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Soil-related Input Parameters for the Biosphere Model

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Revision History

12. Revision/ICN No.	13. Description of Revision/Change
Rev. 00	Initial Issue
Rev. 00ICN 01	Inclusion of discussion of (1) potential effects of future climate change on calculated soil loss estimates and leaching coefficients, ...continued at Addendum 1
Rev. 01	Provide soil-related product output to be used with the Biosphere Model (ERMYN). Parameters and, where appropriate, distributions are given for ......continued at Addendum 2

Addendum 1

(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).

Addendum 2

soil bulk density, partition coefficients, soil erosion rate, enhancement factor for resuspension, soil water capacity at field capacity, and ash bulk density.

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ACRONYMS AND ABBREVIATIONS

BDCF	biosphere dose conversion factor
ERMYN	Environmental Radiation Model for Yucca Mountain Nevada
FEPs	features, events, and processes
GM	geometric mean
GSD	geometric standard deviation
LA	license application
NRCS	Natural Resources Conservation Service
SR	site recommendation
TSPA	total system performance assessment
TSPA-LA	total system performance assessment for the license application
TSPA-SR	total system performance assessment for the site recommendation
TWP	technical work plan
USDA	U. S. Department of Agriculture

1. PURPOSE

This analysis is one of the technical reports containing documentation of the Environmental Radiation Model for Yucca Mountain Nevada (ERMYN), a biosphere model supporting the Total System Performance Assessment (TSPA) for the geologic repository at Yucca Mountain. The biosphere model is one of a series of process models supporting the Total System Performance Assessment (TSPA) for the Yucca Mountain repository. A graphical representation of the documentation hierarchy for the ERMYN biosphere model is presented in Figure 1-1. This figure shows the interrelationships among the products (i.e., analysis and model reports) developed for biosphere modeling, and the plan for development of the biosphere abstraction products for TSPA, as identified in the *Technical Work Plan: for Biosphere Modeling and Expert Support* (BSC 2003 [163602]). It should be noted that some documents identified in Figure 1-1 may be under development at the time this report is issued and therefore not available. 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 Biosphere Model Report* (BSC 2003 [160699]) describes in detail the conceptual model as well as the mathematical model and its input parameters.

The purpose of this analysis was to develop the biosphere model parameters needed to evaluate doses from pathways 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 and ash deposition and, as a direct consequence, radionuclide concentration in resuspended particulate matter in the atmosphere. The analysis was performed in accordance with the technical work plan for the biosphere modeling and expert support (TWP) (BSC 2003 [163602]). This analysis revises the previous one titled *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (CRWMS M&O 2001 [152517]). In REV 00 of this report, the data generated were fixed (i.e., taking no account of uncertainty and variability) values. This revision incorporates 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.

This analysis report supports the treatment of six of the primary features, events, and processes (FEPs) applicable to the Yucca Mountain reference biosphere as defined in the recently published LA FEP list (DTN: MO0303SEPFEPS2.000 [162452]) and addressed in the biosphere model (BSC 2003 [160699]). These FEPs are addressed in the biosphere model report (BSC 2003 [160699]). The parameters developed in this report and the related LA FEPs are listed in Table 1-1.

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 6.2 and summarized in Section 7.1
	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		
	Surface runoff and flooding	2.3.11.02.0A		
	Plant uptake	3.3.02.01.0A		
Solid/liquid 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 6.3 and summarized in Section 7.2
Soil erosion rate	Soil type	2.3.02.01.0A	Soil	The treatment of this parameter is described in Sections 4.1.3 and 6.4 and summarized in Section 7.3
	Radionuclide accumulation in soils	2.3.02.02.0A		
	Soil and sediment transport in the biosphere	2.3.02.03.0A		
	Surface runoff and flooding	2.3.11.02.0A		
Resuspension enhancement factors	Atmospheric transport of contaminants	3.2.10.00.0A	Air	The treatment of this parameter is described in Sections 4.1.5 and 6.5 and summarized in Section 7.4
Soil water content at field capacity	Soil type	2.3.02.01.0A	Soil	The treatment of this parameter is described in Sections 4.1.8 and 6.6 and summarized in Section 7.5
	Radionuclide accumulation in soils	2.3.02.02.0A		
Ash bulk density	Soil type	2.3.02.01.0A	Soil Air	The treatment of this parameter is described in Sections 4.1.9 and 6.7 and summarized in Section 7.6
	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		
	Surface runoff and flooding	2.3.11.02.0A		
	Plant uptake	3.3.02.01.0A		

Notes: [a] FEPs are listed in DTN: MO0303SEPFEPS2.000. [162452].
[b] The effects of the related FEPs are included in the TSPA through the BDCFs. See BSC (2003 [160699], Section 6.2) for a complete description of the inclusion and treatment of FEPs in the biosphere model.

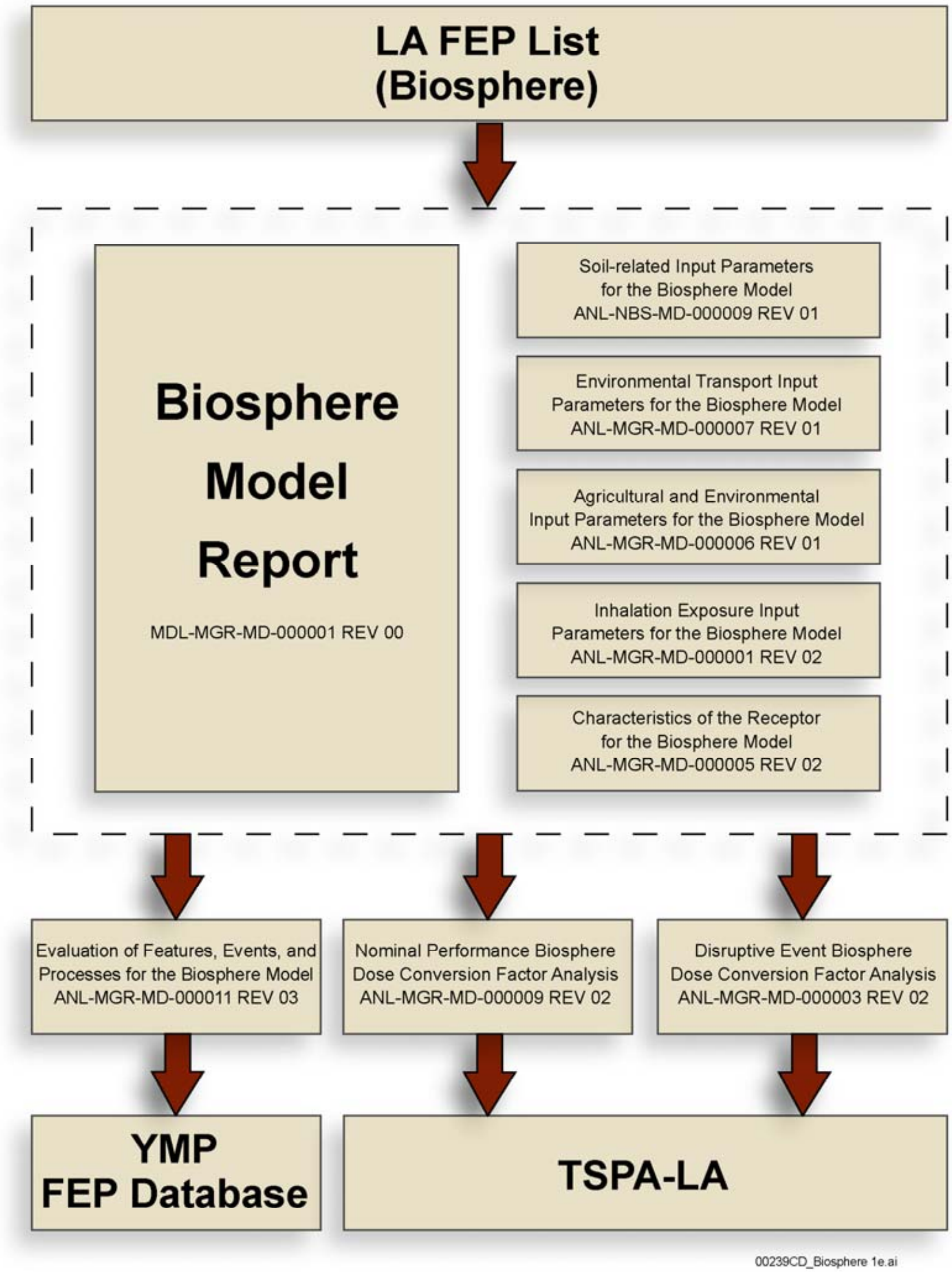

Figure 1-1. Documentation Hierarchy for the Environmental Radiation Model for Yucca Mountain Nevada

Two climate states are considered in this analysis, modern interglacial (current) climate, and glacial transition (future) climate. These climates and their predicted occurrence at Yucca Mountain in the future are described in *Future Climate Analysis* (USGS 2001 [158378]). The modern interglacial climate includes current conditions, which are characterized by hot, dry summers; warm winters; and low precipitation (USGS 2001 [158378], pp. 66 to 67). This climate state is referred to as current climate in this report. The glacial transition climate is characterized by cool, wet winters and warm to cool dry summers relative to current conditions (USGS 2001 [158378], p. 73) and is referred to as future climate in this report.

This analysis develops partition coefficient distributions for 17 elements, which were those represented by the 28 radionuclides identified in *Radionuclide Screening* (BSC 2002 [160059], Section 7, Table 13) for consideration by the post-closure TSPA for the LA (TSPA-LA). 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 2002 [160146], pp. 4, 121, and E.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 2002 [160146], 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 2003 [163602]) and thus is a quality affecting activity in accordance with AP-2.27Q, *Planning for Science Activities* [159604]. Approved quality assurance procedures identified in the TWP (BSC 2003 [163602], 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 2003 [163602], Section 8).

This analysis did not require classification of the quality level of natural barriers or other items in accordance with AP-2.22, *Classification Criteria and Maintenance of the Monitored Geologic Repository Q-Lists*, or other applicable implementing procedures.

3. USE OF SOFTWARE

The only software used during this analysis was the commercial off-the-shelf product 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) were used to calculate values presented in tables as noted in Section 6.

4. INPUTS

4.1 DATA AND TECHNICAL INFORMATION INPUTS

The sources of data and parameters that were used to develop values for the parameters identified in Table 1-1 are shown in Table 4.1-1.

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

Parameter	Source of Data or Parameter
Soil characteristics	DTN: SN9912USDASOIL.000 [142440] Dollarhide (1999 [159253]) Scheffe (2000 [163473]) Hipple (2000 [163474])
	Soil Survey Manual (USDA 1993 [160546], pp. 137 to 139)
Partition coefficients	Elemental partition coefficients for four soil types Sheppard and Thibault (1990 [109991], Tables A-1, A-2, A-3, and A-4)
Soil erosion parameters	Soil erosion data by type and by state. *Summary Report 1997 National Resources Inventory (revised December 2000)* (USDA 2000 [160548]).
Enhancement factor	Enhancement factors for various soil conditions NCRP Report No. 129 (NCRP 1999 [155894], Section 4.2.2)
Deposition parameters	Dry deposition velocity DTN: MO0306SPAETPBM.001 [163814] BSC (2003 [160964])
	Particle distribution parameters NCRP (1999 [155894], p. 68).
	Deposition velocity as a function of particle diameter. Sehmel (1984 [158693], pp. 559)
Atmospheric mass loading	Mass loading distributions DTN: MO0305SPAINEXI.001 [163808]
Soil water content at field capacity	Soil water content at field capacity Allen et al. (1998 [157311], Table 19)
Ash bulk density	Ash bulk density DTN: LA0304WS831811.001 [163477]

4.1.1 Soil Characteristics

The data associated with the soils in Amargosa Valley were taken from a database maintained by the U. S. Department of Agriculture Natural Resources Conservation Service (NRCS) (Dollarhide 1999 [159253]). The data on soils for the analog sites for future climatic conditions were also obtained from the NRCS (Scheffe 2000 [163473]; Hipple 2000 [163474]). These three sets of information are contained in *U.S. Department of Agriculture (USDA) Soil Survey Data - Lathrop Wells* (DTN: SN9912USDASOIL.000 [142440]).

These parameters are from the NRCS, the Federal authority on soil surveys in the United States since 1896. The soil characterization process 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 Natural Resources Conservation Service is judged to be technically adequate for the purposes for which it is used in this analysis.

4.1.2 Partition Coefficients

By definition, the partition coefficient (K_d) is the ratio of the quantity of the solute on unit mass of the solid phase to the quantity of the solute in a unit volume of the solution (i.e., the liquid phase) (Freeze and Cherry 1979 [101173], Section 9.2). Synonyms for K_d with this definition include sorption coefficient and distribution coefficient. Partition coefficient values are required by the Biosphere model to determine the rate of leaching of contaminants from the surface soil (see discussion in Section 6.5.1). The element specific solid/liquid partition coefficients used in this analysis are those recommended by Sheppard and Thibault (1990 [109991]) and presented in their Tables A-1, A-2, A-3, and A-4 for sand soil, loam soil, clay soil, and organic soil respectively. It should be noted that these data are applicable to soils (i.e., surface layers) and should not be used for analyses conducted on either the unsaturated zone or the saturated zone. Tables 4.1-2 through 4.1-5 provide partition coefficient data for the 4 soil types and 17 elements defined to be of interest to TSPA in Section 1.

Sheppard and Thibault (1990 [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 $\geq 70\%$ sand-sized particles were classified as sand soils, and those containing $\geq 35\%$ 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% silt-sized particles. Organic soils contained >30% organic matter and were either classic peat or muck soils, or the litter horizon of a mineral soil.

Based on the ranges of partition coefficients values (Tables 4.1-2 through 4.1-5), this parameter exhibits large uncertainty. 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 variability at specific sites. Local variability of partition coefficients has been reported in the BIOMASS meetings (BIOMASS 2001 [159468], Theme 1, Working Document N0. BIOMASS/T1/WD04, Item 36 on page 9), "It has been shown that measurements of soil K_ds on a single 100x150 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 partition coefficient would be subject to significant variability. This variability should be taken into account when assessing Biosphere modeling.

The Sheppard and Thibault (1990 [109991]) data, based on a comprehensive review, are considered adequate for representing variability and uncertainty in determining leaching rates. The Sheppard and Thibault (1990 [109991]) paper was published by a reputable source, and the paper was subject to technical peer reviews as a condition of publication. The technical information from this paper is considered appropriate for the intended use of providing a data summary of partition coefficient values on which to base the necessary uncertainty distributions.

Table 4.1-2. Element Specific Solid/Liquid Partition Coefficients for Sand Soil

Soil Type – Sand				**Measured Range**	
Element	**Number of Observations**	μ_{ln} [a]	σ_{ln} [b]	**Min**	**Max**
		ln(l/kg)	**ln(l/kg)**	**(l/kg)**	**(l/kg)**
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
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 [109991], Table A-1).

NOTES: [a] μ_{ln} is the mean of the natural logarithms of the observed values.

[b] σ_{ln} is the standard deviation of the natural logarithms of the observed values.

[c] Default values for μ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported.

Table 4.1-3. Element Specific Solid/Liquid Partition Coefficients for Loam Soil

Soil Type – Loam				Measured Range	
Element	**Number of Observations**	μ_{ln} [a]	σ_{ln} [b]	**Min**	**Max**
		ln(l/kg)	**ln(l/kg)**	**(l/kg)**	**(l/kg)**
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 [109991], Table A-2).

NOTES: [a] μ_{ln} is the mean of the natural logarithms of the observed values.

[b] σ_{ln} is the standard deviation of the natural logarithms of the observed values.

[c] Default values for μ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported.

Table 4.1-4. Element Specific Solid/Liquid Partition Coefficients for Clay Soil

Soil Type – Clay				Measured Range	
Element	**Number of Observations**	μ_{ln} [a]	σ_{ln} [b]	**Min**	**Max**
		ln(l/kg)	**ln(l/kg)**	**(l/kg)**	**(l/kg)**
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 [109991], Table A-3).

NOTES: [a] μ_{ln} is the mean of the natural logarithms of the observed values.

[b] σ_{ln} is the standard deviation of the natural logarithms of the observed values.

[c] Default values for μ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported.

Table 4.1-5. Element Specific Solid/Liquid Partition Coefficients for Organic Soil

Soil Type – Organic				Measured Range	
Element	Number of Observations	μ_{ln} [a]	σ_{ln} [b]	Min	Max
		ln(l/kg)	ln(l/kg)	(l/kg)	(l/kg)
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]			
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 [109991], Table A-4).

NOTES: [a] μ_{ln} is the mean of the natural logarithms of the observed values.

[b] σ_{ln} is the standard deviation of the natural logarithms of the observed values.

[c] Default values for μ have been predicted using soil-to-plant concentration ratios when no K_d data have been reported.

4.1.3 Erosion Data

The information presented in this section is taken from the *Summary Report 1997 National Resources Inventory (revised December 2000)* (USDA 2000 [160548]) and is comprised of the average values 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 (USGS 2001 [158378], Table 2). Table 4.1-6 provides the estimated sheet and rill erosion on non-federal land in these 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 [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 4.1-7.

The values presented here are average erosion rates by state. They are used in Section 6.4 to provide approximations for upper limits of rates of erosion that are only of any concern for elements that have high partition coefficients 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 6.4.1, the process of erosion is erratic over time and is dependent on agricultural practices and land stewardship. 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 estimated erosion values are tabulated by land usage. The three categories used for land use are defined in Appendix 3 the *Summary Report 1997 National Resources Inventory (revised December 2000)* (USDA 2000 [160548]) 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.

Table 4.1-6. 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 [160548], Table 10).
NOTE: All units in tons/acre/year.

USDA (2000 [160548], Appendix Table 2, p. 78) provides the estimated average annual sheet and rill erosion in Nevada for 1997 cultivate cropland as being 0.2 tons/acre/year with estimated margins of error of 0.05 tons/acre/year. Where the margin of error is defined (USDA 2000 [160548], p. 76) as "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."

Table 4.1-7. 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 [160548], Table 11).
NOTE: All units in tons/acre/year.

4.1.4 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 4.1-8.

Table 4.1-8. 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 [160548], p. 8).

4.1.5 Enhancement Factor for Resuspension

The National Council on Radiation Protection and Measurements discussed resuspension models in Report No. 129 (NCRP 1999 [155894], Section 4.2.2) and introduced an enhancement factor (E_f), defined as the ratio of airborne particle activity concentration (Bq kg^{-1}) to total surface soil activity concentration (Bq kg^{-1}) (NCRP 1999 [155894], Equation 4.3). The enhancement factor is used to calculate the activity concentration in the air as

$$C_{air} = E_f \times S \times M \quad \text{Eq. 4-1}$$

where

C_{air} = activity concentration in the atmosphere (Bq m^{-3})
E_f = enhancement factor (dimensionless)
S = total surface soil activity (Bq kg^{-1})
M = atmospheric mass loading (kg m^{-3}).

Measurements of E_f are reported for undisturbed surface soil and recently disturbed soil (NCRP 1999 [155894], p. 66). Values were given for both the median value and the range of the measurements. Data upon which these enhancement factors were based were taken at Bikini Atoll, in California, on the Nevada Test Site, and in South Carolina. Some supplementary values for E_f, taken during agricultural tractor operations at Chernobyl on medium to heavily contaminated soil, are also included. This published information is summarized in Table 4.1-9.

The stated intent of NCRP (1999 [155894]), a screening analysis, is to provide limits that can be applied to sites where the surface soil is known to be contaminated with radionuclides. The screening limits are calculated using methods that are chosen to be conservative under most conditions. In the absence of more detailed and specific data, using the recommended values will allow reasonable judgements to be made regarding regulatory compliance. Thus, these data are considered adequate for the intended use.

Table 4.1-9. Median Values for and Ranges of Enhancement Factors

	Enhancement Factor (dimensionless)		
Condition	**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 [155894], p. 66).

NOTES: [a] Disturbed soils include manmade 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.

4.1.6 Deposition Velocity Parameters

The dry deposition velocity was developed in the *Environmental Transport Input Parameters for the Biosphere Model report* (BSC 2003 [160964], Sections 6.2.2.1 and 7.1) and the Product Output from that report (DTN: MO0306SPAETPBM.001 [163814]). The dry deposition velocity will be used to provide an estimate of the mass of particulate material in atmosphere that is deposited in a specific location. The deposition velocity for the current climate, future climate, the groundwater release scenario, and the volcanic release exposure scenario can be represented by a piece-wise linear cumulative distribution represented by the values in Table 4.1-10.

Following the approach developed in BSC (2003 [160964]), the expected sizes for suspended particulate matter can be approximated by a lognormal distribution with the median diameter in the range from 2 to 6 μm and a geometric standard deviation (GSD) of about five (NCRP 1999 [155894], p. 68). The dry deposition velocity as a function of particle diameter is taken from Sehmel (1984 [158693]).

Table 4.1-10. Dry Deposition Velocity and Cumulative Probabilities

Particle Diameter (μm)	Dry Deposition Velocity (m/s)	Cumulative Probability (%)
0.06	3×10^{-4}	0
0.8	1×10^{-3}	16
4.	8×10^{-3}	50
20.	3×10^{-2}	84
250	3×10^{-1}	100

Source: DTN: MO0306SPAETPBM.001 [163814], Section 1.7.

4.1.7 Atmospheric Mass Loading

The report, *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [160965], Table 7-1) and its product output (DTN: MO0305SPAINEXI.001 [163808]) provide the distribution for the average atmospheric mass loading of particulate matter. The information relevant to this discussion is reproduced in Table 4.1-11

Table 4.1-11. Selected Distributions of Mass Loading for the Biosphere Model

Parameter Environment or Condition	Type of Distribution	Mode	Minimum	Maximum
Mass Loading – Nominal Conditions				
Inactive Outdoors (mg/m^3)	Triangular	0.060	0.025	0.100
Crops (mg/m^3)	Triangular	0.120	0.025	0.200

Source: DTN: MO0305SPAINEXI.001 [163808].

4.1.8 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 therefore 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 would occur after flood irrigation or prolonged heavy precipitation) and at the time that all free drainage has ceased (Brady 1984 [100386], p. 97). After free drainage has ceased, the soil micropores or capillary pores remained 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 technical information presented by Allen et al. (1998 [157311], Table 19) for this parameter was employed. These values are reproduced in Table 4.1-12 and provide ranges for water content at field capacity for a range of soils, some of which are found in Amargosa Valley.

Table 4.1-12. 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 [157311], Table 19).

4.1.9 Ash Bulk Density

The bulk density of ash is taken from DTN: LA0304WS831811.001 ([163477], Item 13, Ash Settled Density, in Table 1). In this data set, the bulk density of settled ash is 1.0 g cm^{-3}.

4.2 CRITERIA

Applicable requirements from the *Project Requirements Document* (Canori and Leitner 2003 [161770], Table 2-3) are presented in Table 4.2-1. These project requirements are for compliance with applicable portions of 10 CFR 63 [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 [161770], Table 2-3).

Listed below are the acceptance criteria from the Biosphere Characteristics section of the *Yucca Mountain Review Plan, Information Only* (NRC 2003 [162418], Section 2.2.1.3.14), based on meeting the requirements of 10 CFR 63.114, 10 CFR 63.305, and 10 CFR 63.312 [156605], that relate in whole or in part to this analysis. Similar acceptance criteria and descriptions from the Review Plan (NRC 2003 [162418], Section 2.2.1.3.11; Airborne Transport of Radionuclides) also relate to portions of this analysis.

Acceptance Criterion 1–System Description and Model Integration Are Adequate.

1. Total system performance assessment adequately incorporates important site features, physical phenomena, and couplings, and consistent and appropriate assumptions throughout the biosphere characteristics modeling abstraction process.

2. The total system performance assessment model abstraction identifies and describes aspects of the biosphere characteristics modeling that are important to repository performance, and includes the technical bases for these descriptions. For example, the reference biosphere should be consistent with the arid or semi-arid conditions in the vicinity of Yucca Mountain,

3. Assumptions are consistent between the biosphere characteristics modeling and other abstractions. For example, the U.S. Department of Energy (DOE) should ensure that the modeling of FEPs such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumptions in other TSPA 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 that describe the biosphere, are consistent with present knowledge of conditions in the region, surrounding Yucca Mountain. As appropriate, the 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 BDCFs, are consistent with site characterization data, and are technically defensible.

3. Process-level models used to determine parameter values for the biosphere characteristics modeling are consistent with site characterization data, laboratory experiments, field measurements, and natural analog research.

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 AND STANDARDS

Other than the applicable Codes of Federal Regulations identified in the *Project Requirements Document* (Canori and Leitner 2003 [161770], Table 2-3) and presented in Section 4.2, there were no other codes or standards used in this analysis.

5. ASSUMPTIONS

5.1 TIME INDEPENDENT PARTITION COEFFICIENT

Assumption–Partition coefficients are independent of time.

Rationale–In this report, it is assumed that for a given radionuclide and soil type, the partition coefficient is not a function of time. Values presented in Section 4.1.2 were generated by Sheppard and Thibault (1990 [109991]). These authors 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 [109991], p. 472).

Confirmation Status–This assumption requires no further confirmation because the use of the partition coefficient 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 in the *Biosphere Model Report* (BSC 2003 [160699], Equation 6.4.1-4) is only valid for a constant leaching removal rate which implies that a time independent partition coefficient is required.

Use in the Analysis–This assumption is used in Section 6.3.

5.2 PARTITION COEFFICIENT DISTRIBUTION

Assumption–For given elements and soils, the uncertainty and variability in partition coefficient distributions can be represented by lognormal distributions.

Rationale–For a given element and soil, the measured range of the partition coefficient is large, in many cases spanning several orders of magnitude (Tables 4.1-2 to 4.1-5). Sheppard and Thibault (1990 [109991], p. 472) indicated that partition coefficients are lognormally distributed, and they derived the mean and standard deviations in terms of the logarithm of the parameter. Use of the lognormal distribution can only be considered an approximation because no statistical justification was provided for universally using of this distribution, other than that such a distribution can embrace a wide range of values. Justification of a particular distribution is a potential concern especially for elements with few reported measurements on the partition coefficient. This implied approximation must be carried forward into this report and considered in the context of how it is used.

Confirmation Status–This assumption requires no further confirmation, as the lognormal distribution is consistent with observations and captures the large degree of variability known to exist in partition coefficient values.

Use in the Analysis–This assumption is used throughout this report.

5.3 PARTITION COEFFICIENT VARIABILITY

Assumption–For elements without information on partition coefficient variability, it is reasonable to express the variability using an average of the standard deviations for all other elements for the same soil type.

Rationale–The values for the partition coefficient distributions are given in Tables 4.1-2 to 4.1-5. The parameters to be used in this analysis are the mean of the logarithm of K_d and the standard deviation of the logarithm of K_d. The ERMYN model will use these parameters and the assumption that a given partition coefficient is distributed lognormally to reflect uncertainty when performing a stochastic analysis. However, the standard deviation is not available for all elements. One option for the analysis would be to use a fixed value for the partition coefficient. In light of the data and discussion in Section 4.1.2, this approach is not considered justifiable, nor would it be responsive to comments from earlier work that the variability of the partition coefficients should be included in TSPA calculations.

The assumption is used when the standard deviation of the logarithm of the partition coefficient is unavailable and it is that the average of the standard deviations for the other elements in the same soil type can be used as an approximation for the unknown standard deviation.

This assumption is only required for actinium, carbon, protactinium before 20,000 years and selenium and time 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.

Confirmation Status–This assumption requires no further confirmation.

Use in the Analysis–This assumption is used in Section 6.3.

5.4 CLIMATE CHANGE

Assumption–Climate changes predicted for the Yucca Mountain region (USGS 2001 [158378]; see also Section 1) will not affect the soil types for predicting the soil behavior.

Rationale–The rationale for this assumption as follows.

- Temperatures are predicted to be lower for the glacial transition period, and thermally activated processes of soil generation will be retarded.
- The fraction of organic matter in coarse textured soil at the analog sites (Scheffe 2000 [163473]; Hipple 2000 [163474]) is generally in the range 0 to 3 percent for Hobbs, and up to 4 percent for Spokane, which are representative of the sand and sandy-loams partition coefficient data given in Section 4.1.2 (i.e., much less than the 30 percent organic matter required for classification of organic soils).
- Clay content (3 to 18 percent for Amargosa Valley, less than 35 percent for Hobbs, and generally less than 20 percent for Spokane) (Scheffe 2000 [163473]; Hipple 2000 [163474]) are within the loam category used for the partition coefficients grouping.

The variability of other soil parameters, most notably the partition coefficients that can vary over an order of magnitude, are considered to dominate any changes in dose response due to other soil evolution processes. No further confirmation is required.

Confirmation Status–This assumption requires no further confirmation.

Use in the Analysis–This assumption is used throughout this report.

6. SCIENTIFIC ANALYSIS DISCUSSION

6.1 ELEMENTS OF INTEREST

The *Total System Performance Assessment-License Application Methods and Approach* document (BSC 2002 [160146], Sections 1.3 and 8.1) sets the upper limit of the simulation time for TSPA calculations as 20,000 years. From the information provided in *Radionuclide Screening* (BSC 2002 [160059], Table 13), Table 6.1-1 can be constructed showing the elements of interest for time of up to 20,000 years. Table 6.1-2 shows the additional elements for which data would be required if TSPA-LA were to consider times beyond 20,000 years. To avoid placing limits on TSPA calculations, partition coefficient distribution parameters were generated for the elements defined in Tables 6.1-1 and 6.1-2.

Table 6.1-1. Elements Identified as being Potentially Important to TSPA-LA for Time up to 20,000 Years

Element
Actinium (Ac)
Americium (Am)
Carbon (C)
Cesium (Cs)
Iodine (I)
Neptunium (Np)
Protactinium (Pa)
Plutonium (Pu)
Radium (Ra)
Strontium (Sr)
Technetium (Tc)
Thorium (Th)
Uranium (U)

Source: BSC (2002 [160059], Table 13)

Table 6.1-2. Additional Elements Identified as also being Potentially Important to TSPA-LA for Times beyond 20,000 Years

Element
Chlorine (Cl)
Lead (Pb)
Selenium (Se)
Tin (Sn)

Source: BSC (2002 [160059], Table 13)

6.2 SOIL BULK DENSITY AND OTHER PROPERTIES

The NRCS soil information introduced in Section 4.1.1 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) [156605]. Thus until TSPA-LA calculations have been completed there has to be some uncertainty associated with location of the receptor and the soil characteristics that are applicable. To allow for this uncertainty a set of possible soil series were considered from the list provided by the NRCS. The series used for the analysis were identified from a soil map of the Amargosa Valley (CRWMS M&O 1999 [107736], Figure 1, pp. 2 to 3) as being approximately south of the repository. Table 6.2-1 provides a summary of soil types and thickness of soil layers of interest to agriculture and horticulture. Table 6.2-2 provides the particle-size class and texture of the surface horizon for the soil series included in Table 6.2-1. Table 6.2-3 summarizes the detailed characteristics of the soil type of interest.

Table 6.2-1. Soil Types and Depths

Map Symbol	Soil Name	Depth	
		Upper (in)	Lower (in)
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 [142440].
Dollarhide (1999 [159253]).
CRWMS M&O (1999 [107736], Figure 1, pp. 2 to 3).

Table 6.2-2. 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 [146306]); soil texture definitions from the *Soil Survey Manual* (USDA 1993 [160546], pp. 137 to 139).

NOTES: [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 6.2-3. Soil Characteristics by Soil Type

Soil Name	Clay Content		Moist Bulk Density		Organic Matter	T Factor [a]	Wind Erodibility Group
	Lower	Upper	Lower	Upper	Max		
	(%)		(g/cm^3)		(%)	tons/acre	
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	0.5	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 [142440].
Dollarhide (1999 [159253]). Soil Name and associated properties.

NOTES: [a] 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. The rate is in tons per acre. This parameter is only applicable to the surface layer that is available for erosion.

The densities of the two uppermost layers of each soil type considered are provided in Table 6.2-3. Values in Table 6.2-1 and identified above as being appropriate soil candidates indicate these two layers extend from a depth of approximately 35 cm up to one and a half meters. From BSC (2003 [160976], p. 106), this minimum thickness is greater than the maximum tillage depth considered. Therefore, the density data in Table 6.2-3 can form the basis to estimate the moist bulk density of the soil.

From inspection of the density values in Table 6.2-3, 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 suggested that the distribution of density be assumed to 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 use of moist bulk density for the complete set of soils provided (Dollarhide 1999 [159253]) would not change the estimates of the range or distribution of the parameter.

6.3 SOLID/LIQUID PARTITION COEFFICIENT

Information on the soils near the expected location of the receptor is presented in Section 6.2, and partition coefficient data for various soil types are given in Section 4.1.2. The objective of this section is to identify appropriate distributions with their parameters for the elemental partition coefficients for the range of soils found in the Amargosa Valley. Inspection of Tables 4.1-2 to 4.1-5 indicates that, for a given element and a given soil, the measured range of the partition coefficient is large, spanning in many cases several orders of magnitude. The authors of the review article from which the values were obtained (Sheppard and Thibault 1990 [109991], p. 472) indicated that partition coefficients are lognormally distributed. Therefore, they elected to derive the mean and standard deviations in terms of the logarithm of the parameter. Thus in the absence of site specific data, it is assumed the lognormal distribution is appropriate for the partition coefficient (see Assumption in Section 5.2). No attempt was made to derive any time dependency of the partition coefficients (Assumption in Section 5.1).

Partition coefficient parameters are presented in Tables 4.1-2 to 4.1-5 for each of the four soil types (sand, loam, clay, and organic). Descriptions of the texture categories for the soil types are given in Section 4.1.2.

The maximum organic matter content for Amargosa Valley soils is less than 0.5 percent (Table 6.2-3), and therefore the native soils are not classified as organic (i.e., they do not contain more than 30 percent organic matter). The upper limit of the fractional clay content for Amargosa Valley soils is 18 percent (Table 6.2-3), and therefore the native soils are not classified as clay (i.e., they do not contain 35 percent or more of clay-sized particles).

For the Arizo series, the soil texture is fine sand (Table 6.2-2). 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 [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 are possibly restrictive on crop types). Being composed of more than 85 percent sand, the Arizo series is captured by the sand soils used for the classification of partition coefficients.

The other soil series of interest in the Amargosa Valley are classified as sandy loam (Table 6.2-2). The *Soil Survey Manual* (USDA 1993 [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, the texture of Amargosa Valley soils are between sand and loam with, if anything, a bias to the loam end of the spectrum.

Sheppard and Thibault (1990 [109991], p. 477) reported examining the effect of pH on partition coefficients 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. 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.

One requirement (Acceptance Criterion 3-3 in Section 4.2) is that partition coefficient values used for radionuclides in the soil in Amargosa Valley reasonably account for uncertainty and variability, and do not result in an under-representation of the risk estimate for the defined receptor. The soil types present at the possible location of the receptor fall between the category of soil types (i.e., sand and loam) for which partition coefficient data are available and therefore the partition coefficients presented in Table 4.1-2 and 4.1-3 are considered reasonable to represent Amargosa Valley soils. To select between the two data sets so that risk is not underestimated require further consideration. An increase in the value of the partition coefficient 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 partition coefficient 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 partition coefficient 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 standard deviation of the logarithms of the variable (i.e., partition coefficient) 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 and ζ is the standard deviation of ln(x), then (Golder Associates 2000 [146973], p. B-3) the arithmetic mean (μ) of the variable x is being given by Equation 6-1.

$$\mu = \exp\left(\lambda + 0.5\varsigma^2\right) \qquad \text{Eq. 6-1}$$

Using Equation 6-1 and the values for the logarithmic mean and standard deviations in Table 4.1-2 and 4.1-3, Table 6.3-1 was constructed showing the arithmetic mean for the individual elemental partition coefficients. Table 6.3-1 also shows which soil type has the larger arithmetic mean and provides the logarithmic parameters for the lognormal distribution.

It should be noted that in Table 6.3-1, the cases where there are no data for the standard deviation of the logarithm of the partition coefficient are all considered loam soils. The average 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 standard deviation parameter for those elements where a value is not provided, as per Assumption 5.3 (actinium, carbon and protactinium for the pre-20,000 year period and selenium and tin for the period after 20,000 years).

The partition coefficient data for the lognormal distributions presented in Table 6.3-1 are in terms of the mean (λ) and standard deviation (ζ) of the natural logarithm of the coefficient. This convention was followed here as it was the one used by the author of the paper presenting the data (Sheppard and Thibault 1990 [109991], p. 472). However, as pointed out in Golder Associates (2000 [146973], p. B-3), an alternative way to define the parameters of a lognormal distribution is to use the geometric mean (GM) and geometric standard deviation (GSD). The relationships between the GM and the GSD and μ and ζ are

Table 6.3-1. 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]	mean K_d	mean $\ln(K_d)$[b]	SD $\ln(K_d)$[b]	mean K_d	Soil Type	mean $\ln(K_d)$	SD $\ln(K_d)$
	K_d units l/kg			K_d units l/kg			K_d units l/kg		
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					
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	

Notes [a] Data taken from Table 4.1-2 in Section 4.1.3.
[b] Data taken from Table 4.1-3 in Section 4.1.3.

$$GM = \exp(\mu) \quad \text{Eq, 6-2}$$

$$GSD = \exp(\zeta) \quad \text{Eq. 6-3}$$

The values of the parameters to specify the lognormal distributions to represent the uncertainty and variability of the elemental partition coefficients to be used in the Biosphere Model to support TSPA-LA are summarized Table 6.3-2. The parameter values in terms of μ and ζ and also GM and GSD are provided in Table 6.3-2. The 95 percent confidence interval for a lognormal distribution are approximately at two (1.96) standard deviations logarithmically above and below the GM, i. e., $GM\times(2\times GSD)^{\pm1}$.

Because the TSPA-LA does not require K_d values for the elements that are assessed only to be important after 20,000 years (Section 6.1), the absence of K_d information for chlorine is of no consequence. However, it may be necessary to run the TSPA-LA model for simulations beyond 20,000 years, in which case K_d data for chlorine would be needed. K_d data for chlorine can be estimated because there is a correlation between K_d values and soil-to-plant concentration ratios (Sheppard and Thibault 1990 [109991], p. 472). In *A Review and Analysis of Parameters for*

Assessing Transport of Environmentally Released Radionuclides Through Agriculture (Baes et al. 1984 [103766]), Baes reported the soil to plant transfer concentration ratios for many elements. Included were values for Chlorine (70) and Technetium (95). 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 partition coefficient. The partition coefficient distribution for technetium was used as a surrogate of that of chlorine.

Table 6.3-2. Lognormal Distribution Parameters for Partition Coefficients

Element	Parameter values for a lognormal distribution			
	μ mean of $\ln(K_d)$ [a]	ζ SD of $\ln(K_d)$ [a]	GM	GSD
	K_d units l/kg		K_d units l/kg	
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

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

It is stated in Sheppard and Thibault (1990 [109991], p. 472) that there is an inverse relationship between the two parameters of approximate form $CR \propto K_d^{-2}$. The correlation coefficient between the partition coefficient and the soil to plant transfer factor is being evaluated and reported under another task (BSC 2003 [160964], Section 6.2.1.5) where it was determined to be –0.8. This topic will not be discussed further here.

6.4 EROSION RATES FOR THE GROUNDWATER RELEASE

6.4.1 Background of Soil Removal

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 partition coefficient 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 partition coefficient is a simple linear representation of this reversible process.

In a case where an element has a large partition coefficient, then 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 to the atmosphere leaves any radionuclides introduced by the irrigation water behind in the soil. If these radionuclides in the soil can be transported to the receptor, predicted doses could be increased. Possible mechanisms for this transport include resuspended soil 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 build-up due to continuing irrigation is limited by competing processes that remove radioactivity from the soil. Baes and Sharp (1983 [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 [154659]) can be used. These data were generated using fixed values for partition coefficients and did not consider a distribution to reflect uncertainty. The actual values for the partition coefficients used in support of TSPA-SR (BSC 2001 [154659]) were based on those data presented in Table 4.1-2 for sand soils. The actual data used for some elements in TSPA-SR (BSC 2001 [154659]) are reproduced in Table 6.4-1. Also included in Table 6.4-1 is the time required for the soil build-up to reach 50 percent of its asymptotic value for the radionuclide.

Table 6.4-1. Values of Elemental Partition Coefficients and the Associated Time to Achieve 50 percent Accumulation in Soil

Element	Partition Coefficient [a] (l/kg)	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 [152517], Table 4, Best Estimate Value).

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

[c] CRWMS M&O (2001 [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 a comparable effect with leaching on radionuclide accumulation in soil then there would need to be a reasonable fraction of the top soil removed in the time required for the 50 percent build-up as shown in Table 6.4-1. CRWMS M&O (2001 [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 gm/cm^2 (or 225 kg/m^2) for TSPA-SR. Inspection of Tables 4.1-6 and 4.1-7 suggests that one ton/acre/year (2.24 metric tons/hectare/year from Table 4.1-8) of soil loss is not unreasonable (for non-cultivated land). As one metric ton is 10^3 kg and one hectare is 10^4 m^2, one ton/acre/year is equivalent to 2.24×10^{-1} kg/m^2/y. 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)/225 (kg/m^2)). At this rate of removal, erosion losses would be insignificant compared to leaching losses for I, Np, Tc and U (approximately $K_d \leq 50$ liters/kg) in Table 6.4-1. For Th however this erosion loss rate is about a factor of five above the loss from leaching and therefore erosion would be the more dominant removal mechanism.

For the TSPA-LA, the purpose of developing distributions for the partition coefficients and erosion rates is to take into account in 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 [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, as given in Table 6.2-3. 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 6-2.3 are tons per acre. With the exception of the Shamock soil (T factor of 2 tons/acre), 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/year 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 [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 the annual loss can be removed in only a few days.

Inspection of the values given in Tables 4.1-6 and 4.1-7 indicates that for the present day climate, wind erosion dominates the soil removal process. For the glacial transition climate analog of Spokane, Washington (USGS 2001 [158378]; defined in Section 1), wind erosion contributes approximately half of the total soil loss (Tables 4.1-6 and 4.1-7).

6.4.2 Estimate of Lower Loss Limit

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 (M, kg m^{-3}). The effective settling velocity of these particles is v (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 4.1-7, this state of equilibrium is unlikely, but conservative, as cultivated land loses more soil than non-cultivated land. The rate of contaminated soil loss (L (kg m^{-2} y^{-1})) can be estimated as

$$L = 3.2 \times 10^7 \times \nu \times M \qquad \text{Eq. 6-4}$$

In this equation, the numerical constant is the number of seconds in a year. From Table 4.1-11, the modal value for M (inactive outdoors value) is 6.0×10^{-8} kg m^{-3}. 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.

From Section 4.1.6, an approximation for the median diameter of particulate matter is 4 μm. By using the reported geometric standard deviation of 5 (NCRP 1999 [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.

As mass is proportional to the third power of the linear dimension of particles of a given density, the larger particles although small in number dominate the mass transport. If there are N particles in total, then there are 0.005×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 the remaining 99.5 percent of the particles to 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,

$$N\times A\times(d_{eff})^3 = 0.005\times N\times A\times(250)^3 \quad \text{Eq. 6-5}$$

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

$$d_{eff} = 0.005^{1/3}\times 250 \quad \text{Eq. 6-6}$$

which results in

$$d_{eff} = 42.7\ \mu\text{m} \quad \text{Eq. 6-7}$$

If the right hand side of Equation 6-5 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 43.2μm. Such a small change is of no consequence.

Referring to the source of the depositional velocity, Sehmel (1984 [158693], p. 559) indicates that an approximate dry deposition velocity for this sized particle is about 0.1 m/s, a value consistent with the values given in Table 4.1-10.

The above estimates for the parameters when substituted in Equation 6-4 give an estimated soil loss rate (L) of 0.19 kg m^{-2} $year^{-1}$ (or 0.87 tons $acre^{-1}$ $year^{-1}$). If the surface soil areal density were 225 kg m^{-2}, then the fractional annual loss would be 8.4×10^{-4} $year^{-1}$. This value is consistent with the State average estimated values presented in Table 4.1-7 for wind erosion on non-cultivated cropland.

6.4.3 Estimate of Upper Loss Limit

The annual average erosion rate depends on land use (Tables 4.1-6 and 4.1-7), with higher erosion rates on cultivated land (i.e., lands subject to regular disturbance such as plowing) than uncultivated land. Thus, estimating the upper limit of 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 6.4-2). 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 4.1-6 and 4.1-7). 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 4.1-6 and 4.1-7) for the future climate.

Table 6.4-2. 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			

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

As discussed above, soil removal is the only dose alleviation mechanism for radionuclides that have a large partition coefficient 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 tons per acre per year. This is in excess of the tolerance factor for the soils as given in Table 6.2-3 under T Factor. Therefore, the tolerance factor of 5 tons 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*-value is an upper limit of sustainable soil loss, and therefore any sampled value will be lower.

For the present day conditions in Nevada, only wind erosion has any significant effect. Taking the average rate of loss from Table 4.1-7 for both cultivated ($\approx$ 20 tons acre^{-1} y^{-1}) and non-cultivated ($\approx$1 ton acre^{-1} y^{-1}) and weighting with the mid-point of the percentages of crop in each category gives approximately 4 tons acre^{-1} y^{-1}. This is in reasonable agreement with value estimated above (5 tons acre^{-1} y^{-1}) for the glacial transition period for cultivated land. Furthermore the soil model, as developed in the *Biosphere Model Report* (BSC 2003 [160699], 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.

6.4.4 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} $year^{-1}$, and an upper limit at 1.1 kg m^{-2} $year^{-1}$. 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 simple geometric considerations, is 0.49 kg m^{-2} $year^{-1}$ for this case.

6.5 ENHANCEMENT FACTORS FOR RESUSPENSION

Resuspension of contaminated soil is potentially important for the groundwater and volcanic ash release scenarios in the TSPA-LA. In the case of contaminants introduced into the soil from the use of groundwater for agricultural use, 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 (Section 4.1.5). The change in activity concentration for resuspended particles can be accommodated using an empirical enhancement factor (E_f) (dimensionless). The enhancement factor is the ratio of airborne particle concentration (Bq kg^{-1}) to total surface soil concentration (Bq kg^{-1}), as given by Equation 4-1.

Referring back to the original source of the values presented in Table 4.1-9 (Shinn 1992 [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 factors were measured bare cultivated fields, the data in Table 4.1-9 can be used to estimate the enhancement factors 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. This increase in precipitation is likely to affect the magnitude of atmospheric mass loading of particulate matter (by inhibiting resuspension by wetting the soil surface; that is, water film surface tension) but to have an insignificant effect on the enhancement factor.

The volcanic ash scenario releases particles of the waste attached to larger particles of ash (BSC 2001 [157876], Section 5.4.1, p. 24). 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 factors, 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. These Chernobyl measurements (NCRP 1999 [155894], p. 66) are included in Table 4.1-9 and indicate that for disturbed soils, the Chernobyl enhancement factors indicate an increase of 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 4.1-9) 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 factors (Table 4.1-9). For outdoor activities, the enhancement factor corresponding to the release scenario and condition should be used. However, for indoor exposure, the mass loading inside a dwelling is considered to be related to the annual average mass loading outside, which would be based on undisturbed conditions most of the time. Thus, for indoor exposure, the enhancement factor for undisturbed soil is applicable. The recommended values are given in Table 6.5-1. In cases where deterministic values are required for estimating purposes, the median (50 percent) values in Table 6.5-1 should be used.

Table 6.5-1. Cumulative Distribution Parameters to Model the Enhancement Factors for the Conditions Identified.

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

6.6 SOIL WATER CONTENT AT FIELD CAPACITY

For the four soil types considered, the range of values for the field capacity water content are presented in Table 4.1-12. The appropriate soil type for Amargosa Valley is sandy loam (Section 6.3), which indicates that a suitable range for the parameter 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 [109606], p. 20).

The leaching rate (λ) used in the Biosphere model (BSC 2003 [160699], Equation 6.4.1-10) is given as Eq. 6-8.

$$\lambda = \frac{OW}{d \times \theta \left(1 + \frac{\rho \times K_d}{\theta}\right)} \qquad \text{Eq. 6-8}$$

where

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

From Section 6.2, 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 partition coefficient of 10 liter kg^{-1} (10^{-2} m^3 kg^{-1}), then the term $\rho K_d/\theta$ (≈ 65) is much greater than unity and the parenthetical term can be replaced by without significant error by $\rho K_d/\theta$. In this case, the θ term cancels and the leaching rate in 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 CRWMS M&O (2001 [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 4.1-12) 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.

6.7 ASH BULK DENSITY

The volcanic ash bulk density value, 1.0 g cm^{-3} (Section 4.1.9), is the value recommended for use in TSPA-LA (DTN: LA0304WS831811.001 [163477]) and as such is considered reasonable for use in biosphere modeling. Using this value ensures consistency between the biosphere model and the TSPA-LA evaluation of the consequences of volcanic events. The data presented in DTN: LA0304WS831811.001 [163477] contained no quantification of uncertainty.

7. CONCLUSIONS

This analysis report documents the development of reasonable distributions for five soil related parameters that are representative of environmental conditions expected under current and future climates. These distributions are defined to quantify the uncertainties in the parameter values appropriate for the Amargosa Valley. Also provided, although not developed in this report, is the numerical value of the density of volcanic ash. This density was included here for the sake of completeness of the Biosphere input parameters.

The data presented in this Section are in the Technical Data Management System with a Data Tracking Number of MO0305SPASRPBM.001.

7.1 SOIL BULK DENSITY

If a deterministic value of soil bulk density is required then a value of 1.5 g cm^{-3} will 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.

7.2 SOLID/LIQUID PARTITION COEFFICIENT

The Solid/Liquid Partition Coefficient values used in the Biosphere model will be lognormally distributed with parameters as defined in Table 7.2-1. The use of the lognormal distribution with the two defining parameters incorporates the uncertainties of the elemental partition coefficients within the Amargosa Valley.

If any user of these partition coefficient parameters is performing stochastic simulations that also makes use of the soil-to-plant transfer coefficients developed in BSC (2003 [160964], 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 partition coefficient is required for model validation, the geometric mean given in Table 7.2-1 should be used. If two values of the partition coefficients are required, then it is suggested that the value be at the 95 percent confidence limits of $GM \times (2 \times GSD)^{\pm 1}$.

Table 7.2-1. Lognormal Distribution Parameters for Partition Coefficients

Element	Parameter values for a lognormal distribution			
	μ 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

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

7.3 SOIL EROSION RATE

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} year^{-1} and the upper limit at 1.1 kg m^{-2} year^{-1}. As discussed in Section 6.4, the uncertainty of the soil erosion rate is accommodated by considering the upper and lower limits of the range of possible values.

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} year^{-1}.

7.4 ENHANCEMENT FACTORS FOR RESUSPENSION

When calculating the activity in particulate matter in the atmosphere from resuspension of surface contamination, equation Eq. 4-1 should be used.

$$C_{air} = E_f \times S \times M \qquad \text{Eq. 4-1}$$

where C_{air} (Bq m^{-3}) is the activity concentration in the atmosphere
E_f is a dimensionless enhancement factor,
S (Bq kg^{-1}) is the total surface soil activity, and
M (kg m^{-3}) is the atmospheric mass loading

The enhancement factor incorporates uncertainty and is to be represented by piecewise cumulative distribution with the parameters defined in Table 7.4-1.

Table 7.4-1. Piecewise Cumulative Distribution Parameters to Model the Enhancement Factors for the Conditions Identified.

Condition	Scenario	In-door / Out-door	Enhancement Factor (dimensionless)		
			0%	50%	100%
Undisturbed soil	Both scenarios	Indoor and outdoor	0.21	0.7	1.04
Disturbed soil	Groundwater release	Outdoor	2.2	4.0	6.5
	Volcanic Release	Outdoor	2.8	4.4	8.4

The uncertainties of the enhancement factors for resuspension are captured in the distribution presented in Table 7.4-1.

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 as given in the equation presented in this section. If the equation used in the completed biosphere model for enhancement differs from Equation 4-1, the use of the distributions must be justified or new parameter values must be developed.

7.5 SOIL WATER CONTENT AT FIELD CAPACITY

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 uncertainty of the soil water content at field capacity for possible locations of interest in the Amargosa Valley are incorporated in the defined distribution.

7.6 ASH BULK DENSITY

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.

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