OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SCIENTIFIC ANALYSIS COVER SHEET

1. QA: QA

2. Scientific Analyses Title	
Disruptive Event Biosphere Dose Conversion Factor Analysis	
3. DI (including Revision Number)	
ANL-MGR-MD-000003 REV 02	
4. Total Attachments	5. Attachment Numbers - Number of pages in each
3	Attachment I - 4 pages; Attachment II - 4 pages + CD ROMs; Attachment III - 3 pages

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11. Remarks

This report addresses technical errors identified in TER-02-0054.

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Revision History

12. Revision/ICN No.	13. Description of Revision/Change
REV 00	Initial issue
REV 01	Incorporate revised exposure scenarios, re-developed input parameters, add pathway and limited sensitivity analyses, append list of radionucldies, remove bofunding case, add validation of the biosphere model.
REV 02	Complete revision following development of the new biosphere model, ERMYN.

CONTENTS

TABLES

FIGURES

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ACRONYMS

BDCF	biosphere dose conversion factor
DF	dose factor
ERMYN	Environmental Radiation Model for Yucca Mountain Nevada
FEP	feature, event or process
LA	license application
RMEI	reasonably maximally exposed individual
TSP	total suspended particulate (concentration in air)
TSPA	total system performance assessment
TSPA-LA	total system performance assessment for the license application
TWP	technical work plan

1. PURPOSE

This analysis report, *Disruptive Event Biosphere Dose Conversion Factor Analysis*, is one of the technical reports containing documentation of the ERMYN (Environmental Radiation Model for Yucca Mountain Nevada) biosphere model for the geologic repository at Yucca Mountain, its input parameters, and the application of the model to perform the dose assessment for the repository. 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 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 provides an understanding of how this analysis report contributes to biosphere modeling. This report is one of the two reports that develop biosphere dose conversion factors (BDCFs), which are input parameters for the TSPA model. The *Biosphere Model Report* (BSC 2003 [DIRS 164186]) describes in detail the conceptual model as well as the mathematical model and lists its input parameters. Model input parameters are developed and described in detail in five analysis report (BSC 2003 [DIRS 160964], BSC 2003 [DIRS 160965], BSC 2003 [DIRS 160976], BSC 2003 [DIRS 161239], and BSC 2003 [DIRS 161241]).

The objective of this analysis was to develop the BDCFs for the volcanic ash exposure scenario and the dose factors (DFs) for calculating inhalation doses during volcanic eruption (eruption phase of the volcanic event). The volcanic ash exposure scenario is hereafter referred to as the volcanic ash scenario. For the volcanic ash scenario, the mode of radionuclide release into the biosphere is a volcanic eruption through the repository with the resulting entrainment of contaminated waste in the tephra and the subsequent atmospheric transport and dispersion of contaminated material in the biosphere. The biosphere process model for this scenario uses the surface deposition of contaminated ash as the source of radionuclides in the biosphere. The initial atmospheric transport and dispersion of the ash as well as its subsequent redistribution by fluvial and aeolian processes are not addressed within the biosphere model. The analysis was performed in accordance with the TWP (BSC 2003 [DIRS 163602]).

The biosphere model considers features, events, and processes (FEPs) applicable to the Yucca Mountain biosphere (DTN: MO0303SEPFEPS2.000 [DIRS 162452]). The disposition of these FEPs in the TSPA is through the BDCFs which are the direct input to the TSPA model. The disposition of the included FEPs within the biosphere model is documented in the *Biosphere Model Report* (BSC 2003 [DIRS 164186]). Specifically, the consideration of the included FEPs in the conceptual model is shown in Table 6.2-1, relationships among the biosphere-related FEPs, the biosphere conceptual model, and the exposure scenarios are more fully examined in Section 6.3, and the disposition of the included FEPs within the mathematical model, and their relationship to the model equations and input parameters is presented in Table 6.7-1 of the *Biosphere Model Report* (BSC 2003 [DIRS 164186]).

In addition to producing the BDCFs for the volcanic ash exposure scenario, this analysis develops the values of dose factors for calculation of inhalation exposure during a volcanic eruption. The FEPs that were considered in the development of dose factors are listed in Table 1-1. The disposition of these FEPs in TSPA is through the dose factors that are the input to the TSPA model.

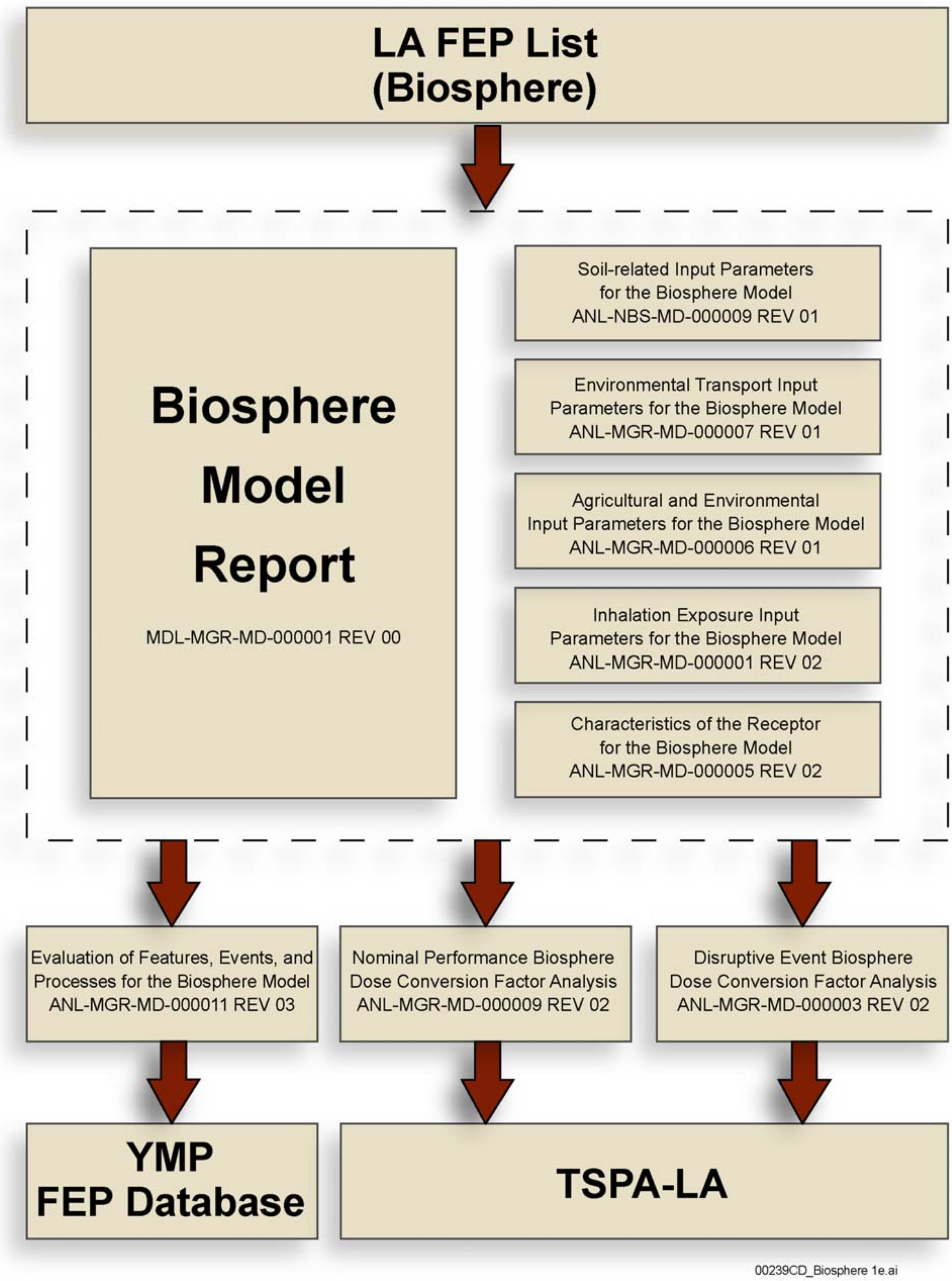


Figure 1-1. Biosphere Model Documentation

Table 1-1. Features, Events and Processes Considered in the Development of Dose Factors

FEP Number [a]	FEP Name [a]	Description of FEP Disposition
1.2.04.07.0A	Ashfall	Volcanic ash is the source of inhalation exposure during volcanic eruption. Inhalation dose is proportional to activity concentration in the airborne ash (Equation 6.3-2).
2.4.01.00.0A	Human characteristics (physiology, metabolism)	Physiology and metabolism of the human receptor were considered in developing the values of breathing rates and dose conversion factors for inhalation, which are used as input to calculate the values of dose factors (Equation 6.3-3).
2.4.04.01.0A	Human lifestyle	Lifestyles and characteristics of people living in Amargosa Valley were considered in developing the values of population proportions and exposure times, which are used as input to calculate the values of dose factors (Equation 6.3-3).
2.4.07.00.0A	Dwellings	Dwellings produce mitigating effect on inhalation dose which is considered in the value of the indoor reduction factor for activity concentration in air which are used to calculate the values of dose factors (Equation 6.3-3).
3.1.01.01.0A	Radioactive decay and In-growth	Contribution from long-lived and short-lived decay products of primary radionuclides is included in the values of dose factors, primarily through the use of effective dose conversion factors for inhalation (Table 6.3-1) and also through including long-lived decay products in the dose factor for a primary radionuclide.
3.2.10.00.0A	Atmospheric transport of contaminants	Although not directly included in the development of the dose factors, atmospheric transport of radionuclides and the process of deposition of contaminated ash on the ground are inherently included in the calculation of the inhalation dose associated with the eruption phase.
3.3.04.02.0A	Inhalation	Dose factors are used in evaluating exposure of the receptor arising from inhalation of contaminated resuspended particles (Equation 6.3-2).
3.3.05.01.0A	Radiation doses	Radiation doses arising from inhalation exposure during volcanic eruption will be evaluated in TSPA using dose factors developed in this analysis.

[a] SOURCE: DTN: M00303SEPFEPS2.000 [DIRS 162452].

This analysis is a revision of the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152536]). The revision was necessary to address the definition of the human receptor in 10 CFR Part 63 [DIRS 156605] and implement the ERMYN biosphere model.

This report includes the disposition of two technical errors cited in the Technical Error Report No. TER-02-0054. The function describing mass loading decay following deposition of volcanic ash (first item in the Technical Error Report) is developed and discussed in the *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965], Sections 6.2 and 6.3). Dose conversion factors for inhalation (second item in the Technical Error Report) are discussed in the *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241], Section 6.5.5). The discussion includes consideration of dose conversion factors for particles of various sizes and justification of the selection of inhalation dose conversion factor values for the biosphere model.

2. QUALITY ASSURANCE

Development of this report involves analysis of data to support performance assessment as identified in the TWP (BSC 2003 [DIRS 163602]) and thus is a quality affecting activity in accordance with AP-2.27Q, *Planning for Science Activities* [DIRS 164032]. Approved quality assurance procedures identified in the TWP (BSC 2003 [DIRS 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 [DIRS 163602], Section 8).

This analysis did not require classifying the quality level of natural barriers or other items in accordance with AP-2.22Q [DIRS 163021], *Classification Criteria and Maintenance of the Monitored Geologic Repository Q-Lists,* or other applicable implementing procedures.

3. COMPUTER SOFTWARE AND MODEL USE

This analysis was performed using the verified and validated model, ERMYN, described in the *Biosphere Model Report* (BSC 2003 [DIRS 164186]). The model files were obtained from the Model Warehouse (DTN: MO0306MWDBGSMF.001 [DIRS 163816]). The model runs were conducted using the GoldSim Graphical Simulation Environment, a graphical, object-oriented computer program for carrying out dynamic, probabilistic simulations (GoldSim Technology Group 2002 [DIRS 160643]).

GoldSim Version 7.50.100 (Software Tracking Number: 10344-7.5.100-00) was qualified under the Office of Civilian Radioactive Waste Management, Quality Assurance program for use on the Yucca Mountain Project (BSC 2003 [DIRS 161572]). The software was obtained from Software Configuration Management, was appropriate for intended use, and was used within the range of validation in accordance with procedure AP-SI.1Q [DIRS 164105], *Software Management*. GoldSim was installed on a DELL Precision Workstation 530 computer (CPU# 151554) and run under the Windows 2000 operating system.

In addition, the commercial off-the-shelf product EXCEL (Version 97 SR-2) was used for data reduction. Standard functions of that software were used to calculate values included in tables in Section 6. The use of those functions, including formulas or algorithms, inputs, and outputs are described in Attachment I.

4. INPUTS

4.1 DATA AND PARAMETERS

The inputs to this analysis are listed in Tables 4.1-1 to 4.1-4. Input parameter values and distributions were generated specifically for the biosphere model input and are appropriate for their intended use. Uncertainty in the input parameters is discussed in the individual analysis reports that document parameter development (BSC 2003 [DIRS 160964], BSC 2003 [DIRS 160965], BSC 2003 [DIRS 160976], BSC 2003 [DIRS 161239], and BSC 2003 [DIRS 161241]).

The parameters were used as input for the ERMYN model for the volcanic ash exposure scenario, which is included in the DTN: MO0306MWDBGSMF.001 [DIRS 163816]. The half-lives and branching fractions for radionuclides included in the biosphere model are listed in Table 4.1-2. Dose conversion factors for inhalation and ingestion for use in the biosphere model are shown in Table 4.1-3. Dose coefficients for exposure to contaminated soil are shown in Table 4.1-4.

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
SURFACE SOIL SUBMODEL								
Radionuclide concentration in ash deposited on ground surface		Fixed	Bq/m2	1	–	–	–	Source of contamination
Radionuclide half-life and branching fraction		Fixed	see Table 4.1-2	see Table 4.1-2	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
Soil bulk density		Triangular	kg/m^3	1500	–	1300	1700	MO0305SPASRPBM.001 [DIRS 163815]
Surface soil depth (tillage depth)		Uniform	m	–	–	0.05	0.30	MO0306SPAAEIBM.001 [DIRS 163812]
Ash bulk density		Fixed	kg/m^3	1000				MO0305SPASRPBM.001 [DIRS 163815]
Thickness of ash deposited on the ground		–	–	–	–	–	–	Calculated in TSPA model
Critical thickness for the resuspension		Uniform	mm	–	–	1	3	MO0306SPAETPBM.001 [DIRS 163814]
AIR SUBMODEL								
Mass loading for crops		Triangular	mg/m^3	0.24	–	0.050	0.600	MO0305SPAINEXI.001 [DIRS 163808]
Mass loading for receptor environments at nominal condition	Active outdoors	Triangular	mg/m^3	5.00	–	1.000	10.000	MO0305SPAINEXI.001 [DIRS 163808]
	Inactive outdoors			0.06	–	0.025	0.100	
	Active indoors			0.10	–-	0.060	0.175	
	Asleep indoors			0.03	–	0.010	0.050	
Additional mass loading for receptor environments at post-volcanic condition	Active outdoors	Triangular	mg/m^3	2.50	–	0.000	5.000	MO0305SPAINEXI.001 [DIRS 163808]
	Inactive outdoors			0.06	–	0.025	0.200	
	Active indoors			0.10	–	0.060	0.175	
	Asleep indoors			0.03	–-	0.010	0.060	
Mass loading function f(t) = $S_0 e^{-\lambda t,}$ with constant λ value	For initial ash depth < 10 mm	Triangular	1/y	0.33	–	0.2	2.0	MO0305SPAINEXI.001 [DIRS 163808] Input to TSPA model
	For initial ash depth ≥ 10 mm			0.20	–	0.125	1.0	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Enhancement factor	Active outdoors	Cumulative	–	–	–	2.8 4.4 8.4	0% 50% 100%	MO0305SPASRPBM.001 [DIRS 163815]
	Inactive outdoors Active indoors Asleep indoors	Cumulative	–	–	–	0.21 0.7 1.04	0% 50% 100%	
Ratio of Rn-222 concentration in air to flux density from soil		Fixed	$(Bq\ m^{-3})/(Bq\ m^{-2}\ s^{-1})$	300	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
PLANT SUBMODEL								
Soil-to-plant transfer factor for leafy vegetables	Chlorine	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	6.4E+01	2.0	1.1E+01	3.8E+02	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			4.6E-02	3.8	1.4E-03	1.4E+00	
	Strontium			1.7E+00	2.0	2.9E-01	1.0E+01	
	Technetium			4.6E+01	2.6	3.8E+00	5.5E+02	
	Tin			3.8E-02	2.0	6.4E-03	2.3E-01	
	Iodine			2.6E-02	9.9	7.2E-05	9.7E+00	
	Cesium			1.2E-01	2.5	1.2E-02	1.2E+00	
	Lead			1.5E-02	4.6	3.0E-04	7.7E-01	
	Radium			6.8E-02	2.7	5.1E-03	9.2E-01	
	Actinium			4.3E-03	2.0	7.2E-04	2.6E-02	
	Thorium			4.3E-03	2.8	3.2E-04	5.9E-02	
	Protactinium			4.6E-03	3.8	1.4E-04	1.4E-01	
	Uranium			1.1E-02	2.0	1.8E-03	6.6E-02	
	Neptunium			5.9E-02	4.4	1.3E-03	2.6E+00	
	Plutonium			2.9E-04	2.0	4.9E-05	1.7E-03	
	Americium			1.2E-03	2.5	1.2E-04	1.3E-02	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Soil-to-plant transfer factor for other vegetables	Chlorine	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	6.4E+01	2.0	1.1E+01	3.8E+02	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			4.6E-02	3.8	1.4E-03	1.4E+00	
	Strontium			7.9E-01	2.0	1.4E-01	4.5E+00	
	Technetium			4.4E+00	3.7	1.5E-01	1.2E+02	
	Tin			1.5E-02	3.6	5.3E-04	4.0E-01	
	Iodine			3.2E-02	4.4	7.0E-04	1.5E+00	
	Cesium			5.0E-02	2.0	8.4E-03	3.0E-01	
	Lead			9.0E-03	3.1	5.0E-04	1.6E-01	
	Radium			1.2E-02	5.3	1.6E-04	8.6E-01	
	Actinium			1.1E-03	4.9	1.8E-05	6.6E-02	
	Thorium			4.4E-04	5.6	5.3E-06	3.6E-02	
	Protactinium			1.1E-03	10.0	3.0E-06	4.3E-01	
	Uranium			6.0E-03	2.8	4.2E-04	8.5E-02	
	Neptunium			3.1E-02	4.9	5.0E-04	1.9E+00	
	Plutonium			1.9E-04	2.0	3.3E-05	1.1E-03	
	Americium			4.0E-04	2.6	3.5E-05	4.6E-03	
Soil-to-plant transfer factor for fruit	Chlorine	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	6.4E+01	2.0	1.1E+01	3.8E+02	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			4.6E-02	3.8	1.4E-03	1.4E+00	
	Strontium			2.9E-01	2.3	3.6E-02	2.4E+00	
	Technetium			4.3E+00	4.6	8.7E-02	2.1E+02	
	Tin			1.5E-02	3.6	5.3E-04	4.0E-01	
	Iodine			5.7E-02	2.8	4.1E-03	7.9E-01	
	Cesium			5.6E-02	2.8	3.8E-03	8.1E-01	
	Lead			1.2E-02	3.3	5.8E-04	2.6E-01	
	Radium			7.3E-03	4.3	1.6E-04	3.2E-01	
	Actinium			8.5E-04	3.4	3.7E-05	2.0E-02	
	Thorium			2.9E-04	4.9	4.8E-06	1.7E-02	
	Protactinium			1.1E-03	10.0	3.0E-06	4.3E-01	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Soil-to-plant transfer factor for fruit (continued)	Uranium	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	6.3E-03	2.9	3.9E-04	1.0E-01	MO0306SPAETPBM.001 [DIRS 163814]
	Neptunium			3.4E-02	6.9	2.3E-04	5.0E+00	
	Plutonium			1.8E-04	3.4	7.8E-06	4.2E-03	
	Americium			5.4E-04	2.3	6.5E-05	4.5E-03	
Soil-to-plant transfer factor for grain	Chlorine	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	2.4E+01	8.4	1.0E-01	5.8E+03	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			2.9E-02	2.0	4.8E-03	1.7E-01	
	Strontium			1.7E-01	2.0	2.8E-02	1.0E+00	
	Technetium			1.6E+00	4.3	3.8E-02	6.8E+01	
	Tin			9.2E-03	2.0	1.5E-03	5.5E-02	
	Iodine			2.5E-02	10.0	6.6E-05	9.4E+00	
	Cesium			2.0E-02	2.2	2.7E-03	1.6E-01	
	Lead			5.5E-03	2.1	8.2E-04	3.8E-02	
	Radium			3.1E-03	4.0	8.8E-05	1.1E-01	
	Actinium			5.4E-04	2.9	3.6E-05	8.0E-03	
	Thorium			1.7E-04	5.2	2.4E-06	1.2E-02	
	Protactinium			9.5E-04	7.2	5.9E-06	1.5E-01	
	Uranium			1.1E-03	3.6	4.1E-05	3.1E-02	
	Neptunium			4.4E-03	6.9	3.1E-05	6.3E-01	
	Plutonium			1.9E-05	4.2	4.8E-07	7.8E-04	
	Americium			7.5E-05	3.2	3.8E-06	1.5E-03	
Soil-to-plant transfer factor for forage crops	Chlorine	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	7.5E+01	2.0	1.3E+01	4.5E+02	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			1.5E-01	5.5	1.9E-03	1.3E+01	
	Strontium			2.1E+00	2.1	3.2E-01	1.3E+01	
	Technetium			2.7E+01	2.7	2.1E+00	3.5E+02	
	Tin			1.6E-01	5.8	1.7E-03	1.5E+01	
	Iodine			4.0E-02	10.0	1.1E-04	1.5E+01	
	Cesium			1.3E-01	3.3	6.3E-03	2.8E+00	
	Lead			1.8E-02	7.0	1.2E-04	2.8E+00	
	Radium			8.2E-02	3.0	4.9E-03	1.4E+00	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Soil-to-plant transfer factor for forage crops (continued)	Actinium	Lognormal[b]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	1.7E-02	5.4	2.2E-04	1.3E+00	MO0306SPAETPBM.001 [DIRS 163814]
	Thorium			1.0E-02	4.2	2.5E-04	3.9E-01	
	Protactinium			1.9E-02	6.7	1.4E-04	2.5E+00	
	Uranium			1.7E-02	6.1	1.6E-04	1.9E+00	
	Neptunium			5.8E-02	5.6	6.8E-04	4.9E+00	
	Plutonium			1.0E-03	10.0	2.7E-06	3.9E-01	
	Americium			2.1E-03	10.0	5.5E-06	7.9E-01	
Correlation coefficient for transfer factors with solid-liquid partition coefficients		Fixed			–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Dry-to-wet weight ratio	Leafy vegetables			–	–	0.041	0%	MO0306SPAAEIBM.001 [DIRS 163812]
						0.054	17%	
						0.060	33%	
						0.078	50%	
						0.081	67%	
						0.084	83%	
						0.093	100%	
	Other vegetables	Cumulative	kg_{dry}/kg_{wet}	–	–	0.035	0%	
						0.063	17%	
						0.078	33%	
						0.08	50%	
						0.103	67%	
						0.122	83%	
						0.240	100%	
	Fruit	Cumulative	kg_{dry}/kg_{wet}	–	–	0.062	0%	
						0.084	25%	
						0.102	50%	
						0.155	75%	
						0.194	100%	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name			Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Dry-to-wet weight ratio (continued)		Grain	Cumulative	kg_{dry}/kg_{wet}	–	–	0.891 0.896 0.906 0.918	0% 33% 67% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
		Forage	Cumulative	kg_{dry}/kg_{wet}	–	–	0.182 0.227 0.238	0% 75% 100%	
Translocation factor		Leafy vegetables	Fixed	–	1.0	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
		Other vegetables Fruit Grain	Cumulative	–	–	–	0.05 0.10 0.30	0 % 50 % 100%	
		Forage	Fixed	–	1.0	–	–	–	
Weathering half-life			Cumulative	d	14	–	5 14 30	0 % 50 % 100 %	MO0306SPAETPBM.001 [DIRS 163814]
Crop growing time	Current climate	Leafy veg.	Fixed	d	75	–	–	–	MO0306SPAAEIBM.001 [DIRS 163812]
		Other veg.			80	–	–	–	
		Fruit			160	–	–	–	
		Grain			200	–	–	–	
		Forage			75	–	–	–	
	Future climate	Leafy veg.	Fixed	d	75	–	–	–	
		Other veg.			100	–	–	–	
		Fruit			105	–	–	–	
		Grain			185	–	–	–	
		Forage			90	–	–	–	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Crop wet yield	Leafy veg.	Cumulative	kg/m^2	–	–	1.08 1.46 1.78 2.01 2.98 3.25 3.83 7.79 7.85	0% 5% 20% 35% 50% 65% 80% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Other veg.	Cumulative	kg/m^2	–	–	2.8 3.37 3.56 3.64 4.92 5.15 6.61	0% 5% 28% 51% 72% 95% 100%	
	Fruit	Cumulative	kg/m^2	–	–	0.73 1.51 2.67 2.92 3.00 3.63 6.89	0% 5% 28% 51% 72% 95% 100%	
	Grain	Cumulative	kg/m^2	–	–	0.27 0.28 0.44 0.54 1.10 1.22	0% 5% 35% 65% 95% 100%	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Crop wet yield (continued)	Forage	Cumulative	kg/m^2	–	–	0.69 1.02 1.87 5.78 6.28	0% 5% 73% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
Crop dry biomass	Leafy veg.	Cumulative	kg/m^2	–	–	0.10 0.13 0.14 0.15 0.16 0.18 0.30 0.42 0.50	0% 5% 20% 35% 50% 65% 80% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Other vegetables	Cumulative	kg/m^2	–	–	0.30 0.40 0.41 0.43 0.44 0.46 0.60	0% 5% 28% 51% 73% 95% 100%	
	Fruit	Cumulative	kg/m^2	–	–	0.10 0.56 0.60 0.65 0.68 1.30	0% 5% 35% 65% 95% 100%	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Crop dry biomass (continued)	Grain	Cumulative	kg/m^2	–	–	0.50 0.61 0.74 1.20 1.97 2.20	0% 5% 35% 65% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Forage	Cumulative	kg/m^2	–	–	0.10 0.23 0.34 1.38 1.50	0% 5% 73% 95% 100%	
Dry deposition velocity		Cumulative	m/s	–	–	3E-4 1E-3 8E-3 3E-2 3E-1	0 % 16 % 50 % 84 % 100 %	MO0306SPAETPBM.001 [DIRS 163814]
ANIMAL SUBMODEL								
Animal product transfer coefficients for meat	Chlorine	Lognormal[b]	d/kg	4.6E-02	2.0	7.7E-03	2.7E-01	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			8.8E-02	5.8	9.6E-04	8.0E+00	
	Strontium			1.4E-03	4.4	3.1E-05	6.2E-02	
	Technetium			1.1E-03	7.2	6.9E-06	1.8E-01	
	Tin			1.9E-02	4.6	3.8E-04	9.9E-01	
	Iodine			1.0E-02	2.8	6.8E-04	1.5E-01	
	Cesium			2.4E-02	2.6	2.1E-03	2.7E-01	
	Lead			6.3E-04	2.6	5.4E-05	7.5E-03	
	Radium			8.1E-04	2.1	1.1E-04	5.7E-03	
	Actinium			7.9E-05	8.2	3.5E-07	1.8E-02	
	Thorium			1.1E-04	10.0	2.8E-07	4.0E-02	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Animal product transfer coefficients for meat (continued)	Protactinium	Lognormal[b]	d/kg	6.6E-05	10.0	1.8E-07	2.5E-02	MO0306SPAETPBM.001 [DIRS 163814]
	Uranium			4.8E-04	3.0	2.9E-05	7.8E-03	
	Neptunium			3.4E-04	8.8	1.3E-06	9.0E-02	
	Plutonium			1.3E-05	10.0	3.3E-08	4.7E-03	
	Americium			3.4E-05	9.0	1.2E-07	9.9E-03	
Animal product transfer coefficients for milk	Chlorine			1.8E-02	2.0	2.9E-03	1.0E-01	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			5.7E-03	2.5	5.5E-04	6.0E-02	
	Strontium			1.7E-03	2.0	2.8E-04	1.0E-02	
	Technetium			2.1E-03	6.0	2.0E-05	2.1E-01	
	Tin			1.1E-03	2.0	1.8E-04	6.3E-03	
	Iodine			9.1E-03	2.0	1.5E-03	5.4E-02	
	Cesium			7.7E-03	2.0	1.3E-03	4.6E-02	
	Lead			1.7E-04	3.0	1.0E-05	2.9E-03	
	Radium			5.8E-04	2.0	1.0E-04	3.4E-03	
	Actinium			7.6E-06	4.1	2.0E-07	2.9E-04	
	Thorium			4.4E-06	2.0	7.4E-07	2.6E-05	
	Protactinium			4.4E-06	2.0	7.4E-07	2.6E-05	
	Uranium			4.9E-04	2.0	8.1E-05	2.9E-03	
	Neptunium			6.3E-06	2.0	1.0E-06	3.9E-05	
	Plutonium			2.3E-07	7.7	1.2E-09	4.4E-05	
	Americium			1.6E-06	4.2	3.9E-08	6.3E-05	
Animal product transfer coefficients for poultry	Chlorine	Lognormal[b]	d/kg	3.0E-02	2.0	5.0E-03	1.8E-01	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			5.1E+00	3.6	1.9E-01	1.4E+02	
	Strontium			3.1E-02	5.8	3.4E-04	2.9E+00	
	Technetium			6.3E-02	10.0	1.7E-04	2.4E+01	
	Tin			3.5E-02	10.0	9.4E-05	1.3E+01	
	Iodine			5.5E-02	9.7	1.6E-04	1.9E+01	
	Cesium			2.6E+00	9.8	7.2E-03	9.3E+02	
	Lead			2.5E-02	10.0	6.6E-05	9.3E+00	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Animal product transfer coefficients for poultry (continued)	Radium	Lognormal[b]	d/kg	1.7E-02	10.0	4.4E-05	6.3E+00	MO0306SPAETPBM.001 [DIRS 163814]
	Actinium			4.0E-03	2.0	6.7E-04	2.4E-02	
	Thorium			5.9E-03	8.0	2.7E-05	1.3E+00	
	Protactinium			3.0E-03	2.0	5.1E-04	1.8E-02	
	Uranium			2.4E-01	10.0	6.5E-04	9.2E+01	
	Neptunium			3.6E-03	2.0	6.0E-04	2.1E-02	
	Plutonium			1.2E-03	10.0	3.2E-06	4.6E-01	
	Americium			1.8E-03	10.0	4.8E-06	6.7E-01	
Animal product transfer coefficients for eggs	Chlorine	Lognormal[b]	d/kg	4.4E-02	10.0	1.2E-04	1.7E+01	MO0306SPAETPBM.001 [DIRS 163814]
	Selenium			7.3E+00	2.0	1.2E+00	4.4E+01	
	Strontium			2.7E-01	2.0	4.5E-02	1.6E+00	
	Technetium			2.4E+00	2.0	4.0E-01	1.4E+01	
	Tin			8.7E-02	10.0	2.3E-04	3.3E+01	
	Iodine			2.6E+00	2.0	4.4E-01	1.6E+01	
	Cesium			5.9E-01	2.3	7.2E-02	4.8E+00	
	Lead			5.6E-02	10.0	1.5E-04	2.1E+01	
	Radium			3.9E-04	10.0	1.0E-06	1.5E-01	
	Actinium			2.9E-03	2.3	3.4E-04	2.5E-02	
	Thorium			3.5E-03	7.3	2.0E-05	5.9E-01	
	Protactinium			2.0E-03	2.0	3.4E-04	1.2E-02	
	Uranium			6.3E-01	2.5	6.0E-02	6.7E+00	
	Neptunium			3.4E-03	2.4	3.4E-04	3.3E-02	
	Plutonium			1.7E-03	7.4	9.7E-06	2.9E-01	
	Americium			4.9E-03	2.0	8.2E-04	2.9E-02	
Animal consumption rate of feed	Meat	Uniform	kg/d	–	–	29	68	MO0306SPAETPBM.001 [DIRS 163814]
	Milk			–	–	50	73	
	Poultry			–	–	0.12	0.40	
	Eggs			–	–	0.12	0.40	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Animal consumption rate of water	Meat	Fixed	L/d	60	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
	Milk	Uniform		–	–	60	100	
	Poultry	Fixed		0.5	–	–	–	
	Eggs	Fixed		0.5	–	–	–	
Animal consumption rate of soil	Meat	Uniform	kg/d	–	–	0.4	1.0	MO0306SPAETPBM.001 [DIRS 163814]
	Milk			–	–	0.8	1.1	
	Poultry			–	–	0.01	0.03	
	Eggs			–	–	0.01	0.03	
EXTERNAL EXPOSURE SUBMODEL								
Population proportion	Outdoor workers	Uniform	%	–	–	2.9	10.7	MO0306SPACRBSM.001 [DIRS 163813]
	Indoor workers			–	–	Cal'ed	Cal'ed	
	Commuters			–	–	4.9	16.3	
	Non-workers			–	–	34.4	44.0	
Time spent by outdoor workers	Active outdoors	Lognormal[c]	h/d	3.1	0.2	2.6	3.7	MO0306SPACRBSM.001 [DIRS 163813]
	Inactive outdoors			4.2	0.3	3.5	5.0	
	Active indoors			6.4	Cal'ed	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			2.0	0.4	1.2	3.3	
Time spent by indoor workers	Active outdoors	Lognormal[c]	h/d	0.3	0.1	0.1	0.7	
	Inactive outdoors			1.5	0.2	1.1	2.1	
	Active indoors			11.9	Cal'ed	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			2.0	0.4	1.2	3.3	
Time spent by commuters	Active outdoors	Lognormal[c]	h/d	0.3	0.1	0.1	0.7	
	Inactive outdoors			2.0	0.2	1.5	2.6	
	Active indoors			5.1	Cal'ed	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			8.3	0.6	6.9	10.0	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Time spent by non-workers	Active outdoors	Lognormal[c]	h/d	0.3	0.1	0.1	0.7	MO0306SPACRBSM.001 [DIRS 163813]
	Inactive outdoors			1.2	0.2	0.8	1.8	
	Active indoors			12.2	Cal'ed	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			2.0	0.4	1.2	3.3	
Building shielding factor	C-14	Fixed	–	0.2	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
	Cl-36			0.4	–	–	–	
	Se-79			0.1	–	–	–	
	Sr-90D			0.4	–	–	–	
	Tc-99			0.2	–	–	–	
	Sn-126D			0.4	–	–	–	
	I-129			0.1	–	–	–	
	Cs-135			0.1	–	–	–	
	Cs-137D			0.4	–	–	–	
	Pu-242			0.1	–	–	–	
	U-238D			0.4	–	–	–	
	Pu-238			0.1	–	–	–	
	U-234			0.2	–	–	–	
	Th-230			0.3	–	–	–	
	Ra-226D			0.4	–	–	–	
	Pb-210D			0.4	–	–	–	
	Pu-240			0.1	–	–	–	
	U-236			0.1	–	–	–	
	Th-232			0.2	–	–	–	
	Ra-228D			0.4	–	–	–	
	U-232			0.3	–	–	–	
	Th-228D			0.4	–	–	–	
	Am-243D			0.4	–	–	–	
	Pu-239			0.3	–	–	–	

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
Building shielding factor (continued)	U-235D	Fixed	–	0.4	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
	Pa-231			0.4	–	–	–	
	Ac-227D			0.4	–	–	–	
	Am-241			0.2	–	–	–	
	Np-237D			0.4	–	–	–	
	U-233			0.4	–	–	–	
	Th-229D			0.4	–	–	–	
Dose coefficient for exposure to contaminated ground surface		Fixed			–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
INHALATION SUBMODEL								
Breathing rate	Active outdoors			1.57	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
	Inactive outdoors			1.08	–	–	–	
	Active indoors			1.08	–	–	–	
	Asleep indoors			0.39	–	–	–	
	Away			1.08 [d]	–	–	–	
Dose conversion factor for inhalation		Fixed			–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
Equilibrium factor for ^{222}Rn decay products	Outdoors			–	–	0.5	0.7	MO0306SPAETPBM.001 [DIRS 163814]
	Indoors			–	–	0.3	0.5	
Dose conversion factor for inhalation of ^{222}Rn decay products		Fixed			–	–	–	MO0306SPACRBSM.001 [DIRS 163813]

Table 4.1-1. Summary of Input Parameter Values and Their Uncertainty Distributions (continued)

Parameter Name		Distribution Type	Units	Mean, Mode, or Fixed Value	SD or SE[a]	Minimum or Value for CD [a]	Maximum or Percentile for CD [a]	DTN/Reference
INGESTION SUBMODEL								
Consumption rate of locally produced food	Leafy vegetables	Lognormal[c]	kg/y	3.78	0.88	–	–	MO0306SPACRBSM.001 [DIRS 163813]
	Other vegetables			4.73	0.67	–	–	
	Fruit			12.68	1.36	–	–	
	Grain			0.23	0.11	–	–	
	Meat			2.85	0.65	–	–	
	Milk			4.66	1.68	–	–	
	Poultry			0.42	0.13	–	–	
	Eggs			5.30	0.83	–	–	
Inadvertent soil ingestion rate		Cumulative	mg/d	–	–	50 100 200	0% 50% 100%	MO0306SPACRBSM.001 [DIRS 163813]
Dose conversion factor for ingestion		Fixed	Sv/Bq	See Table 4.1-3	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
Additional Input Used for Developing Dose Factors								
Estimated proportion of population for volcanic scenario	Non-workers	Fixed	–	0.392	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
	Commuters			0.125	–	–	–	
	Local outdoor workers			0.055	–	–	–	
	Local indoor workers			0.428	–	–	–	

NOTES: [a] SD = standard deviation; SE = standard error; CD = cumulative distribution
[b] Lognormal distribution defined using geometric mean and geometric standard deviation
[c] Lognormal distributions defined using arithmetic mean and arithmetic standard deviation
[d] Breathing rate away (not in contaminated area) has no effect on the results of BDCF calculations. Any value can be used.

Table 4.1-2. Primary Radionuclides and Their Decay Products Included in the Biosphere Model

Primary Radionuclide	Short-lived Decay Product [a]	Branching Fraction, %	Half-life
Carbon-14 (^{14}C)		100	5730 yr
Chlorine-36 (^{36}Cl)		100	3.01E+05 yr
Selenium-79 (^{79}Se)		100	6.50E+04 yr
Strontium-90 (^{90}Sr)		100	29.12 yr
	Yttrium-90 (^{90}Y)	100	64.0 h
Technetium-99 (^{99}Tc)		100	2.13E+05 yr
Tin-126 (^{126}Sn)		100	1.0E+05 yr
	Antimony-126m (^{126m}Sb)	100	19.0 min
	Antimony-126 (^{126}Sb)	14	12.4 d
Iodine-129 (^{129}I)		100	1.57E+07 yr
Cesium-135 (^{135}Cs)		100	2.3E+06 yr
Cesium-137 (^{137}Cs)		100	30.0 yr
	Barium-137m (^{137m}Ba)	94.60	2.552 min
Thorium Series (4n)			
Plutonium-240 (^{240}Pu)		100	6.537E+03 yr
Uranium-236 (^{236}U)		100	2.3415E+07 yr
Thorium-232 (^{232}Th)		100	1.405E+10 yr
Radium-228 (^{228}Ra)		100	5.75E+00 yr
	Actinium-228 (^{228}Ac)	100	6.13 hr
Uranium-232 (^{232}U)		100	72 yr
Thorium-228 (^{228}Th)		100	1.9131 yr
	Radium-224 (^{224}Ra)	100	3.66 d
	Radon-220 (^{220}Rn)	100	55.6 s
	Polonium-216 (^{216}Po)	100	0.15 s
	Lead-212 (^{212}Pb)	100	10.64 h
	Bismuth-212 (^{212}Bi)	100	60.55 min
	Polonium-212 (^{212}Po)	64.07	0.305 μs
	Thallium-208 (^{208}Tl)	35.93	3.07 min
Neptunium Series (4n+1)			
Americium-241 (^{241}Am)		100	432.2 yr
Neptunium-237 (^{237}Np)		100	2.14E+06 yr
	Protactinium-233 (^{233}Pa)	100	27.0 d
Uranium-233 (^{233}U)		100	1.585E+05 yr
Thorium-229 (^{229}Th)		100	7340 yr
	Radium-225 (^{225}Ra)	100	14.8 d
	Actinium-225 (^{225}Ac)	100	10.0 d
	Francium-221 (^{221}Fr)	100	4.8 min
	Astatine-217 (^{217}At)	100	32.3 ms
	Bismuth-213 (^{213}Bi)	100	45.65 min
	Polonium-213 (^{213}Po)	97.84	4.2 μs
	Thallium-209 (^{209}Tl)	2.16	2.20 min
	Lead-209 (^{209}Pb)	–	3.253 h

Table 4.1-2. Primary Radionuclides and Their Decay Products Included in the Biosphere Model (continued)

Primary Radionuclide	Short-lived Decay Product [a]	Branching Fraction, %	Half-life
Uranium Series (4n+2)			
Plutonium-242 (^{242}Pu)		100	3.763E+05 yr
Uranium-238 (^{238}U)		100	4.468E+09 yr
	Thorium-234 (^{234}Th)	100	24.10 d
	Protactinium-234m (^{234m}Pa)	99.80	1.17 min
	Protactinium-234 (^{234}Pa)	0.33	6.70 h
Plutonium-238 (^{238}Pu)		100	87.74E+01 yr
Uranium-234 (^{234}U)		100	2.445E+05 yr
Thorium-230 (^{230}Th)		100	7.7E+04 yr
Radium-226 (^{226}Ra)		100	1600 yr
	Radon-222 (^{222}Rn)	100	3.8235 d
	Polonium-218 (^{218}Po)	100	3.05 min
	Lead-214 (^{214}Pb)	99.98	26.8 min
	Astatine-218 (^{218}At)	0.02	2 s
	Bismuth-214 (^{214}Bi)	100	19.9 min
	Polonium-214 (^{214}Po)	99.98	164.3 μs
	Thallium-210 (^{210}Tl)	0.02	1.3 min
Lead-210 (^{210}Pb)		100	22.3 yr
	Bismuth-210 (^{210}Bi)	100	5.012 d
	Polonium-210 (^{210}Po)	100	138.38 d
Actinium Series (4n+3)			
Americium-243 (^{243}Am)		100	7380 yr
	Neptunium-239 (^{239}Np)	100	2.355 d
Plutonium-239 (^{239}Pu)		100	2.4065E+04 yr
Uranium-235 (^{235}U)		100	703.8E6 yr
	Thorium-231 (^{231}Th)	100	25.52 hr
Protactinium-231 (^{231}Pa)		100	3.276E+04 yr
Actinium-227 (^{227}Ac)		100	21.773 yr
	Thorium-227 (^{227}Th)	98.62	18.718 d
	Francium-223 (^{223}Fr)	1.38	21.8 min
	Radium-223 (^{223}Ra)	100	11.434 d
	Radon-219 (^{219}Rn)	100	3.96 s
	Polonium-215 (^{215}Po)	100	1.78 ms
	Lead-211 (^{211}Pb)	100	36.1 min
	Bismuth-211 (^{211}Bi)	100	2.14 min
	Thallium-207 (^{207}Tl)	99.72	4.77 min
	Polonium-211 (^{211}Po)	0.28	0.516 s

SOURCE: MO0306SPACRBSM.001 [DIRS 163813]

NOTE: [a] Short-lived decay products of primary radionuclides are assumed to be in secular equilibrium with their parents (Section 6.1.1).

Table 4.1-3. Dose Conversion Factors for Inhalation and Ingestion of Radionuclides of Interest

Primary Radionuclide	Short-lived Decay Product	Dose Conversion Factors (Sv/Bq)	
		Inhalation	Ingestion
Carbon-14 (^{14}C) (as CO_2)		6.36E-12	5.64E-10
Chlorine-36 (^{36}Cl)		5.93E-09	8.18E-10
Selenium-79 (^{79}Se)		2.66E-09	2.35E-09
Strontium-90 (^{90}Sr)		6.47E-08	3.85E-08
	Yttrium-90 (^{90}Y)	2.28E-09	2.91E-09
Technetium-99 (^{99}Tc)		2.25E-09	3.95E-10
Tin-126 (^{126}Sn)		2.69E-08	5.27E-09
	Antimony-126m (^{126m}Sb)	9.17E-12	2.54E-11
	Antimony-126 (^{126}Sb)	3.17E-09	2.89E-09
Iodine-129 (^{129}I)		4.69E-08	7.46E-08
Cesium-135 (^{135}Cs)		1.23E-09	1.91E-09
Cesium-137 (^{137}Cs)		8.63E-09	1.35E-08
	Barium-137m (^{137m}Ba)	–	–
Thorium Series (4n)			
Plutonium-240 (^{240}Pu)		1.16E-04	9.56E-07
Uranium-236 (^{236}U)		3.39E-05	7.26E-08
Thorium-232 (^{232}Th)		4.43E-04	7.38E-07
Radium-228 (^{228}Ra)		1.29E-06	3.88E-07
	Actinium-228 (^{228}Ac)	8.33E-08	5.85E-10
Uranium-232 (^{232}U)		1.78E-04	3.54E-07
Thorium-228 (^{228}Th)		9.23E-05	1.07E-07
	Radium-224 (^{224}Ra)	8.53E-07	9.89E-08
	Radon-220 (^{220}Rn)	–	–
	Polonium-216 (^{216}Po)	–	–
	Lead-212 (^{212}Pb)	4.56E-08	1.23E-08
	Bismuth-212 (^{212}Bi)	5.83E-09	2.87E-10
	Polonium-212 (^{212}Po)	–	–
	Thallium-208 (^{208}Tl)	–	–
Neptunium Series (4n+1)			
Americium-241 (^{241}Am)		1.20E-04	9.84E-07
Neptunium-237 (^{237}Np)		1.46E-04	1.20E-06
	Protactinium-233 (^{233}Pa)	2.58E-09	9.81E-10
Uranium-233 (^{233}U)		3.66E-05	7.81E-08
Thorium-229 (^{229}Th)		5.80E-04	9.54E-07
	Radium-225 (^{225}Ra)	2.10E-06	1.04E-07
	Actinium-225 (^{225}Ac)	2.92E-06	3.00E-08
	Francium-221 (^{221}Fr)	–	–
	Astatine-217 (^{217}At)	–	–
	Bismuth-213 (^{213}Bi)	4.63E-09	1.95E-10
	Polonium-213 (^{213}Po)	–	–
	Thallium-209 (^{209}Tl)	–	–
	Lead-209 (^{209}Pb)	2.56E-11	5.75E-11

Table 4.1-3. Dose Conversion Factors for Inhalation and Ingestion of Radionuclides of Interest (continued)

Primary Radionuclide	Short-lived Decay Product	Dose Conversion Factors (Sv/Bq)	
Uranium Series (4n + 2)			
Plutonium-242 (^{242}Pu)		1.11E-04	9.08E-07
Uranium-238 (^{238}U)		3.20E-05	6.88E-08
	Thorium-234 (^{234}Th)	9.47E-09	3.69E-09
	Protactinium-234m (^{234m}Pa)	–	–
	Protactinium-234 (^{234}Pa)	2.20E-10	5.84E-10
Plutonium-238 (^{238}Pu)		1.06E-04	8.65E-07
Uranium-234 (^{234}U)		3.58E-05	7.66E-08
Thorium-230 (^{230}Th)		8.80E-05	1.48E-07
Radium-226 (^{226}Ra)		2.32E-06	3.58E-07
	Radon-222 (^{222}Rn)	–	–
	Polonium-218 (^{218}Po)	–	–
	Lead-214 (^{214}Pb)	2.11E-09	1.69E-10
	Astatine-218 (^{218}At)	–	–
	Bismuth-214 (^{214}Bi)	1.78E-09	7.64E-11
	Polonium-214 (^{214}Po)	–	–
	Thallium-210 (^{210}Tl)	–	–
Lead-210 (^{210}Pb)		3.67E-06	1.45E-06
	Bismuth-210 (^{210}Bi)	5.29E-08	1.73E-09
	Polonium-210 (^{210}Po)	2.54E-06	5.14E-07
Actinium Series (4n + 3)			
Americium-243 (^{243}Am)		1.19E-04	9.79E-07
	Neptunium-239 (^{239}Np)	6.78E-10	8.82E-10
Plutonium-239 (^{239}Pu)		1.16E-04	9.56E-07
Uranium-235 (^{235}U)		3.32E-05	7.19E-08
	Thorium-231 (^{231}Th)	2.37E-10	3.65E-10
Protactinium-231 (^{231}Pa)		3.47E-04	2.86E-06
Actinium-227 (^{227}Ac)		1.81E-03	3.80E-06
	Thorium-227 (^{227}Th)	4.37E-06	1.03E-08
	Francium-223 (^{223}Fr)	1.68E-09	2.33E-09
	Radium-223 (^{223}Ra)	2.12E-06	1.78E-07
	Radon-219 (^{219}Rn)	–	–
	Polonium-215 (^{215}Po)	–	–
	Lead-211 (^{211}Pb)	2.35E-09	1.42E-10
	Bismuth-211 (^{211}Bi)	–	–
	Thallium-207 (^{207}Tl)	–	–
	Polonium-211 (^{211}Po)	–	–

SOURCE: MO0306SPACRBSM.001[DIRS 163813]

NOTES:

DCFs are in units of Sv/Bq.
1 Sv = 100 rem
1 Ci = 3.7×10^{10} Bq

Table 4.1-4. Dose Coefficients for Exposure to Contaminated Soil for Radionuclides of Interest

Primary Radionuclide	**Short-lived Decay Product**	**Dose Coefficient**	
		Ground Surface Sv/s per Bq/m^2	**Infinite Depth Sv/s per Bq/m^3**
Carbon-14 (^{14}C)		1.61E-20	7.20E-23
Chlorine-36 (^{36}Cl)		6.73E-19	1.28E-20
Selenium-79 (^{79}Se)		2.07E-20	9.96E-23
Strontium-90 (^{90}Sr)		2.84E-19	3.77E-21
	Yttrium-90 (^{90}Y)	5.32E-18	1.28E-19
Technetium-99 (^{99}Tc)		7.80E-20	6.72E-22
Tin-126 (^{126}Sn)		5.47E-17	7.89E-19
	Antimony-126m (^{126m}Sb)	1.52E-15	4.98E-17
	Antimony-126 (^{126}Sb)	2.78E-15	9.16E-17
Iodine-129 (^{129}I)		2.58E-17	6.93E-20
Cesium-135 (^{135}Cs)		3.33E-20	2.05E-22
Cesium-137 (^{137}Cs)		2.85E-19	4.02E-21
	Barium-137m (^{137m}Ba)	5.86E-16	1.93E-17
Thorium Series (4n)			
Plutonium-240 (^{240}Pu)		8.03E-19	7.85E-22
Uranium-236 (^{236}U)		6.50E-19	1.15E-21
Thorium-232 (^{232}Th)		5.51E-19	2.79E-21
Radium-228 (^{228}Ra)		0.00E+00	0.00E+00
	Actinium-228 (^{228}Ac)	9.28E-16	3.20E-17
Uranium-232 (^{232}U)		1.01E-18	4.83E-21
Thorium-228 (^{228}Th)		2.35E-18	4.25E-20
	Radium-224 (^{224}Ra)	9.57E-18	2.74E-19
	Radon-220 (^{220}Rn)	3.81E-19	1.23E-20
	Polonium-216 (^{216}Po)	1.65E-20	5.58E-22
	Lead-212 (^{212}Pb)	1.43E-16	3.77E-18
	Bismuth-212 (^{212}Bi)	1.79E-16	6.27E-18
	Polonium-212 (^{212}Po)	0.00E+00	0.00E+00
	Thallium-208 (^{208}Tl)	2.98E-15	1.23E-16
Neptunium Series (4n+1)			
Americium-241 (^{241}Am)		2.75E-17	2.34E-19
Neptunium-237 (^{237}Np)		2.87E-17	4.17E-19
	Protactinium-233 (^{233}Pa)	1.95E-16	5.46E-18
Uranium-233 (^{233}U)		7.16E-19	7.48E-21
Thorium-229 (^{229}Th)		8.54E-17	1.72E-18
	Radium-225 (^{225}Ra)	1.33E-17	5.90E-20
	Actinium-225 (^{225}Ac)	1.58E-17	3.41E-19
	Francium-221 (^{221}Fr)	2.98E-17	8.22E-19
	Astatine-217 (^{217}At)	3.03E-19	9.49E-21
	Bismuth-213 (^{213}Bi)	1.32E-16	4.10E-18
	Polonium-213 (^{213}Po)	0.00E+00	0.00E+00
	Thallium-209 (^{209}Tl)	1.90E-15	6.92E-17
	Lead-209 (^{209}Pb)	3.01E-19	4.14E-21

Table 4.1-4. Dose Coefficients for Exposure to Contaminated Soil for Radionuclides of Interest (continued)

Primary Radionuclide	Short-lived Decay Product	Dose Coefficient	
		Ground Surface Sv/s per Bq/m^2	Infinite Depth Sv/s per Bq/m^3
Uranium Series (4n + 2)			
Plutonium-242 (^{242}Pu)		6.67E-19	6.85E-22
Uranium-238 (^{238}U)		5.51E-19	5.52E-22
	Thorium-234 (^{234}Th)	8.32E-18	1.29E-19
	Protactinium-234m (^{234m}Pa)	1.53E-17	4.80E-19
	Protactinium-234 (^{234}Pa)	1.84E-15	6.18E-17
Plutonium-238 (^{238}Pu)		8.38E-19	8.10E-22
Uranium-234 (^{234}U)		7.48E-19	2.15E-21
Thorium-230 (^{230}Th)		7.50E-19	6.47E-21
Radium-226 (^{226}Ra)		6.44E-18	1.70E-19
	Radon-222 (^{222}Rn)	3.95E-19	1.26E-20
	Polonium-218 (^{218}Po)	8.88E-21	3.02E-22
	Lead-214 (^{214}Pb)	2.44E-16	7.18E-18
	Astatine-218 (^{218}At)	4.18E-18	3.13E-20
	Bismuth-214 (^{214}Bi)	1.41E-15	5.25E-17
	Polonium-214 (^{214}Po)	8.13E-20	2.75E-21
	Thallium-210 (^{210}Tl)	–	–
Lead-210 (^{210}Pb)		2.48E-18	1.31E-20
	Bismuth-210 (^{210}Bi)	1.05E-18	1.93E-20
	Polonium-210 (^{210}Po)	8.29E-21	2.80E-22
Actinium Series (4n + 3)			
Americium-243 (^{243}Am)		5.35E-17	7.60E-19
	Neptunium-239 (^{239}Np)	1.63E-16	4.03E-18
Plutonium-239 (^{239}Pu)		3.67E-19	1.58E-21
Uranium-235 (^{235}U)		1.48E-16	3.86E-18
	Thorium-231 (^{231}Th)	1.85E-17	1.95E-19
Protactinium-231 (^{231}Pa)		4.07E-17	1.02E-18
Actinium-227 (^{227}Ac)		1.57E-19	2.65E-21
	Thorium-227 (^{227}Th)	1.04E-16	2.79E-18
	Francium-223 (^{223}Fr)	5.65E-17	1.06E-18
	Radium-223 (^{223}Ra)	1.28E-16	3.23E-18
	Radon-219 (^{219}Rn)	5.49E-17	1.65E-18
	Polonium-215 (^{215}Po)	1.74E-19	5.44E-21
	Lead-211 (^{211}Pb)	5.08E-17	1.64E-18
	Bismuth-211 (^{211}Bi)	4.58E-17	1.37E-18
	Thallium-207 (^{207}Tl)	3.76E-18	1.06E-19
	Polonium-211 (^{211}Po)	7.61E-18	2.55E-19

SOURCE: MO0306SPACRBSM.001 [DIRS 163813]

4.2 CRITERIA

Table 4.2-1 lists the requirements from the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 161770], Table 2-3) that are applicable to this analysis.

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 161770], Table 2-3

The following NRC staff review criteria (acceptance criteria) from Section 2.2.1.3.14 (Biosphere Characteristics) of the Yucca Mountain Review Plan, Draft Final Report (NRC 2003 [DIRS 162418]), based on the requirements of 10 CFR 63.114, 63.305, and 63.312 [DIRS 156605], are considered when modeling biosphere characteristics. The acceptance criteria are developed for NRC staff review of a repository license application and provide insight as to areas of interest for consideration when developing documentation of biosphere modeling. Only those numbered descriptions of the review criteria in Section 2.2.1.3.14 of the Review Plan that apply to this analysis are included here.

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

- 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.

- 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.

- 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 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 total system performance assessment abstractions.

Acceptance Criterion 2–Data Are Sufficient for Model Justification.

- The parameter values used in the safety case 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 [DIRS 156605]. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

- Data are sufficient to assess the degree to which FEPs related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63 [DIRS 156605], the U.S. Department of Energy should demonstrate that FEPs, 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.

- Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible and reasonably account for uncertainties and variabilities, and are consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63 [DIRS 156605].

- 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.

- 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.

- 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

No codes and standards, other than those identified the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 161770], Table 2-3) and determined to be applicable, were used in this analysis.

5. ASSUMPTIONS

5.1 RECEPTOR ACTIVITY LEVELS DURING ERUPTION

Assumption 1–During a volcanic eruption, the receptor behavior and the related effective daily breathing rate is the same as at nominal conditions.

Rationale–To calculate DFs for the eruption phase of a volcanic event, it is assumed that for the duration of volcanic eruption, the behavior of the receptor would not change compared with typical behavior, to the extend that the effective daily breathing rate would be significantly affected. Because a volcanic eruption is an unusual event, it is possible that people would not behave as they would under normal circumstances. However, it is difficult to predict how the human behavior would change. Some people may seek shelter from falling ash and spend more time indoors where exposure would be reduced, while other people may, for instance, perform ash removal from their property and spend more time outdoors. Under normal, variable wind conditions, the initial, predicted thickness of tephra deposit 20 km south of Yucca Mountain, calculated for the *Total System Performance Assessment for the Site Recommendation* (CRWMS M&O 2000 [153246], Section 3.10.5.1), ranged from less than 1×10^{-8} cm to about 10 cm. About 66 percent of predicted depths were less than 0.1 mm, about 80 percent were less than 1 mm, and about 95 percent were less than 1 cm. In addition, the median duration of a predicted volcanic eruption was 8.2 days (CRWMS M&O 2000 [153246], Section 5.2.9.9). For the small amount of ashfall and an eruption lasting for several days, it is likely that the airborne particulate concentrations would not be substantially different from the pre-eruption levels. If this is the case, people would not modify their behavior to the extent that their effective average daily breathing rate would be affected, in which case the assumption is realistic. If airborne particulate concentrations are much greater than the pre-eruption levels, people would take actions to reduce the amount of ash they inhale, such as staying indoors and wearing masks (Section 6.3.1), and this assumption would lead to conservative results. Overall, using the same lifestyle characteristics parameter values for the eruption phase dose factors as those used for the volcanic ash scenario BDCF calculations is considered reasonable.

Confirmation Status–This assumption does not require further confirmation because the approach captures possible behavioral differences in response to an unusual event, such as a volcanic eruption. Since this assumption is only used to calculate the effective average daily breathing rate, it is considered realistic.

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

5.2 INDOOR MASS LOADING DURING ERUPTION

Assumption 2–During a volcanic eruption, indoor mass loading is 50 percent of the outdoor mass loading.

Rationale–For calculating DFs, it is assumed that during volcanic eruption, the average level of mass loading indoors arising from the original deposition of tephra is one-half of that outdoors, or equivalently, the indoor reduction factor for activity concentration in air is equal to 0.5. This assumption does not concern activity concentrations resuspended due to atmospheric or mechanical processes following the initial deposition.

This assumption is based on the ratio of the post-volcanic mass loading values indoor and outdoor in the absence of soil disturbing activities causing resuspension of deposited ash. Undisturbed conditions were chosen because the process of resuspension and the resulting inhalation of resuspended particulates are included in the BDCFs.

The ERMYN divides the biosphere into the five environments (BSC 2003 [DIRS 161241], Section 6.2). These mutually exclusive environments represent the behavioral and environmental combinations for which a person may receive a substantially different rate of exposure via inhalation or external exposure. These environments are

Away from Potentially Contaminated Area environment accounts for time spent away from areas contaminated by groundwater or volcanic ash, including time spent working and commuting to work by those that work outside of contaminated areas.

Active Outdoors environment, which accounts for time spent active outdoors, includes time spent outdoors in contaminated areas conducting activities that resuspend soil.

Inactive Outdoors environment represents time spent commuting within contaminated areas and time spent outdoors in the contaminated areas conducting activities that do not resuspend soil.

Asleep Indoors includes time spent sleeping indoors within contaminated areas.

Active Indoors includes time spent awake, indoors within contaminated areas, including work time. It is calculated in the model as the remainder of the day not spent in the other environments.

Two environments that are not associated with soil disturbing activities are the inactive outdoor and asleep indoor environments. The modes of the mass loading distributions are 0.060 mg/m^3 and 0.030 mg/m^3 for the inactive outdoor and asleep indoor environments, respectively (DTN: MO0305SPAINEXI.001 [DIRS 163808]), indicating that dwellings provide about 50 percent reduction of the outdoor mass loading level.

Confirmation Status–This assumption does not require further confirmation because it is based on values that are reasonable and consistent with those developed for the biosphere model.

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

6. ANALYSIS

The objectives of this analysis were to calculate:

1. The BDCFs for the volcanic ash scenario to provide the TSPA with the capability to calculate expected dose for a given concentration of radionuclides of interest in, and thickness of, volcanic ash deposited on the ground

2. The DFs that can be used by TSPA to calculate the expected dose from the period of falling volcanic ash that occurs during the volcanic eruption.

The BDCFs are calculated using the ERMYN biosphere model. BDCFs for the volcanic ash scenario apply to the volcanic eruption modeling case of the igneous scenario class. The igneous scenario class is one of the TSPA disruptive scenario classes (BSC 2002 [DIRS 160146], pp. 47 to 48). The disruptive event scenario classes are developed using combinations of screened in FEPs that have a low probability of occurrence but may produce potentially adverse future conditions. The disruptive event scenario classes include the igneous scenario class, which in turn includes the igneous intrusion and volcanic eruption modeling cases, and the seismic scenario class, as well as a special case of the stylized analysis of human intrusion into the repository. The biosphere model for the volcanic ash scenario, and thus the BDCFs generated using this model, support only the volcanic eruption modeling case of the disruptive event scenario classes. The remaining disruptive event scenario classes result in radionuclide releases to groundwater and are supported by the biosphere model for the groundwater scenario.

6.1 GENERAL CONSIDERATIONS

6.1.1 Radionuclides Included in the Analysis

The following 23 radionuclides were identified as important for the TSPA scenario classes involving radionuclide release during a volcanic eruption: strontium-90 (^{90}Sr), technetium-99 (^{99}Tc), tin-126 (^{126}Sn), cesium-137 (^{137}Cs), lead-210 (^{210}Pb), radium-226 (^{226}Ra), actinium-227 (^{227}Ac), thorium-229 (^{229}Th), thorium-230 (^{230}Th), thorium-232 (^{232}Th), protactinium-231 (^{231}Pa), uranium-232 (^{232}U), uranium-233 (^{233}U), uranium-234 (^{234}U), uranium-236 (^{236}U), uranium-238 (^{238}U), neptunium-237 (^{237}Np), plutonium-238 (^{238}Pu), plutonium-239 (^{239}Pu), plutonium-240 (^{240}Pu), plutonium-242 (^{242}Pu), americium-241 (^{241}Am), and americium-243 (^{243}Am) (BSC 2002 [DIRS 160059], p. 39). These radionuclides are referred to in this analysis as the primary radionuclides. The list includes radionuclides that are of potential importance during both the first 20,000 years and the period of up to 1,000,000 years (BSC 2002 [DIRS 160146], Section 1.3). The biosphere model accounts for the decay products of the primary radionuclides. The short-lived decay products (half-lived less than 180 days) are considered to be in secular equilibrium with the parent radionuclide and their contributions to the BDCFs are included in the BDCF for the long-lived radionuclide (either a primary radionuclide or its long-lived decay product). Two decay products of the primary radionuclides, ^{228}Th and ^{228}Ra, have half-lives greater than 180 days and are not automatically included in the BDCFs of the parent when the biosphere model is executed. Instead, for biosphere modeling they are treated like primary radionuclides. After their BDCFs are calculated, they are added to the BDCF of the parent primary radionuclide. In the case of ^{232}Th, its BDCF includes the contribution from ^{228}Ra,

^{228}Th and their short-lived decay products. The BDCF for ^{232}U includes the contribution from ^{228}Th and its short-lived decay products.

6.1.2 Description of the Volcanic Ash Scenario

A detailed description of the volcanic ash scenario, including the associated conceptual and mathematical models, are presented in the *Biosphere Model Report* (BSC 2003 [DIRS 164186], Sections 6.3.2 and 6.5). A brief summary of the main concepts and the modeling approach for the volcanic ash scenario is presented in this section.

The general scenario (the release of radionuclides to the reference biosphere, environmental transport, and the subsequent exposure of the receptor) is shown schematically in Figure 6.1-1. The immediate source of radionuclides in the biosphere for this scenario is contaminated volcanic ash initially deposited on the ground surface following a volcanic eruption.

After radionuclides enter the biosphere, radionuclide migration through the biosphere occurs due to a number of transport processes that lead to contamination and accumulation in the environmental media (e.g., soil, air, flora, and fauna). The following environmental transport processes are explicitly included in the biosphere model for the volcanic ash scenario:

- Resuspension of contaminated soil and ash
- Dry deposition of radionuclides on crop surfaces (resuspension of contaminated soil and subsequent adhesion of soil particles on crop surfaces)
- Initial interception of deposited activity by crop surfaces
- Translocation of contaminants from the site of deposition to the edible portions of crops
- Contaminant retention by crops (considering weathering processes)
- Radionuclide uptake by crops through the roots, and subsequent crop consumption by humans and farm animals
- Radionuclide uptake by animals through consuming contaminated feed and soil, and subsequent transfer to animal products
- Exhalation of radon from the soil.

Human exposure to radionuclides in the environment arises when people come in contact with contaminated environmental media. Table 6.1-1 provides a summary of human exposure pathways included in the biosphere model, as well as environmental media and typical activities that may cause radiation exposure. Inhalation exposure arising from gaseous volcanic emissions was not considered because gaseous radionuclides were not included among radionuclides of interest (Section 6.1.1).

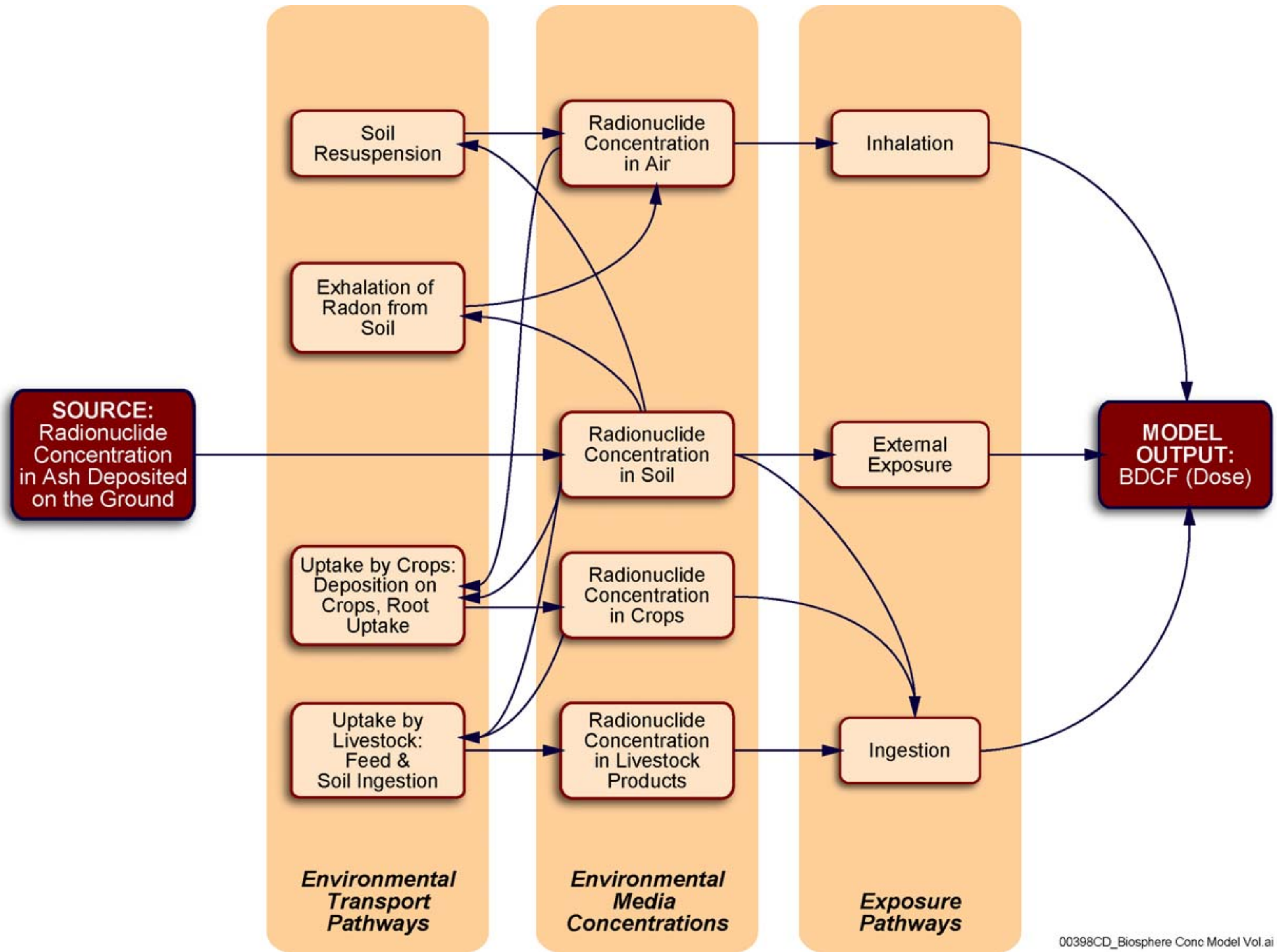


Figure 6.1-1. Conceptual Representation of the Biosphere Model for the Volcanic Ash Scenario

Table 6.1-1. Receptor Exposure Pathways for the Volcanic Ash Scenario

Environmental Medium	Exposure Mode	Exposure Pathways	Examples of Typical Activities
Soil	Ingestion	Inadvertent soil ingestion.	Recreational activities, occupational activities, gardening, fresh fruit and vegetable consumption.
Soil	External	External radiation exposure.	Activities over or near contaminated soil.
Air	Inhalation	Breathing airborne particulates.	Any outdoor activities, including soil-disturbing activities related to work and recreation.
		Breathing gases (^{222}Rn and progeny).	Miscellaneous domestic activities, including sleeping.
Plants (crops consumed by humans and farm animals)	Ingestion	Consuming locally produced crops, including leafy vegetables, other vegetables, fruit, and grain.	Eating and drinking plant material as part of the diet.
Farm Animals (animal products consumed by humans)	Ingestion	Consuming locally produced animal products, including meat (beef and pork), poultry, milk, and eggs.	Eating and drinking animal products as part of the diet.

6.1.3 Climate Change

Climate refers to the meteorological conditions that characteristically prevail in a particular region. The climate model for the Yucca Mountain region was formulated using paleoclimate and paleoenvironmental reconstructions based on microfossil records from Owens Lake, California cores and calcite isotope records from Devil's Hole, Death Valley National Park, Nevada. The sequence and duration of past climate periods are identified from the records and applied to the Yucca Mountain site, which has a similar climate setting. The temperature and precipitation records of present-day meteorological stations at colder and wetter sites are selected to represent future climate states (USGS 2001 [DIRS 158378], Section 6).

For modeling of climate change in TSPA-LA, the climate will be assumed to shift in a series of step changes between three different climate states in the first 10,000 years: present-day climate, monsoon climate (about twice the precipitation of the present day climate), and glacial transition climate (colder than monsoon but similar precipitation) (BSC 2002 [DIRS 160146], p. 75). Within the TSPA model, these shifts require coordination among the coupled submodels because they must all simultaneously change to the appropriate climate state. To support the modeling of climate change in TSPA-LA, the BDCFs must also be appropriate for the given climates. The discussion of the effect of climate change on volcanic ash scenario BDCFs is presented in Section 6.2.6.

6.1.4 Definition of the Receptor

The regulations for licensing the repository include an individual protection standard for the performance of the repository. This standard is expressed as the annual dose limit to a hypothetical person called the reasonably maximally exposed individual (RMEI) (10 CFR 63.311 [DIRS 156605]). Analysis of annual dose includes potentially pathways of radionuclide transport and exposure (10 CFR 63.311 [DIRS 156605]). Changes in the reference biosphere, other than climate changes, are not included.

The RMEI is a hypothetical receptor who meets the following criteria (10 CFR 63.312 [156605]):

- Lives above the highest concentration of radionuclides in the plume of contamination.
- Has a diet and lifestyle representative of people who now reside in the Amargosa Valley based on surveys of the people residing in the Amargosa Valley that determine current diets and lifestyles, and then use the mean values of these factors in the assessments conducted for 10 CFR 63.311 and 10 CFR 63.321 [DIRS 156605].
- Uses well water with average concentrations of radionuclides based on an annual water demand of 3,000 acre-feet.
- Drinks 2 liters of water per day from wells drilled into the groundwater from a point above the highest concentration of radionuclides in the plume of contamination.
- Is an adult who is metabolically and physiologically consistent with present knowledge of adults.

To satisfy 10 CFR 63.312(b) [DIRS 156605] criteria, the dietary and lifestyle characteristics of the RMEI were determined based upon the survey of the people living in the town of Amargosa Valley combined with national information on behavior patterns. Characteristics of the RMEI are documented in BSC (2003 [DIRS 161241]).

6.1.5 Biosphere Model

The ERMYN model was developed to model the biosphere processes for radionuclides released from the geological repository at Yucca Mountain including the environmental transport of radionuclides and human exposure. The documentation of the biosphere model is contained in the *Biosphere Model Report* (BSC 2003 [DIRS 164186]), which provides the following:

1. Description of biosphere model objectives, the reference biosphere, human receptor, exposure scenarios, environmental transport pathways and human exposure pathways (BSC 2003 [DIRS 164186], Section 6.1)
2. Development of the biosphere conceptual model based on the site-specific FEPs, the reference biosphere and human receptor, and a number of assumptions (BSC 2003 [DIRS 164186], Sections 6.2 and 6.3)
3. Description of biosphere mathematical model and its submodels based on the developed conceptual model and other published biosphere models (BSC 2003 [DIRS 164186], Sections 6.4 and 6.5)
4. Summary of model input parameters, including the uncertainty distributions, when applicable (BSC 2003 [DIRS 164186], Section 6.6)

5. Identification of the model improvements compared with the previously used biosphere models (BSC 2003 [DIRS 164186], Section 6.7)

6. Construction of ERMYN implementation tool based on the biosphere mathematical model using GoldSim stochastic simulation software (BSC 2003 [DIRS 164186], Sections 6.8 and 6.9)

7. Verification of the ERMYN implementation tool in GoldSim (BSC 2003 [DIRS 164186], Section 6.10)

8. Model validation by comparison of the conceptual and mathematical models, and the numerical results with other published biosphere models (BSC 2003 [DIRS 164186], Section 7).

The architecture of the biosphere model for the volcanic ash exposure scenario, including its submodels, is shown in Figure 6.1-2. The submodels address radionuclide transport to specific environmental media, such as soil, air, plants, animals, and fish, and the major human exposure pathways.

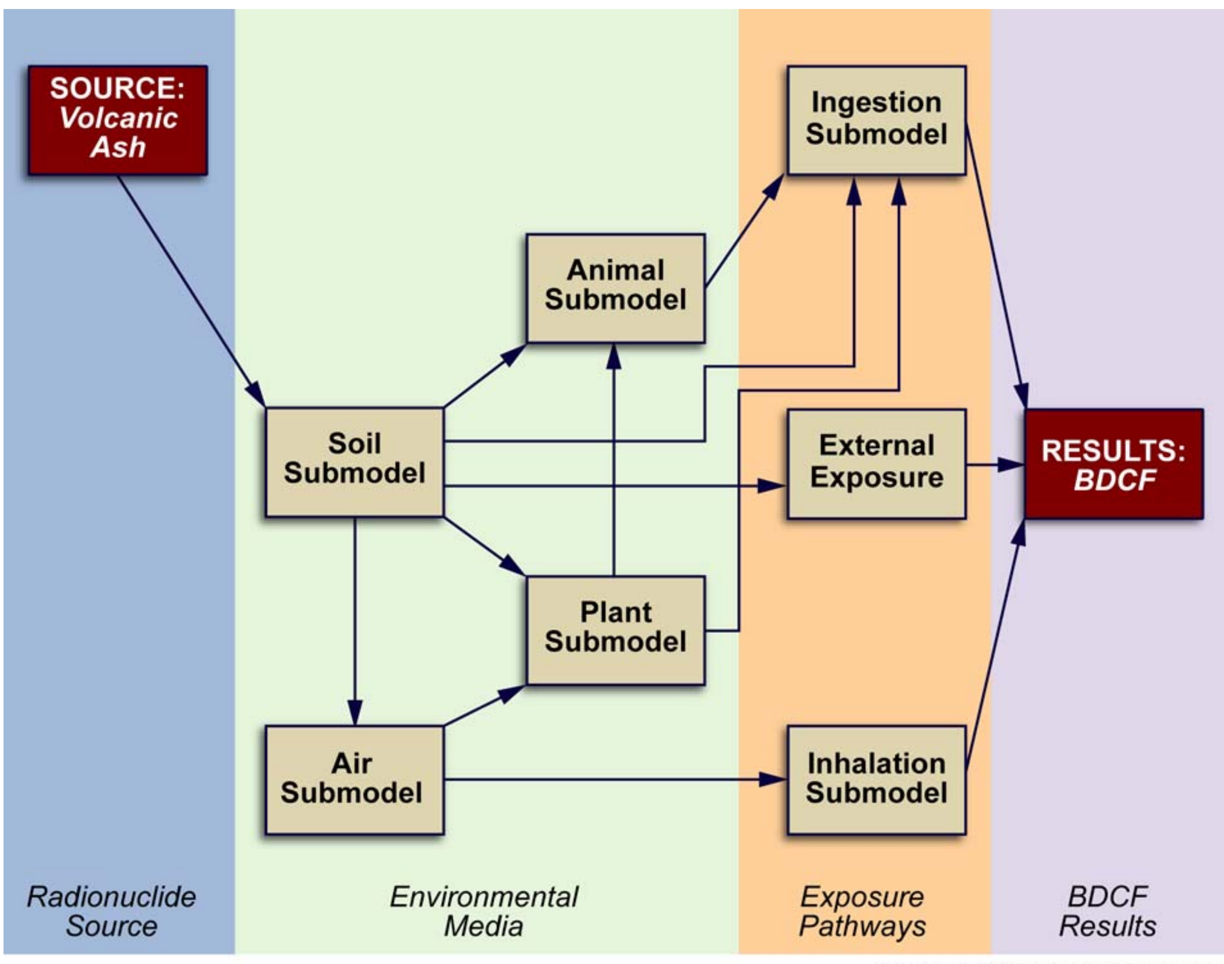


Figure 6.1-2. Relationship between the Biosphere Submodels for the Volcanic Ash Scenario

ERMYN was designed to perform an environmental radiation dose assessment and can calculate either radionuclide-specific dose or provide a radionuclide-specific BDCF for a given receptor. The use of ERMYN in the performance assessment is limited to calculation of BDCFs.

Input parameters for the biosphere model are developed and documented in a series of five model parameter reports:

- BSC 2003 [DIRS 160976]. *Agricultural and Environmental Parameters for the Biosphere Model*. ANL-MGR-MD-000006 REV 01.
- BSC 2003 [DIRS 161241]. *Characteristics of the Receptor for the Biosphere Model*. ANL-MGR-MD-000005 REV 02.
- BSC 2003 [DIRS 160964]. *Environmental Transport Input Parameters for the Biosphere Model*. ANL-MGR-MD-000007 REV 01.
- BSC 2003 [DIRS 160965]. *Inhalation Exposure Input Parameters for the Biosphere Model*. ANL-MGR-MD-000001 REV 02.
- BSC 2003 [DIRS 161239]. *Soil-Related Input Parameters for the Biosphere Model*. ANL-NBS-MD-000009 REV 01.

6.2 DEVELOPMENT OF BIOSPHERE DOSE CONVERSION FACTORS FOR THE VOLCANIC ASH SCENARIO

BDCFs were calculated, using probabilistic analysis, in a series of simulations for each of the 23 primary radionuclides (see Section 6.1.1) and two long-lived decay products, ^{228}Th and ^{228}Ra. Each simulation resulted in 1,000 model realizations (see Attachment III for justification). (Model realization is one of the possible model outcomes obtained as a result of a single round of sampling of the model input parameters.) This section describes the format and the summary of the results of biosphere modeling for the volcanic ash scenario, as well as their use in the TSPA model.

6.2.1 Treatment of Uncertainty

The probabilistic approach was chosen to develop BDCFs. This approach allows statistical sampling of parameter values defined by their probability distribution functions. This method, called Monte Carlo analysis, provides a quantitative evaluation of the parameter uncertainties and their impacts on the modeling outcome. The uncertainty in the model outcome is represented by the probability distribution functions of the BDCFs. Input parameter values were sampled using the Latin Hypercube Sampling for consistency with the sampling technique to be used in TSPA-LA (BSC 2002 [DIRS 160146], Section 7.3). With Latin Hypercube Sampling, the probability distribution is divided into intervals of equal probability. The code then randomly samples a value within each interval, which results in a more even and consistent sampling compared with the conventional Monte Carlo random sampling scheme.

6.2.2 Format of Biosphere Dose Conversion Factors for Volcanic Ash Scenario

The radionuclide concentration in the volcanic ash deposited on the ground surface is the only source of radionuclide contamination for the volcanic ash scenario used for development of BDCFs in this analysis (direct inhalation of ash during eruption phase is treated separately). Radiation pathways discussed in the previous section depend linearly on this source. BDCFs for volcanic ash scenario are a function of the thickness of contaminated soil-ash surface layer. Because of the anticipated gradual decrease in airborne particulate concentration over time, the BDCFs are also a function of time. For the volcanic ash scenario, the BDCFs are given in the following format (BSC 2003 [DIRS 164186], Section 6.5.8.2):

$$BDCF_i(d_a, t) = BDCF_i + \left(BDCF_{inh,v,i} f(t) + BDCF_{inh,p,i}\right) g(d_a) \qquad \text{(Eq. 6.2-1)}$$

where

$BDCF_i(d_a, t)$	=	BDCF for primary radionuclide i for an ash depth d_a at time t following a volcanic eruption (Sv/y per Bq/m^2)
$BDCF_i$	=	BDCF for primary radionuclide i for non-inhalation pathways, such as external exposure, radon inhalation, and ingestion (Sv/y per Bq/m^2)
$BDCF_{inh,v,i}$	=	BDCF for primary radionuclide i for short-term inhalation at post-volcanic level of mass loading in excess of nominal mass loading (Sv/y per Bq/m^2)
$BDCF_{inh,p,i}$	=	BDCF for primary radionuclide i for long-term inhalation at nominal level of mass loading (Sv/y per Bq/m^2)
$f(t)$	=	decay function describing reduction of mass loading with time
d_a	=	thickness of ash (m)
$g(d_a)$	=	function of ash thickness, d_a, representing the fraction of total activity that is available for resuspension.

Three BDCF components are calculated for each primary radionuclide. The first component, $BDCF_i$, is time independent and accounts for three exposure pathways (ingestion, inhalation of radon decay products, and external exposure). The second and third BDCF components account for inhaling airborne particulates. Both of these components depend on ash thickness. The second term ($BDCF_{inh,v,i}$) represents short-term inhalation exposure during the period of increased concentrations of resuspended particulates following volcanic eruption and is time-dependent because mass loading will gradually decrease after an eruption. The third term ($BDCF_{inh,p,i}$) represents long-term inhalation of resuspended particulates under nominal conditions (i.e., when the mass loading is not elevated as the result of volcanic eruption). The results of the BDCF calculations are in the format of 1,000 row vectors, one for each model realization, consisting of three BDCF components for each of the 23 primary radionuclides (i.e., 69 BDCF components per vector) and a value of critical thickness, as explained below. A vector can be regarded as a one-dimensional array containing the results of a single realization of the biosphere model for all primary radionuclides. Technically, the model is executed separately for individual primary radionuclides. The vectors are then produced by compiling the BDCFs for a given realization number. Such an approach is valid because for a given model realization number all radionuclide-independent parameters are the same regardless of a radionuclide.

The function of time, *f(t)* in Equation 6.2-1, accounts for the reduction of mass loading in the years immediately following volcanic eruption. Mass loading decreases exponentially with time (BSC 2003 [DIRS 160965], Section 6.3) as

$$f(t) = e^{-\lambda t} \qquad \text{(Eq. 6.2-2)}$$

where

λ	=	mass loading decrease constant (1/yr)
t	=	time (yr); $t = 0$ is the first year after a volcanic eruption.

The function of ash thickness (BSC 2003 [DIRS 164186], Section 6.5.1), $g(d_a)$, is expressed as

$$g(d_a) = \begin{cases} 1 & \text{when } d_a < d_c \\ \dfrac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \qquad \text{(Eq. 6.2-3)}$$

where d_c is the critical thickness of the ash layer. The critical thickness is defined as the thickness of the surface soil (ash) layer that is available for resuspension. Since this parameter is represented by a distribution, the value of the critical thickness corresponding to the specific BDCF row vector must be used. The critical thickness value is thus added to each of the 1,000 BDCF row vectors.

6.2.3 Results of the Calculations

The outcome of the volcanic ash scenario BDCF calculations consists of the three BDCF components generated for each radionuclide and each model realization (3 radionuclide-dependent BDCF components × 1,000 realizations per radionuclide × (23 + 2) radionuclides = 75,000 data points). A summary of these results, in the form of discrete cumulative probability distributions of BDCFs in 5 percentile increments, plus means and standard deviations, is presented in Tables 6.2-1 to 6.2-3 for the external-ingestion-radon component, short-term inhalation component, and the long-term inhalation component, respectively. The means, standard deviations, and percentiles were calculated in an Excel spreadsheet, which is described in Attachment I. A CD-ROM, with the complete file containing all data points and the calculations of the statistics, is included as Attachment II.

In all tables presenting the results of BDCF calculations, BDCFs for ^{232}Th include contributions from ^{228}Ra and ^{228}Th; BDCFs for ^{232}U include contribution from ^{228}Th.

Table 6.2-1. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products (rem/yr per pCi/m^2)

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	2.11E-09	6.03E-10	9.37E-08	2.67E-08	6.88E-09	1.61E-07	2.40E-08	1.67E-08	2.38E-10	1.14E-07	7.09E-09	6.88E-08
STD	1.68E-09	1.03E-09	1.58E-09	5.53E-10	1.03E-08	9.99E-09	6.84E-09	1.87E-09	2.54E-10	3.17E-09	6.98E-09	2.20E-09
Min.	4.17E-10	1.67E-11	8.95E-08	2.54E-08	7.18E-10	1.40E-07	1.85E-08	1.47E-08	5.63E-11	1.07E-07	2.50E-09	6.44E-08
5%	6.80E-10	4.71E-11	9.13E-08	2.59E-08	1.37E-09	1.46E-07	1.98E-08	1.54E-08	7.77E-11	1.10E-07	2.96E-09	6.63E-08
10%	7.78E-10	6.97E-11	9.17E-08	2.61E-08	1.70E-09	1.48E-07	2.01E-08	1.56E-08	8.97E-11	1.11E-07	3.17E-09	6.67E-08
15%	8.83E-10	8.77E-11	9.21E-08	2.62E-08	2.00E-09	1.50E-07	2.03E-08	1.56E-08	9.99E-11	1.11E-07	3.39E-09	6.71E-08
20%	9.63E-10	1.09E-10	9.24E-08	2.63E-08	2.26E-09	1.52E-07	2.06E-08	1.57E-08	1.06E-10	1.11E-07	3.57E-09	6.74E-08
25%	1.03E-09	1.30E-10	9.27E-08	2.64E-08	2.54E-09	1.53E-07	2.08E-08	1.58E-08	1.14E-10	1.12E-07	3.77E-09	6.76E-08
30%	1.11E-09	1.60E-10	9.29E-08	2.65E-08	2.76E-09	1.54E-07	2.10E-08	1.59E-08	1.22E-10	1.12E-07	3.95E-09	6.78E-08
35%	1.21E-09	1.93E-10	9.32E-08	2.65E-08	3.14E-09	1.56E-07	2.12E-08	1.59E-08	1.32E-10	1.13E-07	4.14E-09	6.80E-08
40%	1.33E-09	2.19E-10	9.34E-08	2.66E-08	3.49E-09	1.58E-07	2.14E-08	1.60E-08	1.40E-10	1.13E-07	4.41E-09	6.81E-08
45%	1.46E-09	2.44E-10	9.36E-08	2.66E-08	3.91E-09	1.60E-07	2.17E-08	1.61E-08	1.53E-10	1.13E-07	4.72E-09	6.83E-08
50%	1.60E-09	2.71E-10	9.38E-08	2.67E-08	4.31E-09	1.62E-07	2.21E-08	1.62E-08	1.65E-10	1.13E-07	5.08E-09	6.85E-08
55%	1.74E-09	3.17E-10	9.39E-08	2.68E-08	4.76E-09	1.63E-07	2.24E-08	1.63E-08	1.78E-10	1.14E-07	5.41E-09	6.87E-08
60%	1.87E-09	3.80E-10	9.42E-08	2.68E-08	5.32E-09	1.65E-07	2.29E-08	1.64E-08	1.94E-10	1.14E-07	5.82E-09	6.89E-08
65%	2.07E-09	4.58E-10	9.44E-08	2.69E-08	5.98E-09	1.66E-07	2.34E-08	1.65E-08	2.15E-10	1.14E-07	6.13E-09	6.91E-08
70%	2.30E-09	5.57E-10	9.46E-08	2.70E-08	6.89E-09	1.68E-07	2.40E-08	1.67E-08	2.34E-10	1.15E-07	6.91E-09	6.93E-08
75%	2.53E-09	6.81E-10	9.48E-08	2.70E-08	7.78E-09	1.70E-07	2.47E-08	1.69E-08	2.71E-10	1.15E-07	7.58E-09	6.95E-08
80%	2.85E-09	8.08E-10	9.51E-08	2.71E-08	8.96E-09	1.71E-07	2.59E-08	1.72E-08	3.05E-10	1.16E-07	8.59E-09	6.99E-08
85%	3.23E-09	1.07E-09	9.53E-08	2.72E-08	1.07E-08	1.73E-07	2.73E-08	1.76E-08	3.60E-10	1.16E-07	1.01E-08	7.03E-08
90%	3.98E-09	1.42E-09	9.56E-08	2.73E-08	1.36E-08	1.75E-07	2.96E-08	1.82E-08	4.33E-10	1.17E-07	1.25E-08	7.10E-08
95%	5.66E-09	2.19E-09	9.61E-08	2.76E-08	1.97E-08	1.77E-07	3.35E-08	1.94E-08	6.09E-10	1.19E-07	1.63E-08	7.21E-08
Max.	1.61E-08	1.83E-08	1.00E-07	3.08E-08	2.27E-07	1.84E-07	1.09E-07	3.78E-08	3.17E-09	1.42E-07	7.90E-08	1.03E-07

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C.xls* as shown in Attachments I and II.

Table 6.2-1. BDCF Component for External Exposure, Ingestion, and Inhalation of Radon Decay Products, rem/yr per pCi/m^2 (continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	3.59E-10	3.40E-10	3.15E-10	1.74E-09	2.06E-08	1.12E-09	1.24E-09	1.24E-09	1.17E-09	2.08E-09	1.16E-08
STD	3.73E-10	3.66E-10	3.47E-10	3.46E-10	2.30E-08	1.43E-09	1.58E-09	1.58E-09	1.50E-09	1.63E-09	1.62E-09
Min.	6.58E-11	5.28E-11	4.24E-11	1.43E-09	1.08E-08	1.88E-10	2.02E-10	2.05E-10	1.93E-10	9.55E-10	1.01E-08
5%	1.07E-10	9.29E-11	8.03E-11	1.50E-09	1.15E-08	2.68E-10	2.91E-10	2.94E-10	2.77E-10	1.09E-09	1.06E-08
10%	1.22E-10	1.08E-10	9.44E-11	1.52E-09	1.17E-08	3.14E-10	3.43E-10	3.45E-10	3.26E-10	1.16E-09	1.07E-08
15%	1.40E-10	1.25E-10	1.11E-10	1.54E-09	1.19E-08	3.77E-10	4.12E-10	4.14E-10	3.91E-10	1.22E-09	1.07E-08
20%	1.54E-10	1.40E-10	1.25E-10	1.55E-09	1.21E-08	4.21E-10	4.61E-10	4.63E-10	4.37E-10	1.27E-09	1.08E-08
25%	1.68E-10	1.52E-10	1.36E-10	1.57E-09	1.24E-08	4.60E-10	5.04E-10	5.06E-10	4.78E-10	1.32E-09	1.09E-08
30%	1.83E-10	1.68E-10	1.51E-10	1.58E-09	1.28E-08	5.00E-10	5.49E-10	5.50E-10	5.21E-10	1.37E-09	1.09E-08
35%	1.98E-10	1.82E-10	1.65E-10	1.59E-09	1.32E-08	5.51E-10	6.05E-10	6.06E-10	5.74E-10	1.43E-09	1.10E-08
40%	2.17E-10	2.01E-10	1.83E-10	1.61E-09	1.35E-08	5.95E-10	6.53E-10	6.55E-10	6.20E-10	1.48E-09	1.10E-08
45%	2.36E-10	2.20E-10	2.01E-10	1.63E-09	1.39E-08	6.67E-10	7.33E-10	7.35E-10	6.96E-10	1.54E-09	1.11E-08
50%	2.53E-10	2.36E-10	2.16E-10	1.65E-09	1.44E-08	7.31E-10	8.04E-10	8.06E-10	7.63E-10	1.63E-09	1.11E-08
55%	2.79E-10	2.62E-10	2.40E-10	1.67E-09	1.50E-08	7.95E-10	8.75E-10	8.76E-10	8.30E-10	1.70E-09	1.12E-08
60%	3.10E-10	2.92E-10	2.69E-10	1.70E-09	1.59E-08	8.72E-10	9.60E-10	9.61E-10	9.11E-10	1.78E-09	1.13E-08
65%	3.37E-10	3.18E-10	2.94E-10	1.72E-09	1.65E-08	9.68E-10	1.07E-09	1.07E-09	1.01E-09	1.91E-09	1.15E-08
70%	3.83E-10	3.64E-10	3.37E-10	1.76E-09	1.75E-08	1.09E-09	1.20E-09	1.20E-09	1.14E-09	2.03E-09	1.16E-08
75%	4.24E-10	4.04E-10	3.75E-10	1.80E-09	1.96E-08	1.24E-09	1.36E-09	1.37E-09	1.30E-09	2.19E-09	1.17E-08
80%	4.88E-10	4.66E-10	4.34E-10	1.86E-09	2.17E-08	1.44E-09	1.58E-09	1.59E-09	1.50E-09	2.45E-09	1.19E-08
85%	5.76E-10	5.53E-10	5.17E-10	1.94E-09	2.53E-08	1.77E-09	1.95E-09	1.95E-09	1.85E-09	2.82E-09	1.24E-08
90%	6.69E-10	6.45E-10	6.03E-10	2.03E-09	3.16E-08	2.23E-09	2.46E-09	2.46E-09	2.34E-09	3.30E-09	1.29E-08
95%	9.24E-10	8.95E-10	8.40E-10	2.23E-09	4.87E-08	3.04E-09	3.36E-09	3.36E-09	3.19E-09	4.28E-09	1.38E-08
Max.	7.22E-09	7.07E-09	6.69E-09	8.09E-09	4.00E-07	1.86E-08	2.06E-08	2.06E-08	1.95E-08	2.16E-08	3.08E-08

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C.xls* as shown in Attachments I and II.

Table 6.2-2. BDCF Component for Short-term Inhalation Exposure, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	5.27E-10	1.77E-11	2.15E-10	6.79E-11	4.93E-08	1.83E-08	1.43E-05	4.60E-06	6.92E-07	4.23E-06	2.73E-06	2.13E-06
STD	3.19E-10	1.07E-11	1.30E-10	4.11E-11	2.98E-08	1.11E-08	8.65E-06	2.78E-06	4.19E-07	2.56E-06	1.65E-06	1.29E-06
Min.	4.92E-11	1.65E-12	2.01E-11	6.34E-12	4.60E-09	1.71E-09	1.33E-06	4.30E-07	6.46E-08	3.95E-07	2.55E-07	1.99E-07
5%	1.46E-10	4.90E-12	5.95E-11	1.88E-11	1.36E-08	5.06E-09	3.95E-06	1.27E-06	1.92E-07	1.17E-06	7.55E-07	5.90E-07
10%	1.87E-10	6.30E-12	7.66E-11	2.42E-11	1.75E-08	6.51E-09	5.08E-06	1.64E-06	2.46E-07	1.50E-06	9.71E-07	7.59E-07
15%	2.22E-10	7.45E-12	9.05E-11	2.86E-11	2.07E-08	7.69E-09	6.01E-06	1.94E-06	2.91E-07	1.78E-06	1.15E-06	8.97E-07
20%	2.54E-10	8.53E-12	1.04E-10	3.27E-11	2.38E-08	8.81E-09	6.89E-06	2.22E-06	3.34E-07	2.04E-06	1.32E-06	1.03E-06
25%	2.91E-10	9.77E-12	1.19E-10	3.75E-11	2.72E-08	1.01E-08	7.89E-06	2.54E-06	3.82E-07	2.34E-06	1.51E-06	1.18E-06
30%	3.30E-10	1.11E-11	1.35E-10	4.25E-11	3.09E-08	1.14E-08	8.95E-06	2.88E-06	4.34E-07	2.65E-06	1.71E-06	1.34E-06
35%	3.66E-10	1.23E-11	1.50E-10	4.72E-11	3.42E-08	1.27E-08	9.93E-06	3.20E-06	4.81E-07	2.94E-06	1.90E-06	1.48E-06
40%	3.95E-10	1.33E-11	1.61E-10	5.09E-11	3.69E-08	1.37E-08	1.07E-05	3.45E-06	5.19E-07	3.17E-06	2.05E-06	1.60E-06
45%	4.30E-10	1.44E-11	1.76E-10	5.54E-11	4.02E-08	1.49E-08	1.17E-05	3.76E-06	5.65E-07	3.45E-06	2.23E-06	1.74E-06
50%	4.65E-10	1.56E-11	1.90E-10	5.99E-11	4.35E-08	1.61E-08	1.26E-05	4.06E-06	6.11E-07	3.73E-06	2.41E-06	1.88E-06
55%	5.05E-10	1.70E-11	2.06E-10	6.51E-11	4.72E-08	1.75E-08	1.37E-05	4.41E-06	6.64E-07	4.05E-06	2.62E-06	2.05E-06
60%	5.50E-10	1.85E-11	2.25E-10	7.09E-11	5.15E-08	1.91E-08	1.49E-05	4.81E-06	7.23E-07	4.42E-06	2.85E-06	2.23E-06
65%	5.89E-10	1.98E-11	2.41E-10	7.59E-11	5.51E-08	2.04E-08	1.60E-05	5.15E-06	7.74E-07	4.73E-06	3.05E-06	2.39E-06
70%	6.29E-10	2.11E-11	2.57E-10	8.10E-11	5.88E-08	2.18E-08	1.71E-05	5.49E-06	8.26E-07	5.05E-06	3.26E-06	2.55E-06
75%	6.73E-10	2.26E-11	2.75E-10	8.68E-11	6.30E-08	2.34E-08	1.83E-05	5.88E-06	8.85E-07	5.40E-06	3.49E-06	2.73E-06
80%	7.56E-10	2.54E-11	3.09E-10	9.74E-11	7.07E-08	2.62E-08	2.05E-05	6.61E-06	9.94E-07	6.07E-06	3.92E-06	3.06E-06
85%	8.30E-10	2.79E-11	3.39E-10	1.07E-10	7.76E-08	2.88E-08	2.25E-05	7.25E-06	1.09E-06	6.66E-06	4.30E-06	3.36E-06
90%	8.95E-10	3.01E-11	3.66E-10	1.15E-10	8.37E-08	3.11E-08	2.43E-05	7.82E-06	1.18E-06	7.19E-06	4.64E-06	3.63E-06
95%	1.12E-09	3.76E-11	4.57E-10	1.44E-10	1.05E-07	3.88E-08	3.03E-05	9.77E-06	1.47E-06	8.98E-06	5.79E-06	4.53E-06
Max.	2.07E-09	6.97E-11	8.47E-10	2.67E-10	1.94E-07	7.20E-08	5.62E-05	1.81E-05	2.72E-06	1.66E-05	1.07E-05	8.40E-06

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C.xls* as shown in Attachments I and II.

Table 6.2-2. BDCF Component for Short-term Inhalation Exposure, rem/yr per pCi/m^2 (continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	2.88E-07	2.82E-07	2.67E-07	2.52E-07	1.15E-06	8.34E-07	9.12E-07	9.12E-07	8.73E-07	9.44E-07	9.36E-07
STD	1.74E-07	1.70E-07	1.61E-07	1.52E-07	6.95E-07	5.05E-07	5.52E-07	5.52E-07	5.28E-07	5.71E-07	5.66E-07
Min.	2.69E-08	2.63E-08	2.49E-08	2.35E-08	1.07E-07	7.78E-08	8.52E-08	8.52E-08	8.15E-08	8.81E-08	8.74E-08
5%	7.97E-08	7.79E-08	7.38E-08	6.97E-08	3.18E-07	2.31E-07	2.52E-07	2.52E-07	2.42E-07	2.61E-07	2.59E-07
10%	1.02E-07	1.00E-07	9.49E-08	8.96E-08	4.09E-07	2.97E-07	3.25E-07	3.25E-07	3.11E-07	3.36E-07	3.33E-07
15%	1.21E-07	1.18E-07	1.12E-07	1.06E-07	4.83E-07	3.51E-07	3.84E-07	3.84E-07	3.67E-07	3.97E-07	3.94E-07
20%	1.39E-07	1.36E-07	1.29E-07	1.21E-07	5.54E-07	4.02E-07	4.40E-07	4.40E-07	4.21E-07	4.55E-07	4.51E-07
25%	1.59E-07	1.56E-07	1.47E-07	1.39E-07	6.34E-07	4.60E-07	5.04E-07	5.04E-07	4.82E-07	5.21E-07	5.17E-07
30%	1.80E-07	1.76E-07	1.67E-07	1.58E-07	7.19E-07	5.22E-07	5.71E-07	5.71E-07	5.47E-07	5.91E-07	5.86E-07
35%	2.00E-07	1.96E-07	1.85E-07	1.75E-07	7.98E-07	5.80E-07	6.34E-07	6.34E-07	6.07E-07	6.56E-07	6.51E-07
40%	2.16E-07	2.11E-07	2.00E-07	1.89E-07	8.61E-07	6.25E-07	6.84E-07	6.84E-07	6.55E-07	7.08E-07	7.02E-07
45%	2.35E-07	2.30E-07	2.18E-07	2.06E-07	9.38E-07	6.81E-07	7.45E-07	7.45E-07	7.13E-07	7.71E-07	7.64E-07
50%	2.54E-07	2.48E-07	2.35E-07	2.22E-07	1.01E-06	7.36E-07	8.05E-07	8.05E-07	7.70E-07	8.33E-07	8.26E-07
55%	2.76E-07	2.70E-07	2.56E-07	2.41E-07	1.10E-06	8.00E-07	8.75E-07	8.75E-07	8.37E-07	9.05E-07	8.98E-07
60%	3.01E-07	2.94E-07	2.79E-07	2.63E-07	1.20E-06	8.71E-07	9.53E-07	9.53E-07	9.12E-07	9.86E-07	9.78E-07
65%	3.22E-07	3.15E-07	2.98E-07	2.82E-07	1.28E-06	9.32E-07	1.02E-06	1.02E-06	9.76E-07	1.06E-06	1.05E-06
70%	3.44E-07	3.36E-07	3.18E-07	3.00E-07	1.37E-06	9.95E-07	1.09E-06	1.09E-06	1.04E-06	1.13E-06	1.12E-06
75%	3.68E-07	3.60E-07	3.41E-07	3.22E-07	1.47E-06	1.07E-06	1.17E-06	1.17E-06	1.12E-06	1.21E-06	1.20E-06
80%	4.13E-07	4.04E-07	3.83E-07	3.61E-07	1.65E-06	1.20E-06	1.31E-06	1.31E-06	1.25E-06	1.36E-06	1.34E-06
85%	4.53E-07	4.43E-07	4.20E-07	3.96E-07	1.81E-06	1.31E-06	1.44E-06	1.44E-06	1.37E-06	1.49E-06	1.47E-06
90%	4.89E-07	4.79E-07	4.53E-07	4.28E-07	1.95E-06	1.42E-06	1.55E-06	1.55E-06	1.48E-06	1.60E-06	1.59E-06
95%	6.11E-07	5.98E-07	5.66E-07	5.35E-07	2.44E-06	1.77E-06	1.94E-06	1.94E-06	1.85E-06	2.00E-06	1.99E-06
Max.	1.13E-06	1.11E-06	1.05E-06	9.91E-07	4.52E-06	3.28E-06	3.59E-06	3.59E-06	3.44E-06	3.72E-06	3.68E-06

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C.xls* as shown in Attachments I and II.

Table 6.2-3. BDCF Component for Long-term Inhalation Exposure, rem/yr per pCi/m^2

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
Mean	1.06E-09	3.57E-11	4.33E-10	1.37E-10	9.93E-08	3.68E-08	2.88E-05	9.27E-06	1.39E-06	8.52E-06	5.50E-06	4.30E-06
STD	6.52E-10	2.19E-11	2.66E-10	8.40E-11	6.09E-08	2.26E-08	1.77E-05	5.69E-06	8.56E-07	5.23E-06	3.38E-06	2.64E-06
Min.	1.19E-10	4.01E-12	4.88E-11	1.54E-11	1.12E-08	4.14E-09	3.24E-06	1.04E-06	1.57E-07	9.58E-07	6.19E-07	4.83E-07
5%	3.46E-10	1.16E-11	1.41E-10	4.45E-11	3.23E-08	1.20E-08	9.37E-06	3.02E-06	4.54E-07	2.77E-06	1.79E-06	1.40E-06
10%	4.32E-10	1.45E-11	1.76E-10	5.57E-11	4.04E-08	1.50E-08	1.17E-05	3.77E-06	5.68E-07	3.47E-06	2.24E-06	1.75E-06
15%	4.93E-10	1.66E-11	2.01E-10	6.35E-11	4.61E-08	1.71E-08	1.34E-05	4.31E-06	6.48E-07	3.96E-06	2.55E-06	2.00E-06
20%	5.57E-10	1.87E-11	2.28E-10	7.18E-11	5.21E-08	1.93E-08	1.51E-05	4.87E-06	7.32E-07	4.47E-06	2.89E-06	2.26E-06
25%	6.11E-10	2.05E-11	2.49E-10	7.87E-11	5.71E-08	2.12E-08	1.66E-05	5.34E-06	8.03E-07	4.90E-06	3.16E-06	2.47E-06
30%	6.57E-10	2.21E-11	2.68E-10	8.47E-11	6.15E-08	2.28E-08	1.78E-05	5.74E-06	8.64E-07	5.28E-06	3.41E-06	2.66E-06
35%	7.29E-10	2.45E-11	2.98E-10	9.39E-11	6.82E-08	2.53E-08	1.98E-05	6.37E-06	9.58E-07	5.85E-06	3.78E-06	2.95E-06
40%	7.82E-10	2.63E-11	3.19E-10	1.01E-10	7.31E-08	2.71E-08	2.12E-05	6.83E-06	1.03E-06	6.28E-06	4.05E-06	3.17E-06
45%	8.34E-10	2.80E-11	3.41E-10	1.07E-10	7.80E-08	2.89E-08	2.26E-05	7.29E-06	1.10E-06	6.70E-06	4.32E-06	3.38E-06
50%	9.02E-10	3.03E-11	3.68E-10	1.16E-10	8.43E-08	3.13E-08	2.45E-05	7.88E-06	1.19E-06	7.24E-06	4.67E-06	3.65E-06
55%	9.60E-10	3.23E-11	3.92E-10	1.24E-10	8.98E-08	3.33E-08	2.60E-05	8.39E-06	1.26E-06	7.71E-06	4.98E-06	3.89E-06
60%	1.04E-09	3.49E-11	4.25E-10	1.34E-10	9.72E-08	3.61E-08	2.82E-05	9.08E-06	1.37E-06	8.35E-06	5.39E-06	4.21E-06
65%	1.12E-09	3.76E-11	4.57E-10	1.44E-10	1.05E-07	3.88E-08	3.03E-05	9.77E-06	1.47E-06	8.98E-06	5.79E-06	4.53E-06
70%	1.22E-09	4.11E-11	5.00E-10	1.58E-10	1.14E-07	4.25E-08	3.32E-05	1.07E-05	1.61E-06	9.83E-06	6.34E-06	4.96E-06
75%	1.33E-09	4.46E-11	5.42E-10	1.71E-10	1.24E-07	4.61E-08	3.60E-05	1.16E-05	1.74E-06	1.07E-05	6.88E-06	5.38E-06
80%	1.46E-09	4.90E-11	5.96E-10	1.88E-10	1.36E-07	5.06E-08	3.96E-05	1.27E-05	1.92E-06	1.17E-05	7.56E-06	5.91E-06
85%	1.65E-09	5.55E-11	6.75E-10	2.13E-10	1.54E-07	5.73E-08	4.48E-05	1.44E-05	2.17E-06	1.33E-05	8.56E-06	6.69E-06
90%	1.89E-09	6.34E-11	7.70E-10	2.43E-10	1.76E-07	6.55E-08	5.12E-05	1.65E-05	2.48E-06	1.51E-05	9.77E-06	7.64E-06
95%	2.32E-09	7.81E-11	9.49E-10	2.99E-10	2.17E-07	8.06E-08	6.30E-05	2.03E-05	3.05E-06	1.87E-05	1.20E-05	9.41E-06
Max.	5.88E-09	1.97E-10	2.40E-09	7.57E-10	5.50E-07	2.04E-07	1.59E-04	5.13E-05	7.72E-06	4.72E-05	3.05E-05	2.38E-05

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C.xls* as shown in Attachments I and II.

Table 6.2-3. BDCF Component for Long-term Inhalation Exposure, rem/yr per pCi/m^2 (continued)

	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	5.80E-07	5.67E-07	5.37E-07	5.07E-07	2.31E-06	1.68E-06	1.84E-06	1.84E-06	1.76E-06	1.90E-06	1.89E-06
STD	3.56E-07	3.48E-07	3.30E-07	3.11E-07	1.42E-06	1.03E-06	1.13E-06	1.13E-06	1.08E-06	1.17E-06	1.16E-06
Min.	6.52E-08	6.38E-08	6.04E-08	5.71E-08	2.60E-07	1.89E-07	2.07E-07	2.07E-07	1.98E-07	2.14E-07	2.12E-07
5%	1.89E-07	1.85E-07	1.75E-07	1.65E-07	7.53E-07	5.47E-07	5.99E-07	5.99E-07	5.73E-07	6.19E-07	6.14E-07
10%	2.36E-07	2.31E-07	2.19E-07	2.06E-07	9.42E-07	6.84E-07	7.48E-07	7.48E-07	7.16E-07	7.74E-07	7.68E-07
15%	2.69E-07	2.63E-07	2.49E-07	2.36E-07	1.07E-06	7.80E-07	8.54E-07	8.54E-07	8.17E-07	8.83E-07	8.76E-07
20%	3.04E-07	2.98E-07	2.82E-07	2.66E-07	1.21E-06	8.82E-07	9.65E-07	9.65E-07	9.23E-07	9.98E-07	9.90E-07
25%	3.34E-07	3.27E-07	3.09E-07	2.92E-07	1.33E-06	9.67E-07	1.06E-06	1.06E-06	1.01E-06	1.09E-06	1.09E-06
30%	3.59E-07	3.51E-07	3.33E-07	3.14E-07	1.43E-06	1.04E-06	1.14E-06	1.14E-06	1.09E-06	1.18E-06	1.17E-06
35%	3.98E-07	3.90E-07	3.69E-07	3.48E-07	1.59E-06	1.15E-06	1.26E-06	1.26E-06	1.21E-06	1.31E-06	1.29E-06
40%	4.27E-07	4.18E-07	3.96E-07	3.74E-07	1.71E-06	1.24E-06	1.35E-06	1.35E-06	1.30E-06	1.40E-06	1.39E-06
45%	4.56E-07	4.46E-07	4.22E-07	3.99E-07	1.82E-06	1.32E-06	1.44E-06	1.44E-06	1.38E-06	1.49E-06	1.48E-06
50%	4.93E-07	4.82E-07	4.57E-07	4.31E-07	1.97E-06	1.43E-06	1.56E-06	1.56E-06	1.49E-06	1.62E-06	1.60E-06
55%	5.25E-07	5.13E-07	4.86E-07	4.59E-07	2.09E-06	1.52E-06	1.66E-06	1.66E-06	1.59E-06	1.72E-06	1.71E-06
60%	5.68E-07	5.56E-07	5.26E-07	4.97E-07	2.27E-06	1.65E-06	1.80E-06	1.80E-06	1.72E-06	1.86E-06	1.85E-06
65%	6.11E-07	5.98E-07	5.66E-07	5.34E-07	2.44E-06	1.77E-06	1.94E-06	1.94E-06	1.85E-06	2.00E-06	1.99E-06
70%	6.69E-07	6.54E-07	6.20E-07	5.85E-07	2.67E-06	1.94E-06	2.12E-06	2.12E-06	2.03E-06	2.19E-06	2.18E-06
75%	7.26E-07	7.10E-07	6.72E-07	6.35E-07	2.89E-06	2.10E-06	2.30E-06	2.30E-06	2.20E-06	2.38E-06	2.36E-06
80%	7.97E-07	7.80E-07	7.39E-07	6.97E-07	3.18E-06	2.31E-06	2.53E-06	2.53E-06	2.42E-06	2.61E-06	2.59E-06
85%	9.03E-07	8.83E-07	8.36E-07	7.90E-07	3.60E-06	2.61E-06	2.86E-06	2.86E-06	2.74E-06	2.96E-06	2.94E-06
90%	1.03E-06	1.01E-06	9.55E-07	9.02E-07	4.11E-06	2.99E-06	3.27E-06	3.27E-06	3.13E-06	3.38E-06	3.35E-06
95%	1.27E-06	1.24E-06	1.18E-06	1.11E-06	5.07E-06	3.68E-06	4.02E-06	4.02E-06	3.85E-06	4.16E-06	4.13E-06
Max.	3.21E-06	3.14E-06	2.98E-06	2.81E-06	1.28E-05	9.30E-06	1.02E-05	1.02E-05	9.74E-06	1.05E-05	1.04E-05

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C.xls* as shown in Attachments I and II.

The BDCFs for the volcanic ash scenario are correlated because most of the input parameters, especially those that are radionuclide-independent, are the same for different radionuclides. Correlations exist between the BDCF components for a given radionuclide and between the BDCFs for individual radionuclides. The rank correlation coefficients for the BDCF components are listed in Table 6.2-4. There is no correlation or a very poor correlation between the BDCF components because they are related to different exposure pathways and thus depend on a different set of input parameters. A stronger correlation exists only between the two inhalation BDCF components, the long-term and the short-term, because they depend on the same set of parameters describing behavior of the receptor and the receptor environments.

Table 6.2-4. Rank Correlation Coefficients for the Volcanic Ash Scenario BDCF Components

Radionuclide	External-Ingestion-Radon and Short-term Inhalation	Short-term Inhalation and Long-term Inhalation	External-Ingestion-Radon and Long-term Inhalation
^{90}Sr	0	0.580	0
^{99}Tc	0	0.580	0
^{126}Sn	0.118	0.580	0.102
^{137}Cs	0.092	0.580	0
^{210}Pb	0	0.580	0
^{226}Ra	0	0.580	0
^{227}Ac	0	0.580	0
^{229}Th	0	0.580	0
^{230}Th	0	0.580	0
^{232}Th	0	0.580	0
^{231}Pa	0	0.580	0
^{232}U	0	0.580	0.100
^{233}U	0	0.580	0
^{234}U	0	0.580	0
^{236}U	0	0.580	0
^{238}U	0	0.580	0
^{237}Np	0	0.580	0
^{238}Pu	0	0.580	0
^{239}Pu	0	0.580	0
^{240}Pu	0	0.580	0
^{242}Pu	0	0.580	0
^{241}Am	0	0.580	0

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C Correlations.xls* as shown in Attachments I and II.

The rank correlations between the BDCF components of different radionuclides have also been calculated. The correlation coefficients for the external-ingestion-radon component are listed in Table 6.2-5. Correlation coefficients for short-term and long-term inhalation components are equal to 1. Details of the calculations are presented in Attachments I and II. Generally, the correlation coefficients for the external exposure-radon-ingestion BDCF components are the highest for actinides (^{227}Ac and heavier radionuclides) and relatively low for lighter radionuclides. This depends on the importance of individual pathways, and input parameters for these pathways, for this BDCF component.

Table 6.2-5. Rank Correlations (Correlation Coefficients) Between the External Exposure-Ingestion-Radon BDCF Components for Individual Radionuclides

	^{90}Sr	^{99}Tc	^{126}Sn	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U
^{90}Sr	1.000											
^{99}Tc	0.261	1.000										
^{126}Sn	0	0	1.000									
^{137}Cs	0.152	0.121	0.840	1.000								
^{210}Pb	0.365	0.247	0	0.136	1.000							
^{226}Ra	0.098	0	0.263	0.241	0	1.000						
^{227}Ac	0.425	0.268	0.105	0.284	0.632	0	1.000					
^{229}Th	0.396	0.250	0.298	0.446	0.588	0.140	0.918	1.000				
^{230}Th	0.425	0.256	0	0.162	0.630	0	0.931	0.918	1.000			
^{232}Th	0.251	0.185	0.719	0.747	0.377	0.260	0.593	0.752	0.500	1.000		
^{231}Pa	0.403	0.226	0	0.188	0.552	0	0.812	0.765	0.818	0.462	1.000	
^{232}U	0.273	0.164	0.682	0.718	0.373	0.215	0.565	0.689	0.455	0.845	0.428	1.000
^{233}U	0.401	0.229	0	0.171	0.520	0	0.689	0.637	0.674	0.401	0.603	0.651
^{234}U	0.400	0.229	0	0.170	0.520	0	0.689	0.637	0.674	0.401	0.603	0.650
^{236}U	0.400	0.229	0	0.170	0.520	0	0.689	0.637	0.674	0.400	0.603	0.650
^{238}U	0.393	0.226	0.157	0.302	0.510	0	0.694	0.680	0.652	0.516	0.591	0.764
^{237}Np	0.255	0.163	0.082	0.192	0.352	0	0.425	0.430	0.418	0.342	0.404	0.323
^{238}Pu	0.419	0.258	0	0.164	0.641	0	0.955	0.889	0.965	0.495	0.837	0.462
^{239}Pu	0.419	0.258	0	0.163	0.641	0	0.955	0.888	0.965	0.494	0.837	0.461
^{240}Pu	0.419	0.258	0	0.164	0.641	0	0.955	0.889	0.965	0.495	0.837	0.462
^{242}Pu	0.419	0.258	0	0.163	0.641	0	0.955	0.889	0.965	0.494	0.837	0.461
^{241}Am	0.427	0.266	0	0.192	0.638	0	0.961	0.901	0.966	0.517	0.840	0.486
^{243}Am	0.403	0.258	0.255	0.411	0.608	0.118	0.953	0.967	0.908	0.712	0.799	0.669

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF Realizations CC_C Correlations.xls* as shown in Attachments I and II.

Table 6.2-5. Rank Correlations (Correlation Coefficients) Between the External Exposure-Ingestion-Radon BDCF Components for Individual Radionuclides (continued)

	^{233}U	**^{234}U**	**^{236}U**	**^{238}U**	**^{237}Np**	**^{238}Pu**	**^{239}Pu**	**^{240}Pu**	**^{242}Pu**	**^{241}Am**	**^{243}Am**
^{90}Sr											
^{99}Tc											
^{126}Sn											
^{137}Cs											
^{210}Pb											
^{226}Ra											
^{227}Ac											
^{229}Th											
^{230}Th											
^{232}Th											
^{231}Pa											
^{232}U											
^{233}U	1.000										
^{234}U	1.000	1.000									
^{236}U	1.000	1.000	1.000								
^{238}U	0.983	0.983	0.983	1.000							
^{237}Np	0.354	0.354	0.354	0.365	1.000						
^{238}Pu	0.687	0.687	0.687	0.665	0.415	1.000					
^{239}Pu	0.687	0.687	0.687	0.665	0.415	1.000	1.000				
^{240}Pu	0.687	0.687	0.687	0.665	0.415	1.000	1.000	1.000			
^{242}Pu	0.687	0.687	0.687	0.665	0.415	1.000	1.000	1.000	1.000		
^{241}Am	0.692	0.692	0.692	0.676	0.426	0.992	0.992	0.992	0.992	1.000	
^{243}Am	0.666	0.666	0.666	0.700	0.438	0.934	0.934	0.934	0.934	0.950	1.000

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTES: Calculated in Excel file *Volcanic BDCF Realizations CC_C Correlations.xls* as shown in Attachments I and II.
Correlation coefficients for the short-term and long-term inhalation components are equal to unity.

Some correlation coefficients in Tables 6.2-4 and 6.2-5 are shown as equal to zero. This absence of correlation between the variables was determined by performing a statistical test on the calculated value of the correlation coefficient. The hypothesis was that the (true) population correlation coefficient is equal to zero. If the calculated value of the correlation coefficient for the sampling distribution is equal to *r*, one can compute the values of a parameter *t*, such that

$$t = \frac{r}{\sqrt{\frac{(1-r^2)}{n-2}}} \qquad \text{(Eq. 6.2-4)}$$

where n is the number of data points in the sampling distribution, and compare its value with Student's *t* for n-2 degrees of freedom (Steel and Torrie 1980 [DIRS 150857], pp. 278 to 279). Table 6.2-6 lists the values of *t* calculated from Equation 6.2-4 for different values of *r*. The hypothesis that the population correlation coefficient is equal to zero (no correlation) can be rejected at the 99% confidence level if the value of *t* is less than 2.576 (Lide and Frederikse 1997 [DIRS 103178], p. A-105). (The one-tail area under the probability distribution function for variable *t* is equal to 0.995 for *t* = 2.576.) This corresponds to the value of *r* equal to 0.0813.

Table 6.2-6. Calculated Values of Correlation Coefficient and Variable *t*

Calculated Correlation Coefficient, r	**t**
0.0000	0.000
0.0100	0.316
0.0200	0.632
0.0300	0.948
0.0400	1.265
0.0500	1.582
0.0600	1.899
0.0610	1.931
0.0620	1.962
0.0630	1.994
0.0700	2.217
0.0780	2.472
0.0790	2.504
0.0800	2.535
0.0810	2.567
0.0812	2.574
0.0813	2.577
0.0820	2.599
0.1000	3.175
0.1200	3.819
0.1400	4.467
0.1600	5.121
0.1800	5.781
0.2000	6.449

SOURCE: Calculated in Excel file *Volcanic BDCF Realizations CC_C Correlations.xls* as shown in Attachments I and II.

(Note that the distribution of t approaches a normal distribution for the large number of degrees of freedom, which is the case here.) The correlation coefficient was thus set to zero for the calculated values less than 0.0813.

Some BDCF components may be correlated because they depend on the same set of input parameters.

6.2.4 The Use of the Volcanic Ash Scenario Biosphere Dose Conversion Factors in the Total System Performance Assessment Model

The calculations of the all-pathway dose for any given primary radionuclide are carried out in the TSPA model by combining the source term with the BDCFs. For the volcanic ash scenario, the mass loading decrease-function and the ash thickness must also be factored in. The total annual dose is the sum of the annual doses from individual radionuclides tracked by the TSPA (primary radionuclides), including decay products. The total annual dose, computed by the TSPA model, is calculated as

$$
\begin{aligned}
D_{total}(t) &= \sum_i BDCF_i(d_{a,}t) \times Cs_i(t) \\
&= \sum_i BDCF_i \times Cs_i(t) \qquad \text{(Eq. 6.2-5)} \\
&\quad + \sum_i \left(BDCF_{inh,v,i} f(t) + BDCF_{inh,p,i}\right) g(d_a) \times Cs_i(t)
\end{aligned}
$$

where

$D_{total}(t)$ = time-dependent total annual dose to a defined receptor resulting from the volcanic radionuclide releases from the repository (Sv/y)

$Cs_i(t)$ = time dependent activity concentration of radionuclide i in volcanic ash deposited on the ground (Bq/m^2).

and the other parameters are defined in Equations 6.2-1 to 6.2-3.

Equations 6.2-1 and 6.2-5 use SI units for consistency with the documentation of the ERMYN model (BSC 2003 [DIRS 164186]). However, any units can be used to define parameters in GoldSim, where the ERMYN model is implemented, as long as they are dimensionally consistent. In the previous assessments, the output of the BDCF calculations was presented in units of rem/yr or mrem/yr per pCi/m^2, and this analysis follows the same format.

6.2.5 Pathway Analysis

The exposure pathway contributions to the BDCFs for volcanic ash scenario are time-dependent and also depend on the thickness of contaminated ash layer. The pathway analysis was first conducted for a specific point-in-time and fixed value of the ash layer thickness. For the point-in-time and fixed-ash-layer-thickness analysis, the values of parameters t and d_a in Equations 6.2-1 to 6.2-3 are constant. From Equations 6.2-1 to 6.2-3, when t = 0 (i.e., for the initial values of ash deposition and before the mass loading decrease occurs) and $d_a = d_c$ (ash layer thickness equal to the critical thickness), then

$$BDCF_i(d_a, t) = BDCF_i + BDCF_{inh,v,i} + BDCF_{inh,p,i} \quad \text{(Eq. 6.2-6)}$$

The percentage contributions of individual exposure pathways to the volcanic ash scenario BDCFs at $t = 0$ and $d_a = d_c$ are listed in Table 6.2-7.

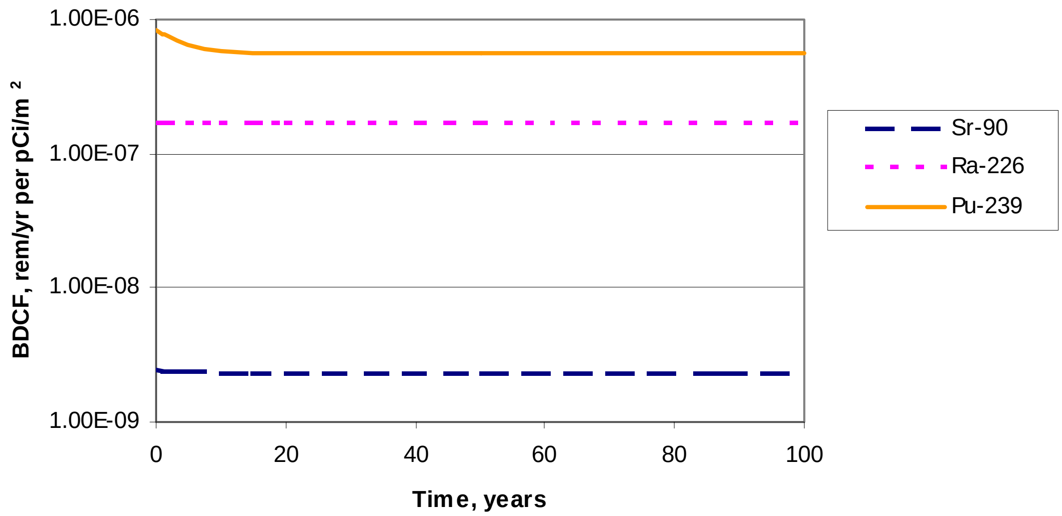
Table 6.2-7. Exposure Pathway Contributions (Percent) for Volcanic Ash Scenario Biosphere Dose Conversion Factors

Radio-nuclide	External	Inhalation			Ingestion								
		Short	Long	Radon	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs	Soil
^{90}Sr	7.2	14.2	28.7	0.0	11.8	9.2	12.1	0.9	5.3	7.0	0.1	2.7	0.8
^{99}Tc	0.3	2.7	5.4	0.0	20.5	4.8	18.6	1.0	6.8	22.4	0.2	17.2	0.0
^{126}Sn	99.2	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
^{137}Cs	98.2	0.3	0.5	0.0	0.1	0.0	0.1	0.0	0.3	0.2	0.2	0.1	0.0
^{210}Pb	0.1	31.7	63.9	0.0	0.5	0.2	1.1	0.1	0.1	0.1	0.0	1.3	0.9
^{226}Ra	36.6	8.4	17.0	37.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
^{227}Ac	0.0	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{229}Th	0.1	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{230}Th	0.0	33.2	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{232}Th	0.9	32.9	66.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{231}Pa	0.0	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{232}U	1.0	32.8	66.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{233}U	0.0	33.2	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{234}U	0.0	33.2	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{236}U	0.0	33.2	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{238}U	0.2	33.1	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{237}Np	0.3	33.0	66.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
^{238}Pu	0.0	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{239}Pu	0.0	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{240}Pu	0.0	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{242}Pu	0.0	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{241}Am	0.0	33.1	66.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
^{243}Am	0.4	33.0	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF CC_C Pathway Analysis.xls* as shown in Attachments I and II.

The evolution of BDCFs with time affects only the short-term inhalation component. The short-term inhalation component accounts for about one-third of the BDCF values presented in Table 6.2-7 for all actinides, including ^{227}Ac. For those radionuclides, the total BDCFs show a greater degree of reduction over time compared with radionuclides with smaller short-term inhalation components. This effect is shown in Figure 6.2-1 for ^{90}Sr, ^{226}Ra, and ^{239}Pu for ash thickness equal to the average value of the critical thickness ($d_a = d_c$). These radionuclides were selected because of the differing pathway contributions. BDCF for ^{90}Sr includes significant contributions from the external, inhalation, and ingestion exposure pathways. Ingestion is a relatively insignificant pathway for ^{226}Ra, while BDCF for ^{239}Pu is dominated by inhalation.

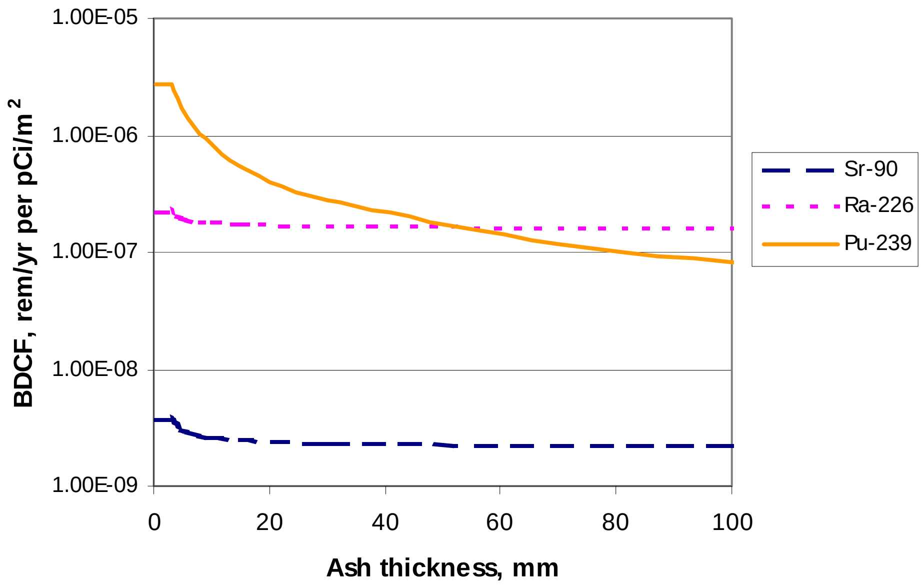


SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF CC_C Pathway Analysis.xls* as shown in Attachments I and II.

Figure 6.2-1. Biosphere Dose Conversion Factors as a Function of Time.

The short-term and the long-term inhalation components of BDCFs are affected by the thickness of the layer of contaminated ash. When the ash layer thickness increases, for a given areal activity concentration on the ground, a smaller fraction of the deposited activity would be available for resuspension because an increasing fraction would be covered by ash. Consequently, the inhalation component would decrease. This effect would be strongest for radionuclides with large BDCF contribution from inhalation, such as ^{239}Pu (Figure 6.2-2). The figure represents the point-in-time conditions for $t = 0$.



SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTE: Calculated in Excel file *Volcanic BDCF CC_C Pathway Analysis.xls* as shown in Attachments I and II.

Figure 6.2-2. Biosphere Dose Conversion Factors as a Function of Ash Thickness.

6.2.6 Climate Change

Annual doses arising from volcanic eruption (Equation 6.2-5) are calculated by combining the biosphere component (BDCFs) with the source term (i.e., the activity concentration of a given radionuclide per unit area). BDCFs are independent of the source term. The discussion of climate change presented here concerns only the biosphere component, the BDCFs because the source term is calculated in the TSPA model.

A single biosphere model input parameter affected by climate change is the growing time of crops for the human and animal consumption, which potentially may affect the ingestion exposure pathway. The ingestion exposure pathway contributes little to the BDCF for most radionuclides (Table 6.2-7). The importance of the ingestion pathway gradually increases as the short-term inhalation BDCF component decreases, so there is the potential for an increased effect of climate change on the BDCFs at later times.

Because climate change affects only the BDCF component associated with ingestion through the growing-time parameter, the value of this component was calculated for a future climate represented by the upper bound of the glacial transition climate. The results, in term of the ratios of the mean pathway BDCF values for the modern and future climates, are presented in Table 6.2-8. The results of pathway analysis (Table 6.2-8) indicate that the biosphere modeling results for the volcanic release of radionuclides are relatively insensitive to the climate change.

Table 6.2-8. Comparison of Pathway Biosphere Dose Conversion Factors for the Volcanic Ash Scenario and the Modern and Future Climates

Radio-nuclide	External	Inhalation			Ingestion									Total
		Short	Long	Radon	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs	Soil	
^{90}Sr	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{99}Tc	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{126}Sn	1.00	1.00	1.00		1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{137}Cs	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{210}Pb	1.00	1.00	1.00		1.00	1.01	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{226}Ra	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{227}Ac	1.00	1.00	1.00		1.00	1.02	0.98	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{229}Th	1.00	1.00	1.00		1.00	1.03	0.98	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{230}Th	1.00	1.00	1.00		1.00	1.03	0.98	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{232}Th+^{228}Ra	1.00	1.00	1.00		1.00	1.01	0.98	1.00	1.01	1.00	1.00	1.00	1.00	1.00
^{231}Pa	1.00	1.00	1.00		1.00	1.01	0.99	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{232}U+^{228}Th	1.00	1.00	1.00		1.00	1.02	0.98	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{233}U	1.00	1.00	1.00		1.00	1.01	0.99	1.00	1.00	1.01	1.00	1.00	1.00	1.00
^{234}U	1.00	1.00	1.00		1.00	1.01	0.99	1.00	1.00	1.01	1.00	1.00	1.00	1.00
^{236}U	1.00	1.00	1.00		1.00	1.01	0.99	1.00	1.00	1.01	1.00	1.00	1.00	1.00
^{238}U	1.00	1.00	1.00		1.00	1.01	0.99	1.00	1.00	1.01	1.00	1.00	1.00	1.00
^{237}Np	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
^{238}Pu	1.00	1.00	1.00		1.00	1.03	0.97	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{239}Pu	1.00	1.00	1.00		1.00	1.03	0.97	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{240}Pu	1.00	1.00	1.00		1.00	1.03	0.97	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{242}Pu	1.00	1.00	1.00		1.00	1.03	0.97	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{241}Am	1.00	1.00	1.00		1.00	1.03	0.98	1.00	1.01	1.01	1.00	1.00	1.00	1.00
^{243}Am	1.00	1.00	1.00		1.00	1.03	0.98	1.00	1.01	1.01	1.00	1.00	1.00	1.00

SOURCE: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306MWDBGSMF.001 [DIRS 163816], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

NOTES: Calculated in Excel file *Volcanic BDCF FC_C Pathway Analysis.xls* as shown in Attachments I and II.
The values in the table are ratios of the pathway BDCFs for the future and modern climates.

Therefore, it is recommended that the BDCFs developed for the modern climate be used for the future climates.

6.3 DOSE FACTORS FOR THE ERUPTION PHASE

The eruption phase of a volcanic event refers to the conditions that exist during the volcanic eruption, before the deposition of volcanic ash on the ground is completed. Because higher concentrations of airborne radioactive particulates are expected in the air during this phase, inhalation of airborne contaminated ash particles is the only pathway considered in the analysis for this phase. The external exposure from contaminated ash is one of the exposure pathways included in the volcanic ash scenario BDCFs (Section 6.2). Inhalation exposure arising from gaseous volcanic emissions was not considered because gaseous radionuclides were not included among radionuclides of interest (Section 6.1.1). Section 6.3.1 contains a summary of mass loading measurements taken during volcanic eruptions. Section 6.3.1 describes the development of dose factors.

6.3.1 Mass Loading Levels During Volcanic Eruption

This section is a summary of airborne particle concentration measurements taken during and immediately after volcanic eruptions. This summary is provided to develop an understanding of airborne concentrations of ash that may occur at the location of the receptor following a volcanic eruption at Yucca Mountain. This information may be used to support evaluation of receptor dose during a volcanic eruption. The biosphere model does not evaluate receptor dose. Inhalation dose from airborne particulate concentrations during volcanic eruption, if necessary, will be calculated as a component of performance assessment.

Most of the measurements reported in this section were taken at ambient monitoring stations during or soon after ash-fall events. Ambient monitoring stations usually are centrally located in communities. The concentrations of airborne particles measured at those stations are representative of regional or local conditions that are not influenced by specific, immediately adjacent activities.

Mount St. Helens–Total suspended particulate (TSP) concentrations at in Yakima, Washington, were as high as 35.6 mg/m^3 and averaged 13.3 mg/m^3 during the first week following the May 18, 1980 eruption of Mount St. Helens (Merchant et al. 1982 [DIRS 160102], pp. 912 to 913). Five to 10 mm of ash were deposited at Yakima during that eruption (Sarna-Wojcicki et al. 1982 [DIRS 160227], Figure 336).

The peak, short-term (about 4 hour) TSP concentration measured in Missoula, Montana, on May 19 (the day of greatest ash fall at that location) was 19.9 mg/m^3. The average daily concentrations there decreased from 11.1 mg/m^3 on May 19 to 0.9 mg/m^3 on May 22 (Johnson et al. 1982 [DIRS 164149], pp. 1067 to 1068). About 2.5 to 5 mm of ash were deposited at Missoula (Sarna-Wojcicki et al. 1982 [DIRS 160227], Figure 336).

The daily average TSP concentration in Clarkston, Washington, on May 18 was 0.68 mg/m^3. About 0.5 mm of ash was deposited there from that day's eruption. At Longview, Washington, the average daily concentration on May 27 was 1.42 mg/m^3. About 1 to 2 mm of ash were deposited on that city during an eruption on May 25 (DTN: MO0008SPATSP00.013 [DIRS 151750], EPA monitoring sites 53-003-0003 and 53-015-0008; Sarna-Wojcicki et al. 1982 [DIRS 160227], Figures 336 and 344).

About 10 percent or less of the ash from Mount St. Helens was ≤10 μm (PM_{10}) (Craighead et al. 1983 [DIRS 160338], p. 6; Buist et al 1986[DIRS 144632], p. 40). PM_{10} is defined as particulate matter with mass median aerodynamic diameter less than 10 μm.

Soufriere Hills–Peak PM_{10} concentrations at 3 locations during an eruption of the Soufriere Hills volcano (Montserrat, British West Indies) in 1997 were about 0.3 to 1.0 mg/m^3 outside at a school, 0.1 mg/m^3 inside a school, and 0.4 to 1.5 mg/m^3 outside at a hotel (Baxter et al. 1999 [DIRS 150713], Figure 3 and p. 1142). The fine ashfall deposits from this volcano typically contained 60 to 70 percent (by weight) of 10 to 125 μm particles and 13 to 20 percent of particles <10 μm. Using a ratio of PM_{10} to TSP concentrations of 1:5 (calculated based on the average fraction of particles <10 μm in the deposited ash), peak TSP concentrations were about 1.5 to 5.0 mg/m^3, 0.5 mg/m^3, and 2.0 to 7.5 mg/m^3, respectively at the three locations. These concentrations likely did not include resuspended particles as they were taken late in the day after activities at the sites had ceased.

Searl et al. (2002 [DIRS 160104], Table 11) estimated mean personal PM_{10} exposure concentrations for various activity levels during and after eruptions of the Soufriere Hills volcano. Using a PM_{10} to TSP ratio of 1:5, estimated TSP concentrations during periods with alert levels to very high levels of ash were 1.5 to 5 mg/m^3 for people inactive indoors, 2.5 to 10 mg/m^3 for active indoors, 5 to 15 mg/m^3 for active outside, and 25 to 50 mg/m^3 for dusty occupations. These estimates include the influence of particle resuspension during activities.

Mt. Spurr–The maximum hourly PM_{10} concentrations in Anchorage Alaska, during the 1992 eruption of Mt. Spurr was 3 mg/m^3. The 24-hour average concentrations the day after the eruption was 0.565 mg/m^3. About 8 to 15 percent (by weight) of ash particles from that eruption collected near Anchorage were <15 μm, and 5 to 10 percent were between 2.5 and 10 μm, resulting in an approximate PM_{10} to TSP ratio of 1:10. Based on this ratio, the peak TSP concentration in Anchorage was about 30 mg/m^3 and the 24-hour average was about 5.5 mg/m^3 (Gordian et al. 1996 [DIRS 160111], p. 290; McGimsey et al. 2001 [DIRS 160386], Figures 11 and 12).

Mt. Sakurijima–Yano et al. (1990 [DIRS 160112], p. 373) stated that peak, 2-minute concentrations higher than 2 mg/m^3 have been measured in high-exposure areas after eruptions of Mount Sakurijima (Japan), and that "these high levels of suspended particulate matter seldom last long, and they usually decrease rapidly to approximately 0.1 mg/m^3."

In summary, daily average concentrations of ash outdoors during an eruption may be as low or lower than 1 mg/m^3 for light ashfall events or as high or higher than 15 mg/m^3 for high ashfall events. Concentrations indoors would be much lower (see also BSC 2003 [160965], Section 6.2 [160965]). It should be noted that high ambient concentrations reported here likely are overestimates of concentrations inhaled because it is well documented that, during volcanic eruptions people take actions to reduce the amount of ash they inhale, such as staying indoors and wearing masks (Johnson et al. 1982 [DIRS 164149]; Buist et al. 1986 [DIRS 144632]; Nania et al. 1994 [DIRS 164156]).

6.3.2 Development of Dose Factors

DFs are developed for the eruption phase, rather than BDCFs because BDCFs are developed for annual exposures and do not address relatively short-term exposure conditions during a volcanic eruption. DF for a given primary radionuclide is numerically equal to the dose resulting from one-day intake of this radionuclide (and associated short-lived decay products, if present) by inhaling air containing a unit activity concentration of the radionuclide under consideration (1 pCi/m^3). Radionuclide intake depends on inhalation exposure time and breathing rate.

The dose to a receptor from inhalation exposure to a given primary radionuclide *i* in airborne particulates is calculated in the biosphere model (modified from BSC 2003 [DIRS 164186], Section 6.4.8.1) as

$$D_{inh,p,i} = EDCF_{inh,i}\left[\sum_n Ca_{i,n} BR_n \sum_m \left(PP_m \; t_{n,m}\right)\right] \qquad \text{Eq. 6.3-1}$$

where

$D_{inh,p,i}$	=	annual dose from inhalation exposure to primary radionuclide *i* in resuspended particles (Sv/yr)
$EDCF_{inh,i}$	=	effective DCF for inhalation of primary radionuclide *i* (Sv/Bq)
n	=	environment index; n = 1 for active outdoors, 2 for inactive outdoors, 3 for active indoors, 4 for asleep indoors, and 5 for away from the contaminated area
$Ca_{i,n}$	=	activity concentration of primary radionuclide *i* in air for environment *n* (Bq/m^3)
BR_n	=	breathing rate for environment *n* (m^3/hr)
m	=	population group index; m = 1 for commuters, 2 for local outdoor workers, 3 for local indoor workers, and 4 for non-workers
PP_m	=	fraction of total population in population group *m*
$t_{n,m}$	=	number of hours per day a population group *m* spends in environment *n* (hr/d).

For calculating the inhalation dose, the exposure times for different population groups and environments, as well as the associated breathing rates, were developed (see Section 4.1 for a list of model input parameters). It is postulated that, for the duration of volcanic eruption, human breathing rates and the fractions of time spent indoors versus outdoors remain relatively unchanged compared to the pre-eruption conditions (Assumption 1). Therefore, same parameter values for lifestyle characteristics as those used for the BDCF calculation were used to develop dose factors for the eruption phase.

Assuming that the radionuclide concentration in the indoor air is a fraction of that in the outdoor air (Assumption 2), Equation 6.3-1 can be modified as

$$\begin{aligned} D_{inh,p,i} &= EDCF_{inh,i}\left[\sum_n Ca_{i,outdoor}\ IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)\right] \\ &= Ca_{i,outdoor} EDCF_{inh,i}\left[\sum_n IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)\right] \\ &= Ca_{i,outdoor}\ DF_i \end{aligned} \qquad \text{(Eq. 6.3-2)}$$

where

$Ca_{i,outdoor}$	=	activity concentration of a radionuclide *i* in outdoor air for the ash that has not yet fallen on the ground (Bq/m^3)
IRF_n	=	indoor reduction factor for activity concentration in air (dimensionless)
DF_i	=	dose factor for a primary radionuclide *i* (Sv/d per Bq/m^3)

Activity concentration of a radionuclide *i* in outdoor air for the ash that has not yet fallen on the ground, $Ca_{i,outdoor}$, does not depend on the outdoor environment, as defined for the biosphere model (i.e., active outdoor and inactive outdoor), because this quantity is independent of human activities. Indoor reduction factor is equal to 1 for the outdoor environments (active outdoors and inactive outdoors) and to 0.5 for the indoor environments (asleep indoors and active indoors), (Assumption 2). The term in the brackets in Equation 6.3-2 is the effective daily breathing rate, i.e., the volume of outdoor air that contains the same amount of contaminant (radionuclide) as the air that is breathed in by a person in one day.

Dose factor in Equation 6.3-2 is expressed as

$$DF_i = EDCF_{inh,i}\left[\sum_n IRF_n\ BR_n \sum_m \left(PP_m\ t_{n,m}\right)\right] \qquad \text{(Eq. 6.3-3)}$$

The effective dose conversion factors for inhalation include, where applicable, contributions from the associated short-lived decay products. They were developed by calculating a sum of the dose conversion factors for inhalation, weighted by the associated branching fractions, as shown in Table 6.3-1. Dose conversion factors used in this analysis (DTN: MO0306SPACRBSM.001 [DIRS 163813]) are from Federal Guidance Report No. 11 (Eckerman et al. 1988 [DIRS 101069]). These DCFs were developed for radiation protection in the workplace and are usually applied to chronic low-dose, low-dose rate exposures. However, the same values are also recommended for conducting radiological assessments for consequence analysis in the case of accidental releases (Sjoreen et al. 2001 [DIRS 164093], Section 4.9.1, where calculated doses can exceed 250 rem (Sjoreen et al. 2001 [DIRS 164093], Table 7.1).

The dose factors are calculated as deterministic quantities using the mean values of parameters. They are provided to allow estimating the dose during the eruption phase. In the previous performance assessment, dose calculated for the eruptive phase did not significantly contribute to the calculated expected annual dose which was shown in the sensitivity analyses for the TSPA for the Site Recommendation (CRWMS M&O 2000 [DIRS 153246], Sections 3.10.3.1 and 5.2.9.9). Calculations of the individual terms in Equation 6.3-3 are shown in Table 6.3-2.

Table 6.3-1. Effective Dose Conversion Factors for Inhalation

Primary Radionuclide	Decay Product (branching fraction if not 100%, half-life)	Dose Conversion Factor (Sv/Bq)	Effective Dose Conversion Factor (Sv/Bq) [c]
C-14	-	6.36E-12	6.36E-12
Cl-36	-	5.93E-09	5.93E-09
Se-79	-	2.66E-09	2.66E-09
Sr-90+D[a]		6.47E-08	6.70E-08
	Y-90 (64.0 hr)	2.28E-09	
Tc-99	-	2.25E-09	2.25E-09
Sn-126+D		2.69E-08	2.74E-08
	Sb-126m (19.0 min)	9.17E-12	
	Sb-126 (14%, 12.4 day)	3.17E-09	
I-129	-	4.69E-08	4.69E-08
Cs-135	-	1.23E-09	1.23E-09
Cs-137+D		8.63E-09	8.63E-09
	Ba-137m (94.6%, 2.552 min)	0.00E+00	
Thorium Series (4n)			
Pu-240	-	1.16E-04	1.16E-04
U-236	-	3.39E-05	3.39E-05
Th-232	-	4.43E-04	4.43E-04
Ra-228+D[b]		1.29E-06	1.37E-06
	Ac-228 (6.13 hr)	8.33E-08	
U-232	-	1.78E-04	1.78E-04
Th-228+D[b]		9.23E-05	9.32E-05
	Ra-224 (3.66 d)	8.53E-07	
	Rn-220 (55.6 s)	0.00E+00	
	Po-216 (0.15 s)	0.00E+00	
	Pb-212 (10.64 h)	4.56E-08	
	Bi-212 (60.55 min)	5.83E-09	
	Po-212 (64.07%, 0.305 µs)	0.00E+00	
	Tl-208 (35.93%, 3.07 min)	0.00E+00	
Neptunium Series (4n + 1)			
Am-241	-	1.20E-04	1.20E-04
Np-237+D		1.46E-04	1.46E-04
	Pa-233 (27.0 d)	2.58E-09	
U-233	-	3.66E-05	3.66E-05
Th-229+D		5.80E-04	5.85E-04
	Ra-225 (14.8 d)	2.10E-06	
	Ac-225 (10.0 d)	2.92E-06	
	Fr-221 (4.8 min)	0.00E+00	
	At-217 (32.3 ms)	0.00E+00	
	Bi-213 (45.65 min)	4.63E-09	
	Po-213 (97.84%, 4.2 µs)	0.00E+00	
	Tl-209 (2.16%, 2.2 min)	0.00E+00	
	Pb-209 (3.253 h)	2.56E-11	

Table 6.3-1. Effective Dose Conversion Factors for Inhalation (continued)

Primary Radionuclide	Decay Product (branching fraction if not 100%, half-life)	Dose Conversion Factor (Sv/Bq)	Effective Dose Conversion Factor (Sv/Bq) [c]
Uranium Series (4n + 2)			
Pu-242	-	1.11E-04	1.11E-04
U-238+D		3.20E-05	3.20E-05
	Th-234 (24.10 d)	9.47E-09	
	Pa-234m (99.80%, 1.17 min)	0.00E+00	
	Pa-234 (0.33%, 6.7 h)	2.20E-10	
Pu-238	-	1.06E-04	1.06E-04
U-234	-	3.58E-05	3.58E-05
Th-230	-	8.80E-05	8.80E-05
Ra-226+D		2.32E-06	2.32E-06
	Rn-222 (3.8235 d)	0.00E+00	
	Po-218 (3.05 min)	0.00E+00	
	Pb-214 (99.98%, 26.8 min)	2.11E-09	
	At-218 (0.02%, 2 s)	0.00E+00	
	Bi-214 (19.9 min)	1.78E-09	
	Po-214 (99.98%, 1.64×10^{-4} s)	0.00E+00	
	Tl-210 (0.02%, 1.3 min)	0.00E+00	
Pb-210+D		3.67E-06	6.26E-06
	Bi-210 (5.012 d)	5.29E-08	
	Po-210 (138.38 d)	2.54E-06	
Actinium Series (4n + 3)			
Am-243+D		1.19E-04	1.19E-04
	Np-239 (2.355 d)	6.78E-10	
Pu-239	-	1.16E-04	1.16E-04
U-235+D		3.32E-05	3.32E-05
	Th-231 (25.52 hr)	2.37E-10	
Pa-231	-	3.47E-04	3.47E-04
Ac-227+D		1.81E-03	1.82E-03
	Th-227 (98.62%, 18.718 d)	4.37E-06	
	Fr-223 (1.38%, 21.8 min)	1.68E-09	
	Ra-223 (11.434 d)	2.12E-06	
	Rn-219 (3.96 s)	0.00E+00	
	Po-215 (1.78 ms)	0.00E+00	
	Pb-211 (36.1 min)	2.35E-09	
	Bi-211 (2.15 min)	0.00E+00	
	Tl-207 (99.72%, 4.77 min)	0.00E+00	
	Po-211 (0.28%, 0.516 s)	0.00E+00	

SOURCE: DTN: MO0306SPACRBSM.001 [DIRS 163813]

NOTES:

[a] "+D" denotes that the radionuclide is treated together with the short-lived (half-life < 180 days) decay product.

[b] Indented radionuclides are long-lived decay products considered separately from the parents.

[c] Calculated as a sum of DCFs for primary radionuclides and the short-lived decay products, weighted by the branching fractions, where applicable.

Table 6.3-2. Supplementary Calculations Supporting Development of Dose Factors

	Proportion of Population, PP_m	Mean Time Spent in Environment, $t_{n,m}$ (hours per day)			
		Active Outdoors	**Inactive Outdoors**	**Asleep Indoors**	**Active Indoors**
Non-workers	39.20%	0.3	1.2	8.3	12.2
Commuters	12.50%	0.3	2	8.3	5.1
Local outdoor workers	5.50%	3.1	4.2	8.3	6.4
Local indoor workers	42.80%	0.3	1.5	8.3	11.9
$\sum_m \left(PP_m \, t_{n,m}\right)$ (h)		0.454	1.593	8.3	10.865
BR_n (m^3/h)		1.57	1.08	0.39	1.08
IRF_n (dimensionless)		1	1	0.5	0.5
$IRF_n \, BR_n \sum_m \left(PP_m \, t_{n,m}\right)$ (m^3)		0.713	1.721	1.619	5.867
$\sum_n IRF_n \, BR_n \sum_m \left(PP_m \, t_{n,m}\right)$ (m^3)					**9.919**

SOURCE: MO0306SPACRBSM.001 [DIRS 163813]

NOTE: The symbols and formulas in the table are the same as those in Equation 6.3-3.

The DFs for radionuclides of interest for the volcanic ash scenario, in units of Sv/d per Bq/m^3 and rem/d per pCi/m^3, calculated using Equation 6.3-3, are summarized in Table 6.3-3. Calculations were performed in an Excel spreadsheet (Attachment I and II).

Table 6.3-3. Dose Factors for Eruptive Phase of the Volcanic Scenario

Radionuclide	**Effective Dose Conversion Factor (Sv/Bq)** [a]	**Dose Factor** [b]	
		Sv/d per Bq/m^3	**rem/d per pCi/m^3**
^{90}Sr	6.70E-08	6.65E-07	2.46E-06
^{99}Tc	2.25E-09	2.23E-08	8.26E-08
^{126}Sn	2.74E-08	2.72E-07	1.01E-06
^{137}Cs	8.63E-09	8.56E-08	3.17E-07
^{210}Pb	6.26E-06	6.21E-05	2.30E-04
^{226}Ra	2.32E-06	2.30E-05	8.51E-05
^{227}Ac	1.82E-03	1.81E-02	6.68E-02
^{229}Th	5.85E-04	5.80E-03	2.15E-02
^{230}Th	8.80E-05	8.73E-04	3.23E-03
^{232}Th + ^{228}Ra + ^{228}Th	5.38E-04	5.33E-03	1.97E-02
^{231}Pa	3.47E-04	3.44E-03	1.27E-02
^{232}U + ^{228}Th	2.71E-04	2.69E-03	9.95E-03
^{233}U	3.66E-05	3.63E-04	1.34E-03
^{234}U	3.58E-05	3.55E-04	1.31E-03
^{236}U	3.39E-05	3.36E-04	1.24E-03
^{238}U	3.20E-05	3.17E-04	1.17E-03
^{237}Np	1.46E-04	1.45E-03	5.36E-03
^{238}Pu	1.06E-04	1.05E-03	3.89E-03
^{239}Pu	1.16E-04	1.15E-03	4.26E-03
^{240}Pu	1.16E-04	1.15E-03	4.26E-03
^{242}Pu	1.11E-04	1.10E-03	4.07E-03
^{241}Am	1.20E-04	1.19E-03	4.40E-03
^{243}Am	1.19E-04	1.18E-03	4.37E-03

NOTES:

[a] From Table 6.3-1.

[b] Calculated by multiplying the effective dose conversion factor for inhalation by the term calculated in Table 6.3-3. The calculations are shown in Excel spreadsheet *Dose Factor Calculations REV C.xls* (Attachments I and II)

7. CONCLUSIONS

This section contains summary recommendations concerning values of the volcanic ash scenario BDCFs and their use in the TSPA model, and the values of DFs for the eruption phase of a volcanic event. The output of this analysis is contained in the data set identified by DTN: MO0307MWDDEBDC.001 titled *Disruptive Event Biosphere Dose Conversion Factors*.

The values of the BDCFs were developed using the ERMYN biosphere model and remain valid within the application and validation limits of the model (BSC 2003 [164186], Section 8.2). Specifically, the BDCFs were developed for a specific assessment context (BSC 2003 [164186], the reference biosphere and the receptor. If used for other situations, the BDCFs may not apply.

For the contaminated volcanic ash exposure scenario, the model applies to a layer of small ash particles that could be resuspended into the air. The model and the BDCFs do not apply to other volcanic media, such as contaminated gas, lava, or coarse ash. Some assumptions regarding the model development (BSC 2003 [164186], Sections 5.12 and 5.15) are based on thin ash deposits; if thick ash deposits occur, the model might overestimate the BDCF values. For example, the external exposure is assumed in the biosphere model to originate from contaminated ground surface. If the deposit were thick, the external exposure would be reduced because of self absorption of the fraction of radiation emitted from contaminated ash/soil. The biosphere model assumes that the entire deposited activity is mixed into the surface soil and available to plants. For the deposits thicker than the rooting depth of plants, a portion of the deposited activity would not be available for plant uptake.

The ERMYN model does not apply during a volcanic eruption when volcanic ash is still in the air (i.e., before initial settling on the ground). For the eruption period, the dose factors should be used.

The applicable acceptance criteria listed in Section 4.2 are addressed. The report describes the results of the biosphere modeling for the volcanic ash exposure scenario and criteria that were considered for the development of the model and its input parameters are implicitly included in the modeling results. The results reflect consideration of the site-specific FEPs, characteristics of the reference biosphere and its features, parameter selection and justification, as well as incorporation of uncertainty in the model and its input parameters. The model for the volcanic ash exposure scenario is briefly described in Section 6.1.5; the model input parameter values, including uncertainty distributions, are presented in Section 4.1.

7.1 INCORPORATION OF UNCERTAINTY

The outputs of this analysis are BDCFs for volcanic ash scenario and modern climate, and DFs for inhalation exposure during the eruptive phase. To incorporate uncertainty in the model input, BDCFs were calculated in a series of 1,000 model realizations. The resulting probability distribution represents uncertainty in the BDCFs. The full set of BDCFs consists of the three BDCF components generated for each of 23 primary radionuclides and each model realization. The summary of these results, in the form of discrete cumulative probability distributions of BDCFs in 5 percentile increments, plus means and standard deviations, is presented in Tables 6.2-1 to 6.2-3 for the external-ingestion-radon component, short-term inhalation component, and the long-term inhalation component, respectively. The full set of BDCF vectors for each realization is included on a CD-ROM (Attachment II) in the file *Volcanic BDCF Realizations CC_C.xls*.

7.2 FORMAT OF THE BIOSPHERE DOSE CONVERSION FACTOR INPUT TO TSPA

Three BDCF components are calculated for each primary radionuclide. The first component, $BDCF_i$, is time independent and accounts for three exposure pathways (ingestion, inhalation of radon decay products, and external exposure). The second and third BDCF components account for inhaling airborne particulates. Both of these components depend on ash thickness. The second term ($BDCF_{inh,v,i}$) represents short-term inhalation exposure during increased concentrations of airborne particulates following volcanic eruption and is time-dependent because mass loading will gradually decrease after an eruption. The third term ($BDCF_{inh,p,i}$) represents long-term inhalation of suspended particulates under nominal conditions (i.e., when the mass loading is not elevated as the result of volcanic eruption). The results of the BDCF calculations are in the format of 1,000 row vectors, one for each model realization, consisting of three BDCF components for each of the 23 primary radionuclides (i.e., 69 BDCF components per vector) and a value of critical thickness of ash corresponding to the specific BDCF vector. A vector can be regarded as a one-dimensional array containing the results of a single realization of the biosphere model for the primary radionuclides.

7.3 USE OF BIOSPHERE DOSE CONVERSION FACTORS FOR VOLCANIC ASH SCENARIO

Calculating the annual all-pathway dose for any given primary radionuclide is done by combining the source term with the BDCFs. In the case of the volcanic ash scenario, the mass loading decrease function and the ash thickness also are factored into the calculations. The total annual dose is the sum of the annual doses from individual radionuclides tracked in the TSPA (primary radionuclides), including their decay products. The total annual dose, computed by the TSPA model, is calculated as

$$
\begin{aligned}
D_{total}(t) &= \sum_i BDCF_i(d_{a,}t) \times Cs_i(t) \\
&= \sum_i BDCF_i \times Cs_i(t) + \qquad \text{(Eq. 7-1)} \\
&\quad + \sum_i \left(BDCF_{inh,v,i} f(t) + BDCF_{inh,p,i}\right) g(d_a) \times Cs_i(t)
\end{aligned}
$$

where

$D_{total}(t)$	=	time-dependent total annual dose to a defined receptor resulting from the volcanic release of radionuclides from the repository (Sv/y)
$Cs_i(t)$	=	time dependent activity concentration of radionuclide i in volcanic ash deposited on the ground (Bq/m^2)
$BDCF_i(d_a, t)$	=	BDCF for primary radionuclide i for an ash depth d_a at time t

following a volcanic eruption (Sv/y per Bq/m^2)

$BDCF_i$ = BDCF for primary radionuclide *i* for external exposure, radon inhalation, and ingestion (Sv/y per Bq/m^2)

$BDCF_{inh,v,i}$ = BDCF for primary radionuclide *i* for short-term inhalation at post-volcanic level of mass loading in excess of nominal mass loading (Sv/y per Bq/m^2)

$BDCF_{inh,p,i}$ = BDCF for primary radionuclide *i* for long-term inhalation at nominal level of mass loading (Sv/y per Bq/m^2).

The time function, *f(t)*, accounts for the reduction of mass loading in the years immediately following volcanic eruption. The mass loading is assumed to decrease exponentially with time as

$$f(t) = e^{-\lambda t} \quad \text{(Eq. 7-2)}$$

where

λ = mass loading decrease constant (1/yr)

t = time (years); $t = 0$ is the first year after a volcanic eruption.

The mass loading decrease constant (Equation 7-2) depends on the ash thickness, and for an initial ash depth of less than 10 mm, it is represented by a triangular probability distribution function with a mode of 0.33/yr, a minimum of 0.2/yr, and a maximum of 2.0/yr (DTN: MO0305SPAINEXI.001 [DIRS 163808]). For an initial ash depth of 10 mm or more, the mass loading decrease constant is represented by a triangular distribution with a mode of 0.20, a minimum of 0.125, and a maximum of 1.0 (DTN: MO0305SPAINEXI.001 [DIRS 163808]).

The function of ash thickness, $g(d_a)$, is expressed as

$$g(d_a) = \begin{cases} 1 & \text{when } d_a < d_c \\ \dfrac{d_c}{d_a} & \text{when } d_a \ge d_c \end{cases} \quad \text{(Eq. 7-3)}$$

where

d_c = critical thickness of ash layer (mm)

The value of the critical thickness is different for each biosphere model realization and has to be sampled in the TSPA code together with the BDCFs from the same vector.

7.4 USE OF DOSE FACTORS

For the eruption period, the dose factors for inhalation exposure pathway should be used instead of the BDCFs. DFs for evaluating doses during volcanic eruptions are listed in Table 6.3-2. To calculate the daily dose from inhaling a specific radionuclide during a volcanic eruption, multiply the activity concentration of that radionuclide in air by the appropriate DF. The total inhalation dose from concentrations of primary radionuclides in air is then calculated as

$$D_{inh} = \sum_i D_{inh,i} = \sum_i DF_i \times Ca_{i,outdoor} \qquad \text{(Eq. 7-4)}$$

where

$D_{inh,\,i}$	=	daily inhalation dose for a primary radionuclide *i* (Sv)
DF_i	=	dose factor for a primary radionuclide *i* (Sv/d per Bq/m^3)
$Ca_{i,outdoor}$	=	activity concentration in air of a primary radionuclide *i* for the ash that has not yet fallen on the ground (Bq/m^3).

7.5 CORRELATIONS, PATHWAY ANALYSIS AND CLIMATE CHANGE

Correlation coefficients for the BDCF components for each individual radionuclide are listed in Table 6.2.4. Rank correlations between the BDCF components of different radionuclides also have been calculated. Correlation coefficients for the external-ingestion-radon component are listed in Table 6.2-5. Correlation coefficients are the highest for the isotopes of actinides. Correlation coefficients for short-term and long-term inhalation components are equal to 1.

Results of pathway analysis are presented in Table 6.2-7. The dominant pathway for isotopes of actinides is inhalation with the long-term component contributing about 2/3 of the dose and the short-term component contributing about 1/3 of the dose. The pathway contributions for the other radionuclides are more diversified. For example, the food consumption pathways are dominant for ^{99}Tc and external exposure pathway is dominant for ^{137}Cs.

The climate change during the period of time considered in this analysis has negligible effect on the BDCFs for the volcanic ash scenario and it is recommended that the modern climate BDCFs be used for dose assessment for the entire period.

8. INPUTS AND REFERENCES

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8.3 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

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8.4 ANALYSIS OUTPUT

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ATTACHMENT I
CALCULATION OF BIOSPHERE DOSE CONVERSION FACTORS AND EXPOSURE PATHWAY CONTRIBUTIONS

This attachment contains a description of the Excel files, which contain calculations generated in this analysis.

Volcanic BDCF realizations CC_C.xls–This Excel file contains the results of 1,000 biosphere model realizations that generated BDCFs for volcanic ash scenario for the modern (current) climate. The BDCFs are arranged by radionuclide in sets of 4 columns per radionuclide in Columns B to DE. For each realization and each radionuclide, three BDCF components were generated: external-inhalation-radon, short term inhalation, and long term inhalation. The fourth value per radionuclide is the critical thickness, which is the same for a given model realization for each radionuclide. The results of individual realizations are in rows 36 to 1,035. The values were copied from the GoldSim results summaries.

Row 7 contains the means of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel AVERAGE function for the specified cell range.

Row 8 contains standard deviations of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel STDEV function for the specified cell range.

Row 10 contains minima of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel MIN function for the specified cell range.

Row 30 contains maxima of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel MAX function for the specified cell range.

Rows 11 to 29 contain the percentiles in the increments of 5 of the values in rows 36 to 1,035 of the corresponding columns, calculated using the Excel PERCENTILE function for the specified cell range.

Volcanic BDCF realizations CC_C Correlations.xls–This Excel file contains calculations of the rank correlation coefficients.

The BDCFs are arranged by radionuclide in sets of 6 columns per radionuclide in Columns B to EI. For each realization and each radionuclide, the three BDCF components (external-inhalation-radon, short-term inhalation, and long term inhalation) are in the first, third, and fifth column of each set of 6. The second, fourth and sixth column contain the rank of each adjacent cell, calculated using the Excel RANK function for the specified range of cells. The BDCF values and their ranks for individual model realizations are in rows 13 to 1,012.

Row 11 contains the correlation coefficients for the BDCF components for a given radionuclide. The rank correlation coefficients are in the second, fourth and sixth column of the set of 6 for each radionuclide. The correlation coefficients were calculated using the Excel CORREL function.

Rows 1,018 to 1,040 contain the 23 by 23 table of rank correlation coefficients for the external-ingestion-radon BDCF components for all 23 primary radionuclides.

The rows beneath contain supplementary calculations of the Student's *t* values for the range of correlation coefficient values and the summary of the BDCF component correlation coefficients.

Volcanic BDCF CC_C Pathway Analysis.xls–This Excel file contains calculations of pathway contributions to BDCFs for the modern climate. The workbook consists of 28 worksheets, containing pathway BDCFs for individual realizations and individual radionuclides. The first worksheet (*Pathway Summary*) contains the summery of the mean pathway BDCFs. The second to twenty-eighth worksheets contain the pathway BDCFs from individual realizations for 23 primary radionuclides, 2 long-lived decay products, ^{228}Ra and ^{228}Th, and the 2 decay products combined with their respective primary radionuclide, ^{232}Th + ^{228}Ra + ^{228}Th and ^{232}U + ^{228}Th. The mean values are also included. The pathway BDCFs for 1,000 realizations are in rows 10 to 1,009 of each spreadsheet for an individual radionuclide. The values were copied from GoldSim pathway results summary, following each run of the model. Row 6 contains the mean values calculated using the Excel AVERAGE function.

The *Pathway Summary* worksheet contains the mean values of pathway BDCFs copied from the individual radionuclide worksheets. These values are shown in rows 9 to 35 for individual radionuclides and in Columns C to O for individual exposure pathways. Column P contains the sum of the external, ingestion and radon pathways. Column Q contain the total BDCF for a radionuclide, which is a sum of individual pathway BDCFs.

Rows 43 to 69 contain the calculated percent values of the individual pathway contributions to the total BDCF. These values were calculated by dividing the mean pathway BDCFs by the total BDCF for a given radionuclide. Rows 72 to 94 contain the percent pathway contributions for pasting into the report.

Volcanic BDCF FC_C Pathway Analysis.xls–This Excel file contains calculations of pathway contributions to BDCFs for the future climate represented by the upper bound of the glacial transition climate. The workbook consists of 28 worksheets, containing pathway BDCFs for individual realizations and individual radionuclides. The first worksheet (*Pathway Summary*) contains a summery of the mean pathway BDCFs and a comparison with the modern climate pathway BDCFs. The layout of the workbook for the future climate is similar to the workbook for the modern climate. The values were copied from the GoldSim pathway results summary, following each run of the model. Row 6 contains the mean values calculated using the Excel AVERAGE function.

The *Pathway Summary* worksheet contains the mean values of pathway BDCFs copied from the individual radionuclide worksheets. These values are shown in rows 9 to 35 for individual radionuclides and in Columns C to O for individual exposure pathways. Column P contains the sum of the external, ingestion and radon pathways. Column Q contain the total BDCF for a radionuclide, which is a sum of individual pathway BDCFs.

Rows 76 to 102 contain the summary of the current climate pathway BDCF results copied from the *Volcanic BDCF CC_B Pathway Analysis.xls* file (*Pathway Summary* worksheet, rows 9 to 35).

Rows 109 to 131 contain the ratios of pathway BDCFs for the future and the modern climates.

Dose Factor Calculations REV C.xls–This Excel file contains calculations of the DFs factors computed using Equation 6.3-3.

Calculation of the effective breathing rate (term in the bracket in Equation 6.3-3) are in rows 10 to 19. Dose factors for individual radionuclides are calculated in rows 27 to 53. Column C contains the values of effective dose conversion factor for inhalation of a given radionuclide and its short-lived decay products, if applicable. Column D contains the value of the effective daily breathing rate calculated above. Columns E and F contain calculations of daily inhalation dose in Sv/d if the activity concentration in air is 1 Bq/ m^3 and in rem/d for activity concentration of 1 pCi/m^3, respectively. Daily doses are calculated as the product of daily activity intakes of a given radionuclide and the corresponding inhalation effective dose conversion factor.

ATTACHMENT II

LISTING OF FILES GENERATED IN THE ANALYSIS

This attachment contains the listing of files generated in this analysis. The files are included on the CD-ROM, which is a part of this attachment. Figure II-1 shows the list of GoldSim files for the modern climate, Figure II-2 shows the list of GoldSim files for the future climate, and Figure II-3 shows the Excel files containing the summary of the results as well and the calculation of dose factors, correlation coefficients, and pathway analysis.

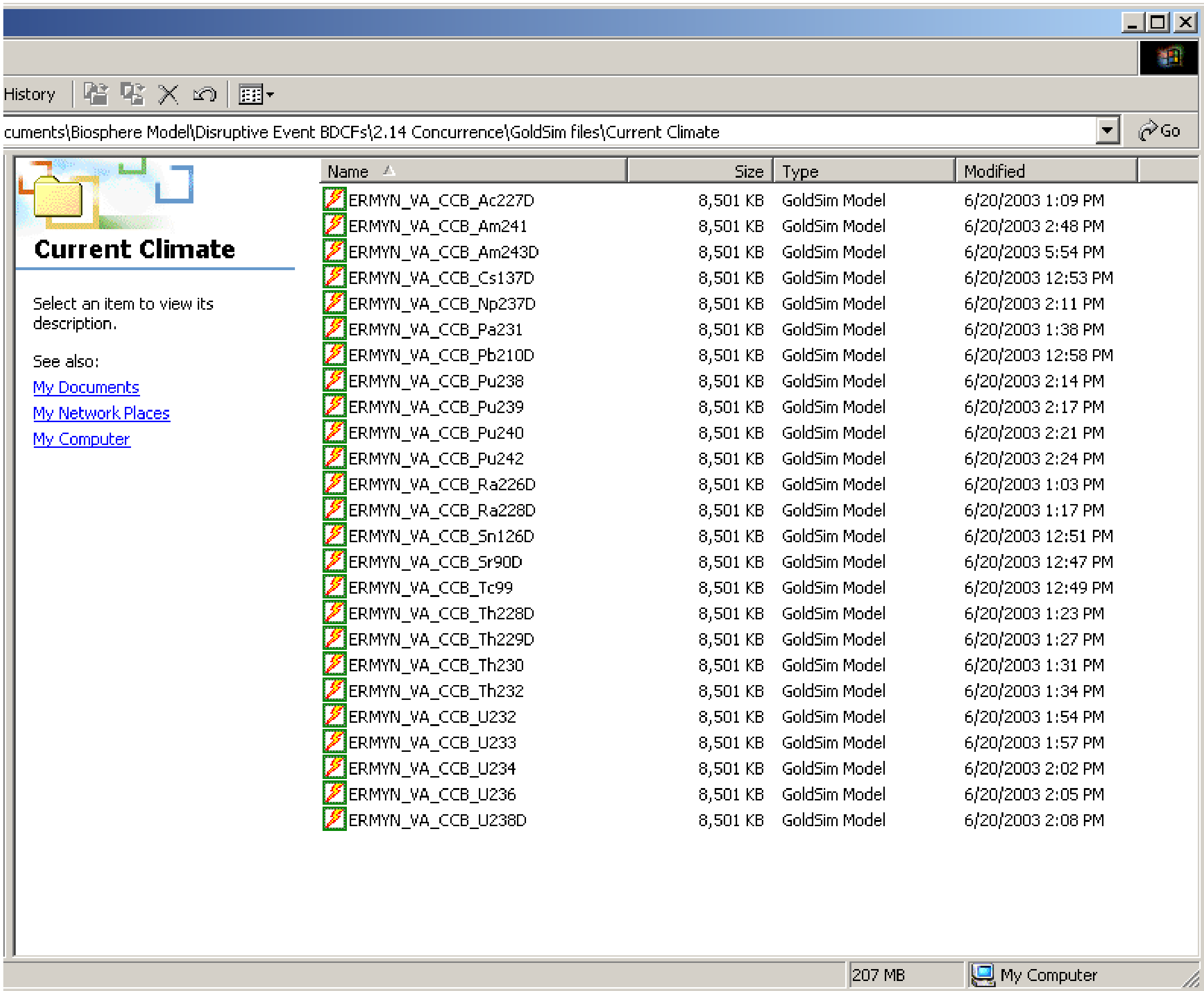


Figure II-1. GoldSim Files for the Modern Climate Generated in this Analysis

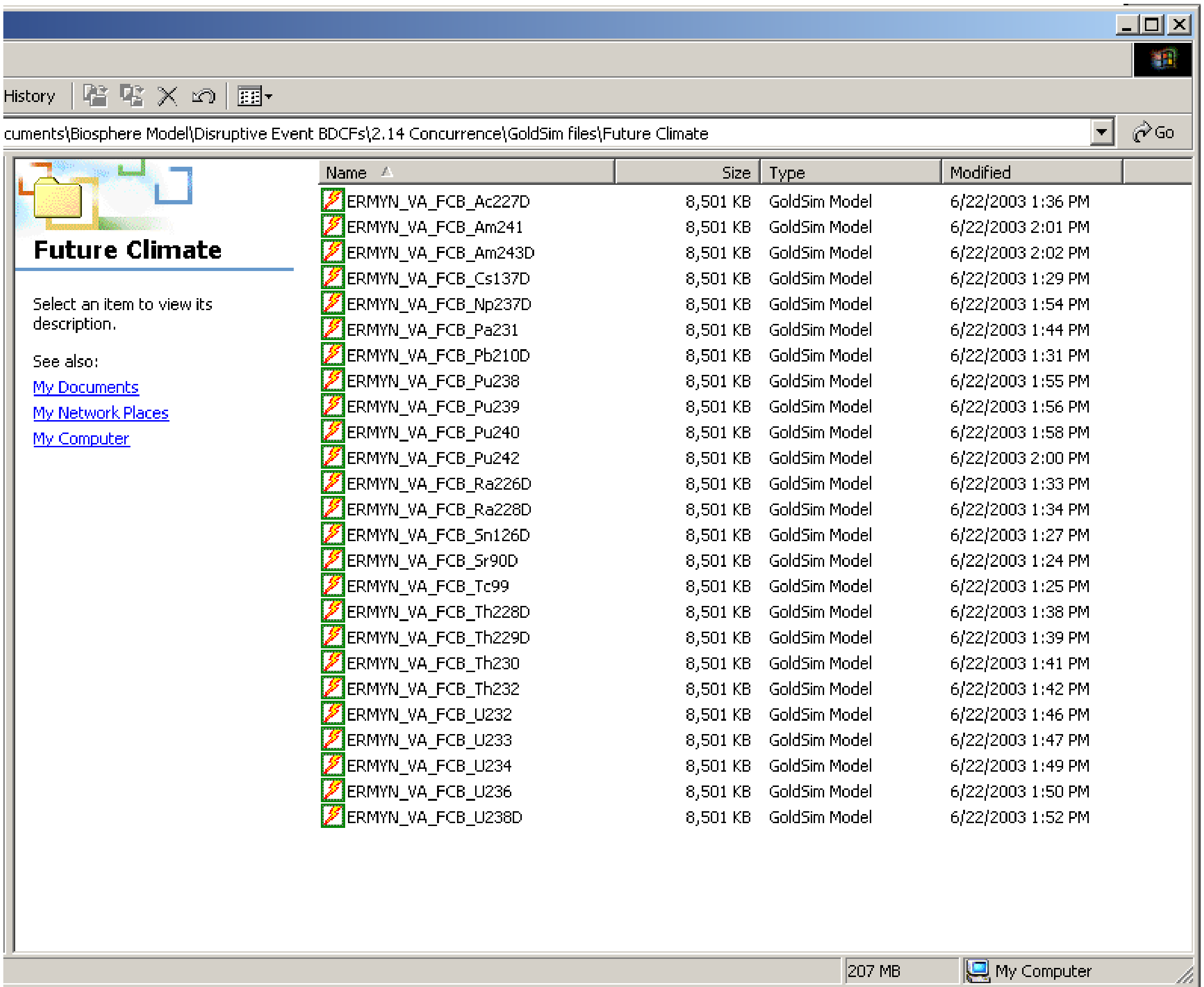


Figure II-2. GoldSim Files for the Future Climate Generated in this Analysis

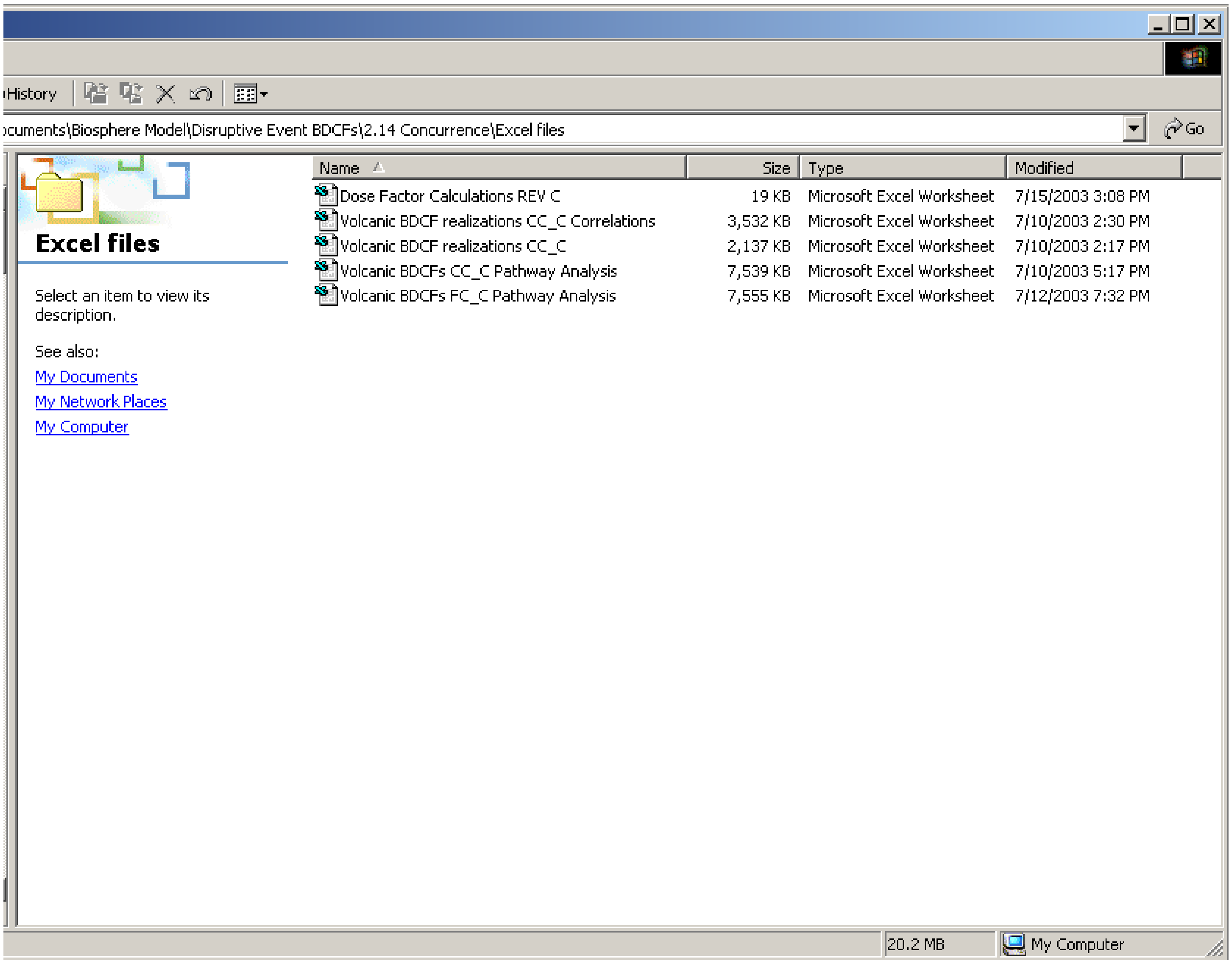
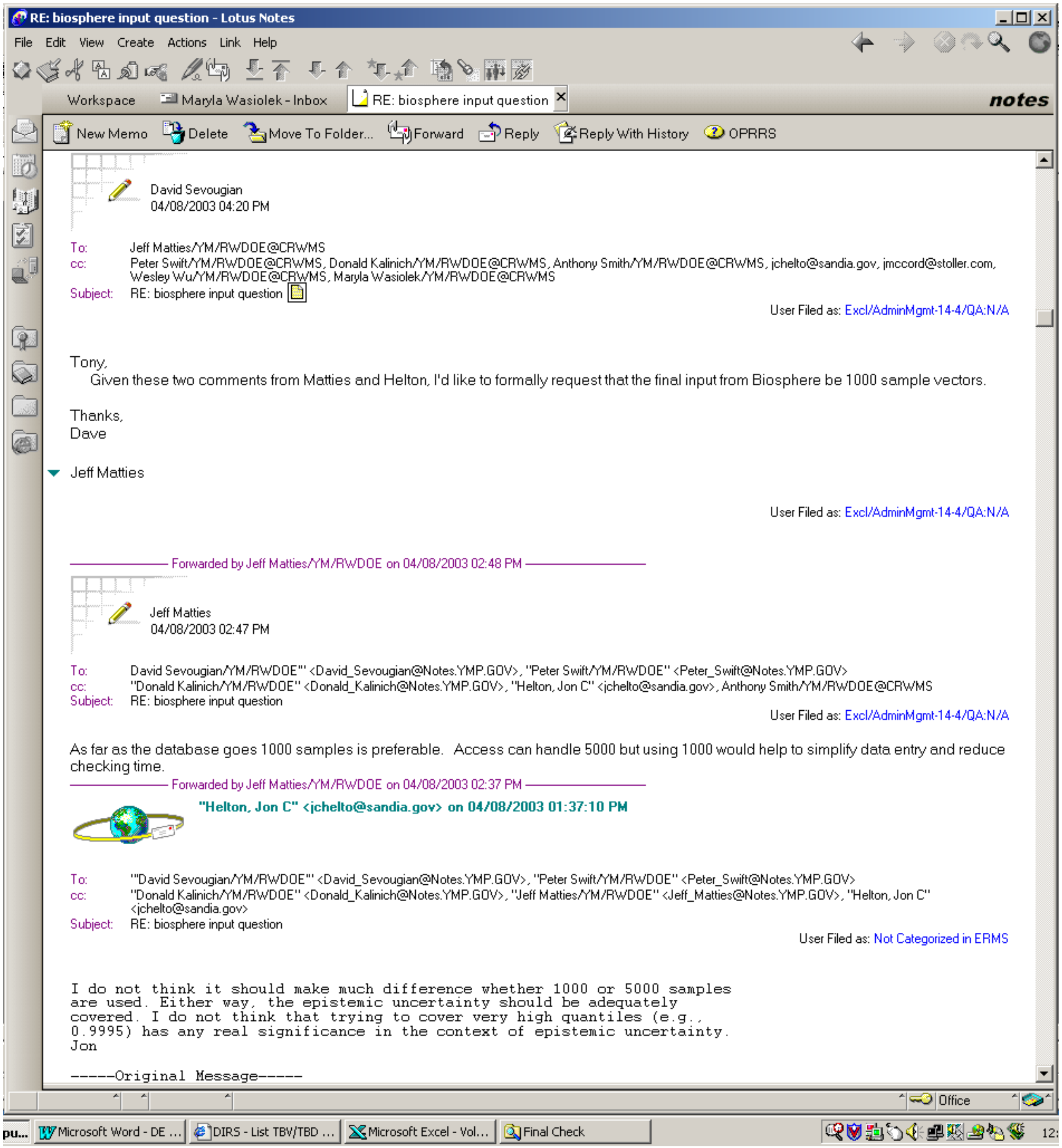


Figure II-3. Excel Files Containing BDCF and Dose Factor Results, Correlation, and Pathway Analyses

ATTACHMENT III

REQUEST FOR 1,000 MODEL REALIZATIONS

This attachment contains a copy of the request from the TSPA staff specifying the number of biosphere model realization and providing justification for this decision.



RE: biosphere input question - Lotus Notes

David Sevougian
04/08/2003 04:20 PM

To: Jeff Matties/YM/RWDOE@CRWMS
cc: Peter Swift/YM/RWDOE@CRWMS, Donald Kalinich/YM/RWDOE@CRWMS, Anthony Smith/YM/RWDOE@CRWMS, jchelto@sandia.gov, jmccord@stoller.com, Wesley Wu/YM/RWDOE@CRWMS, Maryla Wasiolek/YM/RWDOE@CRWMS
Subject: RE: biosphere input question

User Filed as: Excl/AdminMgmt-14-4/QA:N/A

Tony,
Given these two comments from Matties and Helton, I'd like to formally request that the final input from Biosphere be 1000 sample vectors.

Thanks,
Dave

Jeff Matties

User Filed as: Excl/AdminMgmt-14-4/QA:N/A

——— Forwarded by Jeff Matties/YM/RWDOE on 04/08/2003 02:48 PM ———

Jeff Matties
04/08/2003 02:47 PM

To: David Sevougian/YM/RWDOE" <David_Sevougian@Notes.YMP.GOV>, "Peter Swift/YM/RWDOE" <Peter_Swift@Notes.YMP.GOV>
cc: "Donald Kalinich/YM/RWDOE" <Donald_Kalinich@Notes.YMP.GOV>, "Helton, Jon C" <jchelto@sandia.gov>, Anthony Smith/YM/RWDOE@CRWMS
Subject: RE: biosphere input question

User Filed as: Excl/AdminMgmt-14-4/QA:N/A

As far as the database goes 1000 samples is preferable. Access can handle 5000 but using 1000 would help to simplify data entry and reduce checking time.

——— Forwarded by Jeff Matties/YM/RWDOE on 04/08/2003 02:37 PM ———

"Helton, Jon C" <jchelto@sandia.gov> on 04/08/2003 01:37:10 PM

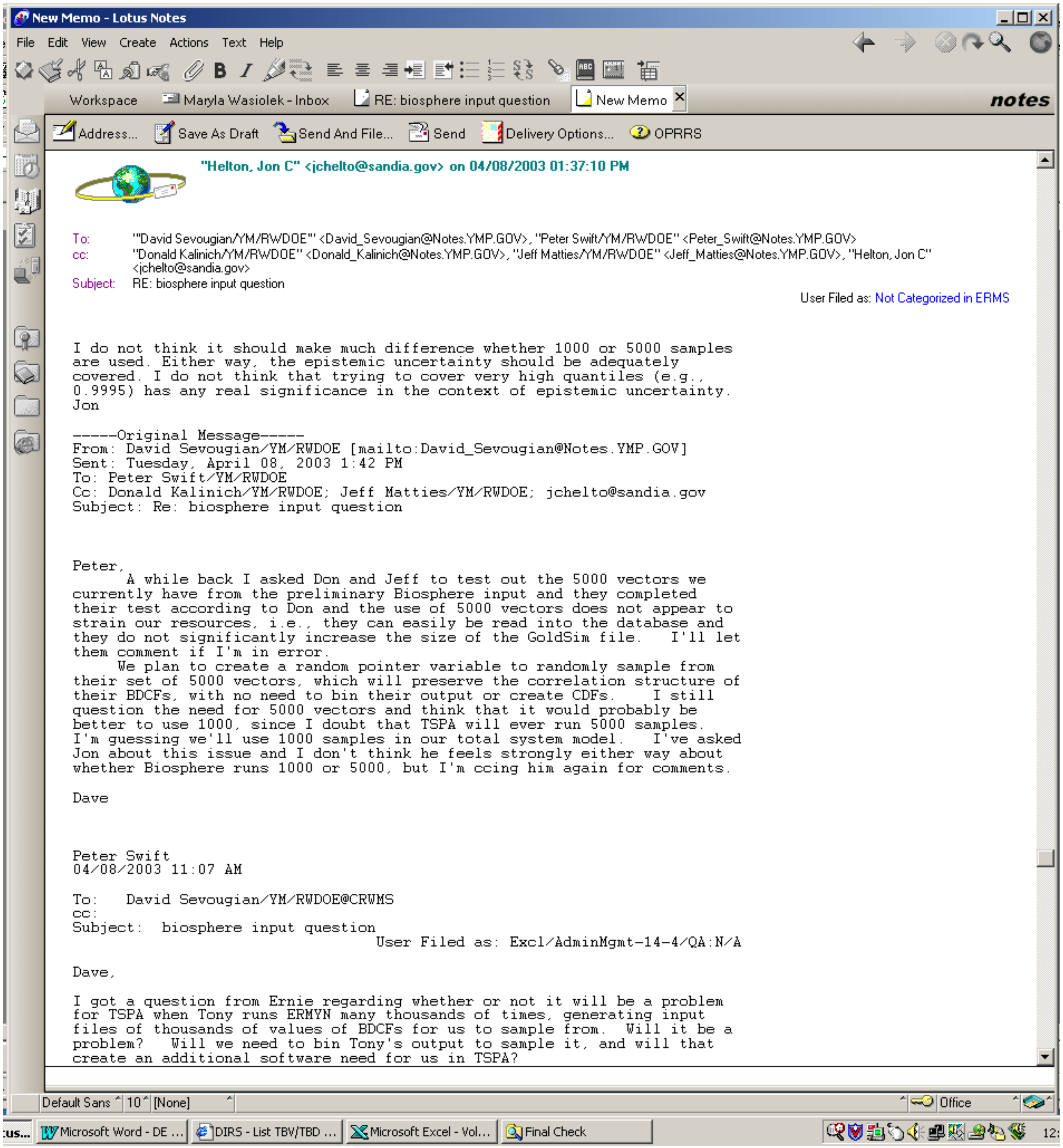
To: "David Sevougian/YM/RWDOE" <David_Sevougian@Notes.YMP.GOV>, "Peter Swift/YM/RWDOE" <Peter_Swift@Notes.YMP.GOV>
cc: "Donald Kalinich/YM/RWDOE" <Donald_Kalinich@Notes.YMP.GOV>, "Jeff Matties/YM/RWDOE" <Jeff_Matties@Notes.YMP.GOV>, "Helton, Jon C" <jchelto@sandia.gov>
Subject: RE: biosphere input question

User Filed as: Not Categorized in ERMS

I do not think it should make much difference whether 1000 or 5000 samples are used. Either way, the epistemic uncertainty should be adequately covered. I do not think that trying to cover very high quantiles (e.g., 0.9995) has any real significance in the context of epistemic uncertainty.
Jon

-----Original Message-----

Figure III-1. Image of the Message Containing the Request for 1,000 Realizations of the Biosphere Model (part 1)


New Memo - Lotus Notes

"Helton, Jon C" <jchelto@sandia.gov> on 04/08/2003 01:37:10 PM

To: "David Sevougian/YM/RWDOE" <David_Sevougian@Notes.YMP.GOV>, "Peter Swift/YM/RWDOE" <Peter_Swift@Notes.YMP.GOV>
cc: "Donald Kalinich/YM/RWDOE" <Donald_Kalinich@Notes.YMP.GOV>, "Jeff Matties/YM/RWDOE" <Jeff_Matties@Notes.YMP.GOV>, "Helton, Jon C" <jchelto@sandia.gov>
Subject: RE: biosphere input question

User Filed as: Not Categorized in ERMS

I do not think it should make much difference whether 1000 or 5000 samples are used. Either way, the epistemic uncertainty should be adequately covered. I do not think that trying to cover very high quantiles (e.g., 0.9995) has any real significance in the context of epistemic uncertainty.
Jon

-----Original Message-----
From: David Sevougian/YM/RWDOE [mailto:David_Sevougian@Notes.YMP.GOV]
Sent: Tuesday, April 08, 2003 1:42 PM
To: Peter Swift/YM/RWDOE
Cc: Donald Kalinich/YM/RWDOE; Jeff Matties/YM/RWDOE; jchelto@sandia.gov
Subject: Re: biosphere input question

Peter,
A while back I asked Don and Jeff to test out the 5000 vectors we currently have from the preliminary Biosphere input and they completed their test according to Don and the use of 5000 vectors does not appear to strain our resources, i.e., they can easily be read into the database and they do not significantly increase the size of the GoldSim file. I'll let them comment if I'm in error.
We plan to create a random pointer variable to randomly sample from their set of 5000 vectors, which will preserve the correlation structure of their BDCFs, with no need to bin their output or create CDFs. I still question the need for 5000 vectors and think that it would probably be better to use 1000, since I doubt that TSPA will ever run 5000 samples. I'm guessing we'll use 1000 samples in our total system model. I've asked Jon about this issue and I don't think he feels strongly either way about whether Biosphere runs 1000 or 5000, but I'm ccing him again for comments.

Dave

Peter Swift
04/08/2003 11:07 AM

To: David Sevougian/YM/RWDOE@CRWMS
cc:
Subject: biosphere input question
User Filed as: Excl/AdminMgmt-14-4/QA:N/A

Dave,

I got a question from Ernie regarding whether or not it will be a problem for TSPA when Tony runs ERMYN many thousands of times, generating input files of thousands of values of BDCFs for us to sample from. Will it be a problem? Will we need to bin Tony's output to sample it, and will that create an additional software need for us in TSPA?

Figure III-2. Image of the Message Containing the Request for 1,000 Realizations of the Biosphere Model (part 2)