentration (Bq kg^{-1}) (NCRP 1999 [DIRS 155894], Equation 4.3). In the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Equation 6.4.2-2), this enhancement factor is introduced as follows:

$$Ca_{h,i,n} = f_{enhance,n}\, Cs_{m,i}\, S_n \qquad \text{(Eq. 6-11)}$$

where

$Ca_{h,i,n}$ = activity concentration of radionuclide i in the air from soil resuspension for the assessment of human inhalation exposure in environment n (Bq m^{-3})

$f_{enhance,n}$ = enhancement factor for the activity concentration of resuspended particulates in environment n (dimensionless)

$Cs_{m,i}$ = equilibrium activity concentration of radionuclide i in the surface soil per unit mass (Bq kg^{-1})

S_n = concentration of total resuspended particulates (mass loading) for evaluation of inhalation exposure for environment n (kg m^{-3})

n = index of the environments: active outdoors ($n = 1$), inactive outdoors ($n = 2$), active indoors ($n = 3$), asleep indoors ($n = 4$), and one outside of the contaminated area ($n = 5$).

Measurements of $f_{enhance,n}$ are reported for undisturbed surface soil and recently disturbed soil (NCRP 1999 [DIRS 155894], p. 66). Values were given for both the median value and the range of the measurements. Data used to derive these enhancement factors were collected at Bikini Atoll, in California, on the Nevada Test Site, and in South Carolina. Some supplementary values for $f_{enhance,\ n}$, taken during agricultural tractor operations at Chernobyl on medium to heavily contaminated soil, are also included. This published information is summarized in Table 6.4-1.

Table 6.4-1. Median Values and Ranges of the Enhancement Factor

Condition	Enhancement Factor (dimensionless)		
	Lower Limit	Median	Upper Limit
Undisturbed soil	0.21	0.7	1.04
Recently disturbed soil [a]	2.2	4	6.5
Chernobyl [b]	2.8	4.4	8.4

Source: NCRP (1999 [DIRS 155894], p. 66).

[a] Disturbed soils include man made disturbances (e.g., bulldozer blading and raked surfaces), and natural disturbances (e.g., wildfires and soil thawing). Manmade disturbances are those that are not natural.

[b] Agricultural tractor operations.

Referring back to the original source of the values presented in Table 6.4-1, Shinn (1992 [DIRS 160115], Table 1, p. 1188) shows that the non-Nevada data were gathered on bare cultivated fields. The sources of contamination were nuclear fall out (Bikini Atoll), a processing facility smokestack release (South Carolina), and sewage sludge (California). Because the enhancement factor is a function of the affinity of the radionuclides to bind to soil particles, the data measured for bare cultivated fields, and given in Table 6.4-1, can be used to estimate the enhancement factor for Amargosa Valley fields. It should be noted that the analog sites for future climates are located in regions were precipitation is greater than in Amargosa Valley. The range of enhancement factor being based on data from various locations is considered to embrace variations expected from climate change.

The source of radionuclides for the volcanic scenario is ash where particles of the waste are attached to larger particles of ash (BSC 2004 [DIRS 170026], Section 6.5.2.6) that are released during an extrusive volcanic event and deposited on the soil surface. The radioactive contamination deposited on the ground is granular, whereas for the groundwater release scenario the individual atoms of the radionuclides are uniformly dispersed in the irrigation water and will become uniformly dispersed in soil. Of the types of information available on the enhancement factor, such a granular release from an eruptive event is more reasonably approximated by the Chernobyl incident where nuclear fuel was ejected into the atmosphere as particles. The Chernobyl measurements (NCRP 1999 [DIRS 155894], p. 66) are included in Table 6.4-1 and indicate that, for disturbed soils, the enhancement factor is about 20 percent above data taken at contaminated sites in the United States. After the ash-waste mixture has been incorporated into the soil and is in an undisturbed state, the incorporation values return to the undisturbed soil values.

To use the enhancement factor data (Table 6.4-1) to reflect the observed variability for stochastic modeling, a piecewise linear cumulative distribution should be used, which is simply a percentile cumulative representation of the data where any interpolation between data points is linear. The lower and upper limits are the end points of the distribution, and the median is used as the other defining point of the distribution. Agricultural activities that disturb the soil (e.g., plowing and discing) increase particulate mass loading and therefore increase inhalation exposure to the machine operator and any other nearby persons. Soil disturbing activities also increase the enhancement factor (Table 6.4-1). For outdoor activities, the enhancement factor corresponding to the release scenario and condition should be used. Mass loading indoors would be influenced by the level of activity indoors and by levels of mass loading outdoors. Because mass loading outdoors around dwellings would be representative of undisturbed soil conditions most of the time, the enhancement factor for undisturbed soil is applicable for indoor exposure. Soil disturbing activities occur in the receptor environment that is categorized in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.4.2.1) as active outdoors (n = 1). In all the other receptor environments within the contaminated area (inactive outdoors (n = 2) and both active indoors (n = 3) and indoor asleep (n = 4)) the soil is assumed to be undisturbed. The fifth category of n = 5 applies to time spent outside areas of contamination where the enhancement factor does not apply. The recommended values are given in Table 6.4-2. In cases where deterministic values are required for estimating purposes, the median (50 percent) values in Table 6.4-2 should be used.

Table 6.4-2. Cumulative Distribution Parameters to Model the Enhancement Factor for the Conditions Identified

Condition	Exposure Scenario	Indoor/Outdoor	Enhancement Factor (dimensionless)		
			Lower Limit	**50%**	**Upper Limit**
Undisturbed soil[a]	Both scenarios	Indoor and outdoor	0.21	0.7	1.04
Disturbed soil[b]	Groundwater	Outdoor	2.2	4.0	6.5
	Volcanic ash	Outdoor	2.8	4.4	8.4

[a] Undisturbed soil values apply to both biosphere model exposure scenarios and all receptor environments except “active outdoors”

[b] Disturbed soil applies only to the receptor environment “active outdoors”

6.5 SOIL WATER CONTENT AT FIELD CAPACITY

Direct measurement of volumetric water content at field capacity is not a routine analysis in standard USDA soil survey procedures, and this information was not available for the major soil series considered in this analysis. Field capacity water content is defined as the water content remaining in soils after complete saturation (such as would occur after flood irrigation or prolonged heavy precipitation) and at the time that all free drainage has ceased (Brady 1984 [DIRS 100386], p. 97). After free drainage has ceased, the soil micropores or capillary pores remain filled with water, but water has moved out of the macropores due to gravitational forces.

Assumptions could be made about the soil particle density to allow a soil water content at field capacity to be estimated. Such an approach would require additional assumptions regarding the interstitial mix of air and water at field capacity. Rather, the data presented by Allen et al. (1998 [DIRS 157311], Table 19) for this parameter was employed. These values are reproduced in Table 6.5-1 and provide ranges for water content at field capacity for a range of soils, some of which are found in Amargosa Valley. The data show that as the soil under consideration changes from sand to loam (i.e., towards smaller particles with fewer macropores), the lower and upper limits of water content at field capacity increases.

Table 6.5-1. Soil Water Content at Field Capacity

Soil Type	Soil Water Content at Field Capacity (m^3 m^{-3})	
	Lower Limit	Upper Limit
Sand	0.07	0.17
Loamy Sand	0.11	0.19
Sandy Loam	0.18	0.28
Loam	0.20	0.30

Source: Allen et al. (1998 [DIRS 157311], Table 19).

The appropriate soil type for Amargosa Valley is sandy loam (Section 6.2). Therefore, a suitable range for the soil water content is 0.18 to 0.28. This range is corroborated by other data where the midpoint value for sandy loams is given as 0.23 with a range of 0.124 to 0.329 (Baes and Sharp 1983 [DIRS 109606], p. 20).

The soil water content at field capacity is used in the biosphere model to calculate the leaching rate, which was discussed earlier in Section 6.2 (Equation 6-2). From Section 6.1, the bulk density of surface soil has a mean value of 1.5 g cm^{-3} (1.5×10^3 kg m^{-3}); and from this section, the water content at field capacity is 0.23. If an element has a K_d of 10 L kg^{-1} (10^{-2} m^3 kg^{-1}), then the term $\rho K_d/\theta$ ($\approx$ 65) in Equation 6-2 is much greater than unity and the parenthetical term can be replaced, without significant error, by $\rho K_d/\theta$. In this case, the θ term cancels and the leaching rate is independent of the water content. Any small resulting error can be considered to be accommodated by the uncertainty in K_d.

In cases where K_d is small, as is the case for technetium and possibly iodine and carbon, the approximation above does not apply (for technetium, $\rho K_d/\theta \approx 0.9$). In this case, the value used for the water content of the soil has an effect on the value of the leaching rate. However, for these elements (technetium, iodine, and carbon), the results presented in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539], Table 9) indicate that the effect on BDCFs of the radionuclide build-up in soil is approximately 1 percent. With this insensitivity on BDCFs, it is considered that the uncertainties in the other parameters in the soil pathway are sufficient to allow for any small underestimate in soil water content.

The ranges of values for the field capacity water content of soil (Table 6.5-1) are therefore adequate for the intended purpose. The recommended range of values for the soil water content is 0.18 to 0.28, the values for sandy loam soils. Because the BDCFs are relatively insensitive to this parameter, it is recommended that the parameter be considered to have a uniform distribution over the defined range.

6.6 ASH BULK DENSITY

The volcanic ash bulk density value, 1.0 g cm^{-3} (Section 4.1.6), is the value recommended for use in TSPA-LA (DTN: LA0407DK831811.001 [DIRS 170768]) and as such is considered reasonable for use in biosphere modeling of ash on uncultivated lands (BSC 2004 [DIRS 169460], Section 6.5.1.2). Using this value ensures consistency between the biosphere model and the TSPA-LA evaluation of the consequences of volcanic events.

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7. CONCLUSIONS

7.1 PARAMETER DISTRIBUTIONS

This analysis report documents the development of reasonable distributions for five soil-related parameters that are representative of environmental conditions expected under present-day and future climates. These distributions are defined to quantify the uncertainties in the parameter values appropriate for the Amargosa Valley. The values and distributions developed for these five soil-related parameters are the same for both climate conditions.

Also provided, although not developed in this report, is a sixth parameter representing the numerical value of the density of volcanic ash. This density was included here for the sake of completeness of the biosphere model input parameters.

The data presented in this section are in the Technical Data Management System with a Data Tracking Number of MO0407SPASRPBM.002 (*Soil Related Parameters For The Biosphere Model*).

7.1.1 Soil Bulk Density

The soil bulk density presented below is appropriate for the present-day and future climates and applies to the groundwater exposure scenario and the volcanic ash exposure scenario. If a deterministic value of soil bulk density is required then a value of 1.5 g cm^{-3} should be used. If a distribution is required to perform sensitivity and uncertainty studies then the soil bulk density will be taken to be a triangular distribution over the density range of 1.3 g cm^{-3} and 1.7 g cm^{-3} with a mode at 1.5 g cm^{-3}. Uncertainties in this parameter are incorporated by use of this distribution.

7.1.2 Partition Coefficient

The distributions for the K_ds given below apply to the groundwater release scenario for the present-day and future climates. The K_d values used in the biosphere model will be lognormally distributed with parameters as defined in Table 7.1-1. The use of the lognormal distribution with the two defining parameters incorporates the uncertainties of the elemental K_ds within the Amargosa Valley.

If these K_d parameters are used in stochastic simulations that also make use of the soil-to-plant transfer coefficients developed in the *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672], Section 6.2.1.5), then they should use stochastic sampling of the two parameters that are correlated. The correlation coefficient should be -0.8.

In the event that a single deterministic value for the K_d is required for model validation, the GM given in Table 7.1-1 should be used. If two values of the K_ds are required, then it is suggested that these values be at the 95 percent confidence limits of GM × $GSD^{\pm 2}$.

Table 7.1-1. Lognormal Distribution Parameters for Partition Coefficients

Element	Parameter values for a lognormal distribution			
	λ mean of ln(K_d) [a]	ζ SD of ln(K_d)[a]	GM	GSD
	K_d units L kg^{-1}		K_d units L kg^{-1}	
Elements required for initial 20,000 years (required for TSPA-LA)				
Actinium (Ac)	7.3	1.8	1.5×10^3	6.0
Americium (Am)	7.6	2.6	2.0×10^3	1.3×10^1
Carbon (C)	2.9	1.8	1.8×10^1	6.0
Cesium (Cs)	8.4	1.3	4.4×10^3	3.7
Iodine (I)	1.5	2.0	4.5	7.4
Neptunium (Np)	3.2	1.2	2.5×10^1	3.3
Protactinium (Pa)	7.5	1.8	1.8×10^3	6.0
Plutonium (Pu)	7.1	1.2	1.2×10^3	3.3
Radium (Ra)	10.5	3.1	3.6×10^4	2.2×10^1
Strontium (Sr)	3.0	1.7	2.0×10^1	5.5
Technetium (Tc)	-2.0	1.8	0.14	6.0
Thorium (Th)	8.0	2.1	3.0×10^3	8.2
Uranium (U)	3.5	3.2	3.3×10^1	2.5×10^1
Additional elements required after 20,000 years (not required for TSPA-LA)				
Chlorine (Cl)	-2.0	1.8	0.14	6.0
Lead (Pb)	9.7	1.4	1.6×10^4	4.1
Selenium (Se)	5.0	1.8	1.5×10^2	6.0
Tin (Sn)	6.1	1.8	4.5×10^2	6.0

[a] n(x) is the natural logarithm of x.

7.1.3 Soil Erosion Rate

The soil erosion rate given below applies to the groundwater release scenario for the present-day and future climates. If the biosphere model uses the soil erosion mechanism in the prediction of radionuclide accumulation in soils, then the erosion rate will be as follows. The distribution for the annual erosion rate will be triangular. The lower limit and mode will be at 0.19 kg m^{-2} y^{-1} and the upper limit at 1.1 kg m^{-2} y^{-1}. As discussed in Section 6.3, considering the upper and lower limits of the range of possible values accommodates the uncertainty of the soil erosion rate.

If a single deterministic value is required to estimate the erosion rate then it is recommended that the mean value of the distribution be used, which is 0.49 kg m^{-2} y^{-1}.

7.1.4 Enhancement Factor for Resuspension

The enhancement factor for resuspension given below applies to the present-day and future climates. Exposure specific values are identified where appropriate. The enhancement factor incorporates uncertainty and is to be represented by a piecewise cumulative distribution with the parameters defined in Table 7.1-2.

Table 7.1-2. Piecewise Cumulative Distribution Parameters to Model the Enhancement Factor for the Conditions Identified

Condition	Scenario	Indoor / Outdoor	Enhancement Factor (dimensionless)		
			Lower Limit	50%	Upper Limit
Undisturbed soil[a]	Both scenarios	Indoor and outdoor	0.21	0.7	1.04
Disturbed soil[b]	Groundwater release	Outdoor	2.2	4.0	6.5
	Volcanic release	Outdoor	2.8	4.4	8.4

[a] Undisturbed soil values apply to all biosphere model exposure cases except "active outdoors".
[b] Disturbed soil applies only to the biosphere model exposure case "active outdoors".

The uncertainties in the enhancement factor for resuspension are captured in the distribution presented in Table 7.1-2.

In the event that a single value is required for the parameters, the median (50 percent) values should be used.

One restriction for subsequent use of the recommended parameter distributions is that they are intended for use in the biosphere model using Equation 6-11. If the equation used in the completed biosphere model for enhancement differs from Equation 6-11, the use of the distributions must be justified or new parameter values must be developed.

7.1.5 Soil Water Content at Field Capacity

The soil water content at field capacity given below applies to the groundwater release scenario for the present-day and future climates. If a deterministic value for the soil water content at field capacity is required then a value of 0.23 will be used. If a distribution is required to perform sensitivity and uncertainty studies then the water content at field capacity will be taken to be a uniform distribution over the range of 0.18 to 0.28. The uncertainties of the soil water content at field capacity for possible locations of interest in the Amargosa Valley are incorporated in the defined distribution.

7.1.6 Ash Bulk Density

The value for ash bulk density given below applies to the present-day and future climates for the volcanic ash exposure scenario. The bulk density of volcanic ash within the biosphere is fixed value of 1.0 g cm^{-3}. Uncertainty in ash bulk density is not considered.

7.2 HOW THE ACCEPTANCE CRITERIA WERE ADDRESSED

The following information describes how this analysis contributes to satisfying the acceptance criteria in the *Yucca Mountain Review Plan* (NRC 2003 [DIRS 163274], Sections 2.2.1.3.13 and 2.2.1.3.14). Only those acceptance criteria that are applicable to this report, as identified in Section 4.2, are discussed.

This analysis report is one of ten reports (Figure 1-1) supporting biosphere modeling and describes how the biosphere model has addressed the applicable acceptance criteria. A consideration of all ten reports is required to understand how the biosphere model satisfies the biosphere acceptance criteria.

The manner in which the acceptance criteria applicable to this analysis were addressed is described below.

Acceptance Criteria from Section 2.2.1.3.13: Redistribution of Radionuclides in Soil

Acceptance Criterion 2: Data are Sufficient for Model Justification

(1) This analysis generates the distributions for soil-related parameters as prescribed by the Biosphere model to predict the transport of radionuclides through soil and by resuspension of soil (*Biosphere Model Report,* BSC 2004 [DIRS 169460] Section 6.4.1.3, 6.4.1.4, and 6.4.2.1). The justifications for the parameter distributions developed in this report, and the consistency of those distributions with the conditions in the Yucca Mountain region, are described in Section 6, with additional justification for the assumption given in Section 5. The data identified in Section 4.1 were used, interpreted, and appropriately synthesized into the parameter distributions as described in Section 6.

(2) The sufficiency of data used to develop parameter distributions used in the modeling of radionuclide redistribution in soil is described in Sections 4.1 and 6. Demonstration that the parameter distributions are consistent with present knowledge of the conditions in the Yucca Mountain region is in Section 6. Sensitivity and uncertainty analyses are addressed in other biosphere modeling reports listed in Figure 1-1.

Acceptance Criterion 3: Data Uncertainty is Characterized and Propagated Through the Model Abstraction

(1) The soil-related parameters and their distributions to support the biosphere model are developed in Section 6 of this analysis from the data identified in Section 4.1. These data and the resulting abstractions in Section 6, account for the expected uncertainty and variability in the site-specific parameters required to provide a reasonable assessment the dose consequences to the specified receptor. Sensitivity and uncertainty analyses are addressed in other biosphere modeling reports listed in Figure 1-1.

(2) The data used in this analysis for soil type, texture, density, and water content at field capacity discussed in Section 4.1 are based upon local conditions. The data identified in Section 4.1.4 was based in part on data measured at the nearby Nevada Test Site.

(3) The data identified in Section 4.1 permitted the analysis in Section 6 to develop distributions to represent parametric uncertainty and variability for use in the biosphere process model and alternative conceptual submodels. Where appropriate this analysis identifies correlation between parameters, one of which is developed in another analysis. Sensitivity and uncertainty analyses are addressed in other biosphere modeling reports listed in Figure 1-1.

<u>Acceptance Criteria from Section 2.2.1.3.14: Biosphere Characteristics</u>

Acceptance Criterion 1: System Description and Model Integration are Adequate

(3) This analysis considers information about climate change, soil characteristics, partition coefficients, erosion, radionuclide resuspension that are used to developed parameters to support the biosphere model in a manner that is consistent with other reports identified in Figure 1-1. The parameter for the settled ash density is taken directly from the source that provides this information for use in TPSA-LA (DTN: LA0311DK831811.001 [DIRS 166301]).

Acceptance Criterion 2: Data are Sufficient for Model Justification

(1) The justification for the parameter distributions developed in this report, and the consistency of those distributions with the conditions in the Yucca Mountain region, are described in Section 6. The data identified in Section 4.1 were used, interpreted, and appropriately synthesized into the parameter distributions as described in Section 6.

(2) The sufficiency of data used to develop parameter distributions used in the modeling of features, events, and processes related to biosphere characteristics modeling is described in Sections 4.1 and 6. Demonstration that the parameter distributions are consistent with present knowledge of the conditions in the Yucca Mountain region is in Section 6. Sensitivity and uncertainty analyses and consideration of alternative conceptual models are addressed in other biosphere modeling reports listed in Figure 1-1.

Acceptance Criterion 3: Data Uncertainty is Characterized and Propagated Through the Model Abstraction

(1) The technical defensibility of the assumption used in this analysis is included in Section 5. The technical defensibility of the probability distribution developed for each parameter is described in Section 6. These distributions of parameter uncertainty and variability are shown in Section 6 to reasonably represent local conditions while not under representing any risk estimate made from their subsequent use in the biosphere model. The consideration given to local conditions and climate states in developing parametric data is consistent with the definition of the reasonably maximally exposed individual.

(2) The defensibility of the technical bases for the parameter distributions is described in Section 6. The data and developed distributions for parameters and mass loading parameter distributions are based on or are consistent with site characterization data and the climate to be found at the location of the reasonably maximally exposed individual during the compliance time period is described in Sections 4.1 and 6.

(4) The bounding values of the parameter distributions developed in this analysis were selected to adequately represent uncertainty, as described in Section 6. One correlation between biosphere model input parameters is identified in this analysis, Section 7.1.2.

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8.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

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