OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SCIENTIFIC ANALYSIS COVER SHEET

1. QA: QA

2. Scientific Analyses Title
Nominal Performance Biosphere Dose Conversion Factor Analysis

3. DI (including Revision Number)
ANL-MGR-MD-000009 REV 02

4. Total Attachments	5. Attachment Numbers - Number of pages in each
3	Attachment I - 5 pages; Attachment II - 5 pages + CD-ROM; Attachment III - 3 pages

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11. Remarks

This report addresses technical errors identified in TER-02-0055.

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Revision History

12. Revision/ICN No.	13. Description of Revision/Change
REV 00	Initial issue
REV 01	Revision to incorporate the analysis of the climate change effects on the Biosphere Dose Conversion Factors for nominal performance; add pathway and limited uncertainty analyses; append the list of radionuclides to include
REV 02	Complete revision following development of the new biosphere model.

Addendum 1

those important for up to 1 million years after the potential repository closure; remove bounding case; change the document title; and add biosphere model validation (moved from ANL-MGR-MD-000011 REV 00). Entire AMR has been revised because changes were extensive.

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ACRONYMS AND ABBREVIATIONS

BDCF	biosphere dose conversion factor
ERMYN	Environmental Radiation Model for Yucca Mountain, Nevada
FEP	feature, event, or process
LA	license application
RMEI	reasonably maximally exposed individual
TSPA	total system performance assessment
TWP	technical work plan

1. PURPOSE

This analysis report is one of the technical reports containing documentation of the Environmental Radiation Model for Yucca Mountain, Nevada (ERMYN), a biosphere model supporting the Total System Performance Assessment (TSPA) for the license application (LA) for the Yucca Mountain repository. This analysis report describes the development of biosphere dose conversion factors (BDCFs) for the groundwater exposure scenario, and the development of conversion factors for assessing compliance with the groundwater protection standard.

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 two reports that develop biosphere BDCFs, which are input parameters for the TSPA model. The *Biosphere Model Report* (BSC 2003 [DIRS 164186]) describes in detail the ERMYN conceptual model and mathematical model. The input parameter reports (BSC 2003 [DIRS 160964]; BSC 2003 [DIRS 160965]; BSC 2003 [DIRS 160976]; BSC 2003 [DIRS 161239]; BSC 2003 [DIRS 161241]) contain detailed description of the model input parameters. This report describes biosphere model calculations and their output, the BDCFs, for the groundwater exposure scenario.

The objectives of this analysis are to develop BDCFs and conversion factors for the TSPA. The BDCFs will be used in performance assessment for calculating annual doses for a given concentration of radionuclides in groundwater. The conversion factors will be used for calculating gross alpha particle activity in groundwater and the annual dose from beta- and photon-emitting radionuclides.

For the groundwater exposure scenario, radionuclides enter the biosphere from a well that extracts contaminated groundwater from an aquifer. Human exposure arises from using the contaminated water for domestic and agricultural purposes. BDCFs for the groundwater scenario apply to the TSPA modeling cases that consider groundwater release of radionuclides from the repository at Yucca Mountain. The nominal scenario class and some modeling cases from the disruptive scenario classes (i.e., igneous intrusion or human intrusion) may result in the release of radionuclides to groundwater. Dose assessments for such releases require BDCFs for the groundwater scenario.

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 direct inputs 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

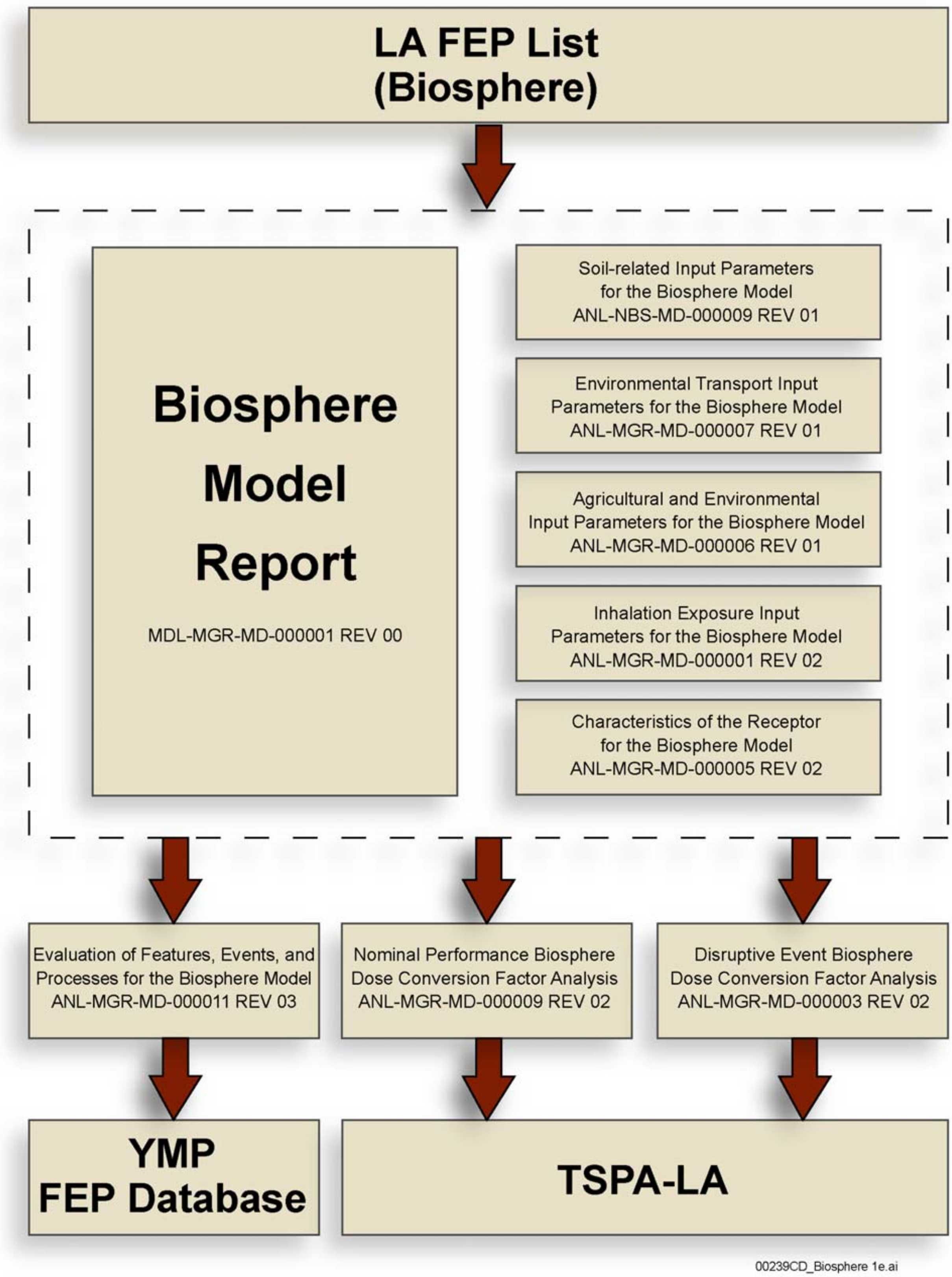


Figure 1-1. Biosphere Model Documentation and Total System Performance Assessment Feeds

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 groundwater exposure scenario, this analysis develops conversion factor values for calculating gross alpha particle activity in groundwater and the annual dose from beta- and photon-emitting radionuclides. The FEPs considered in the development of conversion factors are listed in Table 1-1. The disposition of these FEPs in TSPA is through the conversion factors that are inputs for the TSPA.

Table 1-1. Features, Events and Processes Considered in the Development of Conversion Factors for Groundwater Protection

FEP Number [a]	FEP Name [a]	Description of FEP Disposition
1.4.07.02.0A	Wells	A well is initial source of contaminated groundwater in the biosphere.
2.4.01.00.0A	Human characteristics (physiology, metabolism)	Physiology and metabolism of the human receptor were considered in developing the values of dose conversion factors for ingestion, which are used as input to calculate the values of conversion factors (Equation 6.3-3).
2.4.04.01.0A	Human lifestyle	Lifestyles and characteristics of people living in Amargosa Valley are reflected in the value of the daily consumption rate of water (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 conversion factors, through the use of effective dose conversion factors for inhalation (Table 6.3-4) and also through including decay products in the total number of alpha particles associated with a primary radionuclide (Table 6.3-3).
3.3.01.00.0A	Contaminated drinking water, foodstuffs and drugs	Locally obtained contaminated drinking water causes ingestion dose (Equations 6.3-2 and 6.3-4)
3.3.04.01.0A	Ingestion	Conversion factors for beta-gamma emitters are used in evaluating exposure of the receptor arising from ingestion of contaminated water (Equations 6.3-2 to 6.3-4).
3.3.05.01.0A	Radiation doses	Radiation doses arising from ingestion of contaminated water will be evaluated in TSPA using conversion factors developed in this analysis.

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

This analysis is a revision of the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (CRWMS M&O 2001 [DIRS 152539]). This revision reflects changes in the definition of the human receptor and the development of an improved biosphere model. The analysis was performed in accordance with the *Technical Work Plan: for Biosphere Modeling and Expert Support* (TWP) (BSC 2003 [DIRS 163602]).

This report includes the disposition of technical errors (Technical Error Report No. TER-02-0055) related to modeling resuspension, plant uptake, and surface soil. The current approach to modeling these items is described in the *Biosphere Model Report* (BSC 2003 [164186]). The resuspension model is a part of the air submodel (BSC 2003 [164186], Section

6.4.2.1); plant uptake is addressed in the plant submodel (BSC 2003 [164186], Section 6.4.3); surface soil is modeled in the surface soil submodel (BSC 2003 [164186], Section 6.4.1).

2. QUALITY ASSURANCE

Development of this report involved analysis of data to support performance assessment, as identified in the TWP (BSC 2003 [DIRS 163602]), and thus it was a quality affecting activity. Approved quality assurance procedures identified in the TWP (BSC 2003 [DIRS 163602], Section 4) were used to conduct and document the activities described in this report. Electronic data used in this analysis were controlled in accordance with methods specified in the TWP (BSC 2003 [DIRS 163602], Section 8).

This analysis did not require classification of 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 a verified and validated model, the ERMYN model, which is 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 is implemented 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 appropriate for the application of constructing ERMYN using GoldSim software, and was used within the range of validation in accordance with procedure AP-SI.1Q [DIRS 164105], *Software Management*. GoldSim was installed by software configuration management 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 EXCEL functions were used to calculate values presented in tables in Section 6. The use of these 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 biosphere model input and are appropriate for the 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]; BSC 2003 [DIRS 161241]).

The parameters were used as input for the ERMYN model for the groundwater exposure scenario (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								
Activity concentration of a radionuclide in well water		Fixed	Bq/m^2	1	–	–	–	Source of contamination
Annual average irrigation rate	Modern climate	Normal	m/yr	0.94	0.08	0.73	1.15	MO0306SPAAEIBM.001 [DIRS 163812]
	Monsoon climate upper bound	Fixed		0.52	–	–	–	
	Glacial transition climate lower bound	Fixed		0.88	–	–	–	
	Glacial transition climate upper bound	Normal		0.50	0.04	0.40	0.60	
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]
Surface soil erosion rate		Triangular	$kg/(m^2\ yr)$	0.19	–	0.19	1.1	MO0305SPASRPBM.001 [DIRS 163815]
Soil solid/liquid partition coefficient	Carbon	Lognormal[b]	L/kg	1.8E+01	6.0E+00	–	–	MO0305SPASRPBM.001 [DIRS 163815]
	Chlorine			1.4E-01	6.0E+00	–	–	
	Selenium			1.5E+02	6.0E+00	–	–	
	Strontium			2.0E+01	5.5E+00	–	–	
	Technetium			1.4E-01	6.0E+00	–	–	
	Tin			4.5E+02	6.0E+00	–	–	
	Iodine			4.5E+00	7.4E+00	–	–	
	Cesium			4.4E+03	3.7E+00	–	–	
	Lead			1.6E+04	4.1E+00	–	–	
	Radium			3.6E+04	2.2E+01	–	–	
	Actinium			1.5E+03	6.0E+00	–	–	
	Thorium			3.0E+03	8.2E+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
	Protactinium			1.8E+03	6.0E+00	–	–	
	Uranium			3.3E+01	2.5E+01	–	–	
	Neptunium			2.5E+01	3.3E+00	–	–	
	Plutonium			1.2E+03	3.3E+00	–	–	
	Americium			2.0E+03	1.3E+01	–	–	
Overwatering rate	Modern climate	Cumulative	m/y	–	–	0.009 0.030 0.045 0.076 0.128 0.233 0.275	0% 19% 38% 57% 76% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Upper bound of glacial transition climate	Cumulative	m/y	–	–	0.004 0.020 0.047 0.072 0.104 0.150 0.177	0% 19% 38% 57% 76% 95% 100%	
Volumetric water content		Uniform	–	–	–	0.18	0.28	MO0305SPASRPBM.001 [DIRS 163815]
AIR SUBMODEL								
Mass loading for crops at nominal conditions		Triangular	mg/m^3	0.12	–	0.025	0.200	MO0305SPAINEXI.001 [DIRS 163808]
Mass loading for receptor environments at nominal conditions	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	

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 at nominal conditions	Active outdoors	Cumulative	–	–	–	2.2 4.0 6.5	0% 50% 100%	MO0305SPASRPBM.001 [DIRS 163815]
	Inactive outdoors Active indoors Asleep indoors	Cumulative	–	–	–	0.21 0.7 1.04	0% 50% 100%	
Evaporative cooler water transfer fraction		Uniform	–	–	–	0	1	MO0306SPAETPBM.001 [DIRS 163814]
Evaporative cooler water use (evaporation) rate		Lognormal[b]	L/hr	17	1.7	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Evaporative cooler air flow rate		Cumulative	m^3/h	–	–	1,700 8,300 10,200	0% 50% 100%	MO0306SPAETPBM.001 [DIRS 163814]
Correlation coefficient for evaporative cooler water use (evaporation) and air flow rates		Fixed	–	0.8	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Radon release factor		Fixed	$(Bq/kg)/(Bq/m^3)$	0.25	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
House ventilation rate	Average	Lognormal[c]	1/hr	1.0	1.1	–	–	MO0306SPAETPBM.001 [DIRS 163814]
	Evap. cooler on	Uniform		–	–	1	30	
Fraction of radon from soil entering the house		Uniform	–	–	–	0.1	0.25	MO0306SPAETPBM.001 [DIRS 163814]
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	

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
	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	
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	

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
	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	
	Uranium			6.3E-03	2.9	3.9E-04	1.0E-01	
	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	

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
	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	
	Actinium			1.7E-02	5.4	2.2E-04	1.3E+00	
	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 and solid-liquid partition coefficients		Fixed	–	-0.8	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Dry-to-wet weight ratio	Leafy vegetables	Cumulative	kg_{dry}/kg_{wet}	–	–	0.041 0.054 0.060 0.078 0.081 0.084 0.093	0% 17% 33% 50% 67% 83% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Other vegetables	Cumulative	kg_{dry}/kg_{wet}	–	–	0.035 0.063 0.078 0.08 0.103 0.122 0.240	0% 17% 33% 50% 67% 83% 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
		Fruit	Cumulative	kg_{dry}/kg_{wet}	–	–	0.062 0.084 0.102 0.155 0.194	0% 25% 50% 75% 100%	
		Grain	Cumulative	kg_{dry}/kg_{wet}	–	–	0.891 0.896 0.906 0.918	0% 33% 67% 100%	
		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	–	–	–	
Fraction of overhead irrigation		Leafy vegetables	Normal	–	0.75	0.10	0.49	1.0	MO0306SPAAEIBM.001 [DIRS 163812]
		Other vegetables			0.75	0.10	0.49	1.0	
		Fruit			0.50	0.10	0.24	1.0	
		Grain			0.90	0.05	0.77	1.0	
		Forage			0.90	0.05	0.77	1.0	
Weathering half-life			Cumulative	d	14	–	5 14 30	0 % 50 % 100 %	MO0306SPAETPBM.001 [DIRS 163814]
Crop growing time	Modern climate	Leafy veg.	Fixed	d	75	–	–	–	MO0306SPAAEIBM.001 [DIRS 163812]
		Other veg.			80	–	–	–	
		Fruit			160	–	–	–	
		Grain			200	–	–	–	
		Forage			75	–	–	–	

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
	Upper bound of glacial transition climate	Leafy veg.	Fixed	d	75	–	–	–	
		Other veg.			100	–	–	–	
		Fruit			105	–	–	–	
		Grain			185	–	–	–	
		Forage			90	–	–	–	
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%	

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
	Grain	Cumulative	kg/m^2	–	–	0.27 0.28 0.44 0.54 1.10 1.22	0% 5% 35% 65% 95% 100%	
	Forage	Cumulative	kg/m^2	–	–	0.69 1.02 1.87 5.78 6.28	0% 5% 73% 95% 100%	
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%	

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
	Fruit	Cumulative	kg/m^2	–	–	0.10 0.56 0.60 0.65 0.68 1.30	0% 5% 35% 65% 95% 100%	
	Grain	Cumulative	kg/m^2	–	–	0.50 0.61 0.74 1.20 1.97 2.20	0% 5% 35% 65% 95% 100%	
	Forage	Cumulative	kg/m^2	–	–	0.10 0.23 0.34 1.38 1.50	0% 5% 73% 95% 100%	
Daily average irrigation rate modern climate	Leafy vegetables	Cumulative	mm/d	–	–	4.00 5.11 5.19 5.21 5.38 5.46 5.98 7.06	0% 5% 20% 35% 50% 80% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]

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
	Other vegetables	Cumulative	mm/d	–	–	5.00 6.05 6.65 6.85 7.62 8.19 8.32 9.18 10.83	0% 5% 20% 35% 50% 65% 80% 95% 100%	
	Fruit	Cumulative	mm/d	–	–	4.00 5.38 7.00 7.56 8.35 8.60 10.15	0% 5% 28% 51% 72% 95% 100%	
	Grain	Cumulative	mm/d	–	–	3.00 3.44 3.58 3.86 7.67 9.05	0% 5% 35% 65% 95% 100%	
	Forage	Cumulative	mm/d	–	–	5.00 5.84 6.18 9.00 10.62	0% 5% 73% 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
Daily average irrigation rate upper bound of glacial transition climate	Leafy vegetables	Cumulative	mm/d	–	–	3.00 3.34 3.51 3.86 3.92 4.02 4.18 4.93	0% 5% 20% 50% 65% 80% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Other vegetables	Cumulative	mm/d	–	–	2.00 2.73 3.08 3.48 4.08 4.16 4.43 4.95 5.84	0% 5% 20% 35% 50% 65% 80% 95% 100%	
	Fruit	Cumulative	mm/d	–	–	2.00 2.51 3.48 4.33 4.38 4.79 5.65	0% 5% 28% 51% 72% 95% 100%	
	Grain	Cumulative	mm/d	–	–	1.00 1.99 3.42 3.93 4.11 4.85	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
	Forage	Cumulative	mm/d	–	–	3.00 3.64 4.01 5.03 5.94	0% 5% 73% 95% 100%	
Irrigation amount per application, modern climate	Leafy vegetables	Cumulative	mm	–	–	6.0 7.4 8.4 10.0 10.9 20.8 22.0 23.6 27.8	0% 5% 20% 35% 50% 65% 80% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Other vegetables	Cumulative	mm	–	–	8.0 9.0 18.7 19.7 21.2 32.9 34.9 41.2 48.6	0% 5% 20% 35% 50% 65% 80% 95% 100%	
	Fruit	Cumulative	mm	–	–	5.0 6.0 30.2 35.5 48.4 49.2 58.1	0% 5% 28% 51% 72% 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
	Grain	Cumulative	mm	–	–	43.0 48.7 50.1 50.3 77.9 91.9	0% 5% 35% 65% 95% 100%	
	Forage	Cumulative	mm	–	–	50.0 56.5 57.5 60.2 71.0	0% 5% 72% 95% 100%	
Irrigation amount per application, upper bound of glacial transition climate	Leafy vegetables	Cumulative	mm	–	–	7.0 7.8 8.0 9.0 10.1 19.3 22.0 26.1 30.8	0% 5% 20% 35% 50% 65% 80% 95% 100%	MO0306SPAAEIBM.001 [DIRS 163812]
	Other vegetables	Cumulative	mm	–	–	10.0 11.3 14.4 17.7 20.1 34.1 37.2 40.3 47.6	0% 5% 20% 35% 50% 65% 80% 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
	Fruit	Cumulative	mm	–	–	6.0 7.3 31.4 34.6 43.2 54.4 64.2	0% 5% 28% 51% 72% 95% 100%	
	Grain	Cumulative	mm	–	–	28.0 32.2 46.2 59.9 66.7 78.7	0% 5% 35% 65% 95% 100%	
	Forage	Cumulative	mm	–	–	43.0 48.3 52.5 61.9 73.0	0% 5% 73% 95% 100%	
Irrigation intensity		Uniform	cm/hr	–	–	1.0	7.5	MO0306SPAAEIBM.001 [DIRS 163812]
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]

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 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	
	Protactinium			6.6E-05	10.0	1.8E-07	2.5E-02	
	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	Lognormal[b]	d/L	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	

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
	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	
	Radium			1.7E-02	10.0	4.4E-05	6.3E+00	
	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	

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
	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	
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	
FISH SUBMODEL								
Bioaccumulation factor	Carbon	Lognormal[b]	L/kg	4.6E+03	3.2	2.3E+02	9.2E+04	MO0306SPAETPBM.001 [DIRS 163814]
	Chlorine			2.2E+02	5.6	2.6E+00	1.9E+04	
	Selenium			2.3E+02	2.0	3.9E+01	1.2E+03	
	Strontium			4.6E+01	2.0	7.8E+00	2.8E+02	
	Technetium			2.0E+01	2.0	3.3E+00	1.2E+02	
	Tin			2.5E+03	2.0	4.2E+02	1.5E+04	
	Iodine			4.5E+01	2.6	3.8E+00	5.3E+02	
	Cesium			3.5E+03	2.2	4.7E+02	2.5E+04	
	Lead			2.9E+02	2.5	2.7E+01	3.1E+03	
	Radium			6.7E+01	2.2	9.2E+00	5.0E+02	
	Actinium			2.9E+01	3.0	1.7E+00	5.0E+02	
	Thorium			1.1E+02	2.5	1.0E+01	1.2E+03	

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
	Protactinium			1.2E+01	2.0	2.0E+00	7.1E+01	
	Uranium			1.4E+01	3.0	8.4E-01	2.3E+02	
	Neptunium			3.0E+01	2.9	1.9E+00	4.7E+02	
	Plutonium			4.1E+01	4.7	7.9E-01	2.2E+03	
	Americium			5.2E+01	2.3	5.8E+00	4.6E+02	
Water concentration modifying factor, modern climate	Carbon	Fixed	–	1.0	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
	Other elements	Uniform	–	–	–	2.2	6.1	
Water concentration modifying factor, modern climate	Carbon	Fixed	–	1.0	–	–	–	
	Other elements	Uniform	–	–	–	1.5	3.3	
SPECIAL CARBON–14 MODEL								
C-14 emission rate		Fixed	1/yr	22	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Annual water demand		Fixed	m^3/yr	3,714,450	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Annual average wind speed	Inhalation	Uniform	m/s	–	–	2.1	2.8	MO0306SPAETPBM.001 [DIRS 163814]
	Crops			–	–	1.5	2.3	
C-14 mixing height	Inhalation	Fixed	m	2	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
	Crops			1	–	–	–	
Fraction of air-derived carbon in plants		Fixed	–	0.98	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Fraction of soil-derived carbon in plants		Fixed	–	0.02	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Fraction of stable carbon in plants	Leafy vegetables	Fixed	–	0.09	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
	Other vegetables			0.09	–	–	–	
	Fruit			0.09	–	–	–	
	Grain			0.40	–	–	–	
	Forage			0.09	–	–	–	
Fraction of stable carbon in soil		Fixed	–	0.03	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]

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
Concentration of stable carbon in air		Fixed	kg/m^3	1.8E-04	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Concentration of stable carbon in water		Fixed	kg/L	2.0E-05	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Fraction of stable carbon in animal products	Meat	Fixed	–	0.24	–	–	–	MO0306SPAETPBM.001 [DIRS 163814]
	Milk			0.2	–	–	–	
	Poultry			0.07	–	–	–	
	Eggs			0.15	–	–	–	
EXTERNAL EXPOSURE SUBMODEL								
Population proportion	Outdoor workers	Uniform	%	–	–	2.9	8.1	MO0306SPACRBSM.001 [DIRS 163813]
	Indoor workers			–	–	Cal'ed	Cal'ed	
	Commuters			–	–	33.9	44.5	
	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			4.0	0.3	3.3	4.8	
	Active indoors			6.6	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			1.3	0.2	0.9	1.9	
	Active indoors			12.1	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			1.4	0.2	1.0	2.0	
	Active indoors			6.0	Cal'ed	–	–	
	Asleep indoors			8.3	0.1	8.0	8.6	
	Away			8.0	0.5	6.8	9.4	

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	
	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	–	–	–	
	U-235D			0.4	–	–	–	
	Pa-231			0.4	–	–	–	

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
	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 soil (infinite depth)		Fixed	(Sv/y)/(Bq/m^2)	See Table 4.1-4	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
INHALATION SUBMODEL								
Breathing rate	Active outdoors	Fixed	m^3/h	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	Sv/Bq	See Table 4.1-3	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
Fraction of houses with evaporative coolers		Binomial	–	0.738	Batch size = 187	–	–	MO0306SPAETPBM.001 [DIRS 163814]
Evaporative cooler use factor	Modern climate	Uniform	–	–	–	0.32	0.46	MO0306SPAETPBM.001 [DIRS 163814]
	Upper bound of glacial transition climate	Uniform	–	–	–	0.03	0.14	
Equilibrium factor for ^{222}Rn decay products	Outdoors	Uniform	–	–	–	0.5	0.7	MO0306SPAETPBM.001 [DIRS 163814]
	Indoors	Uniform	–	–	–	0.3	0.5	
Dose conversion factor for inhalation of ^{222}Rn decay products		Fixed	Sv/Bq	1.33E-8	–	–	–	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 water		Fixed	L/d	2.0	–	–	–	MO0306SPACRBSM.001 [DIRS 163813]
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	–	–	
	Fish			0.23	0.10	–	–	
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]

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	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	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	87.74 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 [b]
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: Short-lived decay products of primary radionuclides are assumed to be in secular equilibrium with their parents.

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]

In addition, technical information from the rule at 10 CFR Part 63 [DIRS 156605] regarding the individual protection standard and the groundwater protection standard was used. Also, technical information from Eckerman and Ryman 1993 [DIRS 107684] and Lide and Frederikse 1997 [DIRS 103178] regarding fundamental properties of nuclear transformations (such as the type and energy of radiation and the half life) of radionuclides of interest was used in Section 6.3.

4.2 CRITERIA

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

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, Final Report* (NRC 2003 [DIRS 163274]), 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.

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 features, events, and processes, such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumptions in other total system performance assessment abstractions; and

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. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided; and

- Data are sufficient to assess the degree to which features, events, and processes related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63, the U.S. Department of Energy should demonstrate that features, events, and processes, which describe the biosphere, are consistent with present knowledge of conditions in the region, surrounding Yucca Mountain. As appropriate, the U.S. Department of Energy sensitivity and uncertainty analyses (including consideration of alternative conceptual models) are adequate for determining additional data needs, and evaluating whether additional data would provide new information that could invalidate prior modeling results and affect the sensitivity of the performance of the system to the parameter value or model.

Acceptance Criterion 3–Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

- 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;

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

- 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 or 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

Assumption–The BDCFs for the average lower bound of the glacial transition climate can be estimated from the BDCFs for the modern climate and the upper bound of the glacial transition climate, and they are proportional to the long-term, average annual irrigation rate for these climates.

Rationale–The climate at Yucca Mountain is expected to change in the future. Although forecasting long-term (e.g., for the next 10,000 years) climate change is speculative, the future climate at Yucca Mountain was predicted based on the study of past climates (USGS 2001 [DIRS 158378], p. 11). The predicted future climate states, durations, and future climate analog locations are summarized in Table 5-1.

Table 5-1. Predicted Future Climates and the Future Climate Analog Locations

Climate State	Duration	Representative Meteorological Stations
Modern interglacial climate	400 to 600 years	Yucca Mountain region
Monsoon climate	900 to 1,400 years	Average lower bound: Yucca Mountain region Average upper bound: Nogales, Arizona Hobbs, New Mexico
Glacial transition climate	8,000 to 8,700 years	Average lower bound: Beowawe, Nevada Delta, Utah Average upper bound: Spokane, Washington Rosalia, Washington St. John, Washington

Source: USGS (2001 [DIRS 158378], Table 2).

A proportionality function was developed based on BDCFs for the modern (interglacial) climate and BDCFs for the average upper bound of the glacial transition climate. These climates represent the two extreme conditions, with respect to temperature and precipitation, predicted to occur in the Yucca Mountain region during the 10,000-year postclosure period. To determine the dependence of BDCFs on climate, the range of each climate-dependent biosphere model input value was calculated. The range for each parameter spanned from the value for the modern climate to the value for the upper bound of the glacial transition climate. Model simulations were run using these parameter ranges as input. Rank correlation coefficients were calculated for the climate-dependent model-input parameters and the model output (i.e., the BDCFs), as described in Section 6.2.2. Correlation coefficients were highest for the long-term average annual irrigation rate (Table 6.2-3). It was assumed that the BDCFs for a given radionuclide were proportional to the value of the annual average irrigation rate. Using this proportionality, BDCFs for the monsoon climate and the glacial transition climate for each radionuclide were calculated by interpolation between the values (extremes) for the modern climate and the upper bound of the glacial transition climate (Section 6.2.2).

Confirmation Status–This assumption does not require further confirmation because it is based on a realistic approach.

Use in the Analysis–The assumption is used in Section 6.2.2.

Since BDCFs for the groundwater exposure scenario are developed by executing the biosphere model, any applicable ssumptions made in the *Biosphere Model Report* (BSC 2003 [164186], Section 5) and in the supporting analysis reports, documenting development of the model parameters (BSC 2003 [DIRS 160964]; BSC 2003 [DIRS 160965]; BSC 2003 [DIRS 160976]; BSC 2003 [DIRS 161239]; BSC 2003 [DIRS 161241]), are implicitly included in this analysis. These upstream assumptions are discussed in Section 5 of model and analysis reports.

6. SCIENTIFIC ANALYSIS DISCUSSION

The objectives of this analysis are to calculate:

1. BDCFs for the groundwater exposure scenario. These BDCFs will be used in the TSPA for calculating the annual dose from a given concentration of a radionuclide in groundwater and for determining compliance with the individual protection standard (10 CFR 63.311 [DIRS 156605])

2. Conversion factors that will be used to calculate gross alpha particle activity in groundwater and the annual dose from beta- and photon-emitting radionuclides resulting from drinking 2 liters of water per day. These conversion factors will be used in the TSPA-LA for demonstrating compliance with the groundwater protection standard (10 CFR 63.331 [DIRS 156605]).

A radionuclide-specific BDCF for the groundwater exposure scenario is numerically equal to the all-pathway annual dose that a specified receptor would receive if groundwater containing a unit activity concentration of a given radionuclide were extracted from a well and used by the receptor for irrigation or domestic purposes.

BDCFs for the groundwater exposure scenario apply to the TSPA cases that consider the release of radionuclides to groundwater. Scenario classes considered for TSPA include the nominal scenario class and the disruptive scenario classes (BSC 2002 [DIRS 160146], pp. 47 to 48). The nominal scenario class represents the most likely evolution of the repository system and includes favorable and some potentially adverse future conditions. The disruptive event scenario classes consider combinations of FEPs that have a low probability of occurrence but may produce additional potentially adverse future conditions. The disruptive event scenario classes include the igneous (which includes the igneous intrusion and volcanic eruption cases) and seismic classes, as well as a special case analyzing the stylized intrusion of a human into the repository.

Both types of TSPA scenario classes (i.e., the nominal and disruptive) may result in the release of radionuclides to the groundwater. Assessment of doses for such releases involves BDCFs for the groundwater exposure scenario. Biosphere exposure scenarios should not be confused with TSPA scenario classes. The biosphere exposure scenarios consider radiological consequences of radionuclide releases to the reference biosphere in a given medium, such as the groundwater, irrespective of the cause of contamination in the groundwater.

6.1 GENERAL CONSIDERATIONS

6.1.1 Radionuclides Included in the Analysis

Twenty-eight radionuclides were identified as important for the TSPA during the compliance period (up to 10,000 years) and the period up to 1,000,000 years for scenario classes involving radionuclide releases to groundwater. These radionuclides are referred to in this analysis as primary radionuclides, and include: carbon-14 (^{14}C), chlorine-36 (^{36}Cl), selenium-79 (^{79}Se), strontium-90 (^{90}Sr), technetium-99 (^{99}Tc), tin-126 (^{126}Sn), iodine-129 (^{129}I), cesium-135 (^{135}Cs), 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) (BSC 2003 [DIRS 164186], Sections 5.2 and 6.3.5). These decay products for radionuclides of interest are listed in Table 4.1-2. The biosphere model also accounts for the decay and ingrowth of the long-lived decay products in the soil and adds BDCF contributions of the long-lived decay products to that of the parent primary radionuclide (BSC 2003 [DIRS 164186], Section 6.4.1.2). 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. For biosphere modeling ^{228}Th and ^{228}Ra are treated like primary radionuclides. After BDCFs are calculated for these radionuclides, their BDCFs are added to the BDCF of the parent primary radionuclide. In the case of ^{232}Th, the 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 Groundwater Exposure Scenario

A detailed description of the groundwater exposure scenario, including the associated conceptual and mathematical models, are presented in the *Biosphere Model Report* (BSC 2003 [DIRS 164186], Sections 6.3.1 and 6.4). A brief summary of the main concepts and the modeling approach for the groundwater exposure scenario is presented in this section.

Radionuclide release to the reference biosphere, environmental transport, and exposure of the receptor are shown schematically in Figure 6.1-1. The source of radionuclides in the biosphere is contaminated groundwater extracted from a well, which is the interface between the geosphere and biosphere. The biosphere model does not consider water treatment between extraction and use, and therefore radionuclide concentrations in the well water are the same as those in the groundwater. This and other biosphere analyses frequently use the term groundwater, rather than well water, when referring to the water used in the reference biosphere.

Radionuclide transport in the reference biosphere is initiated when contaminated groundwater is used for agricultural and domestic purposes. Five modes of groundwater use are considered in the model: human consumption, domestic use (evaporative coolers), crop irrigation, animal consumption, and fish farming.

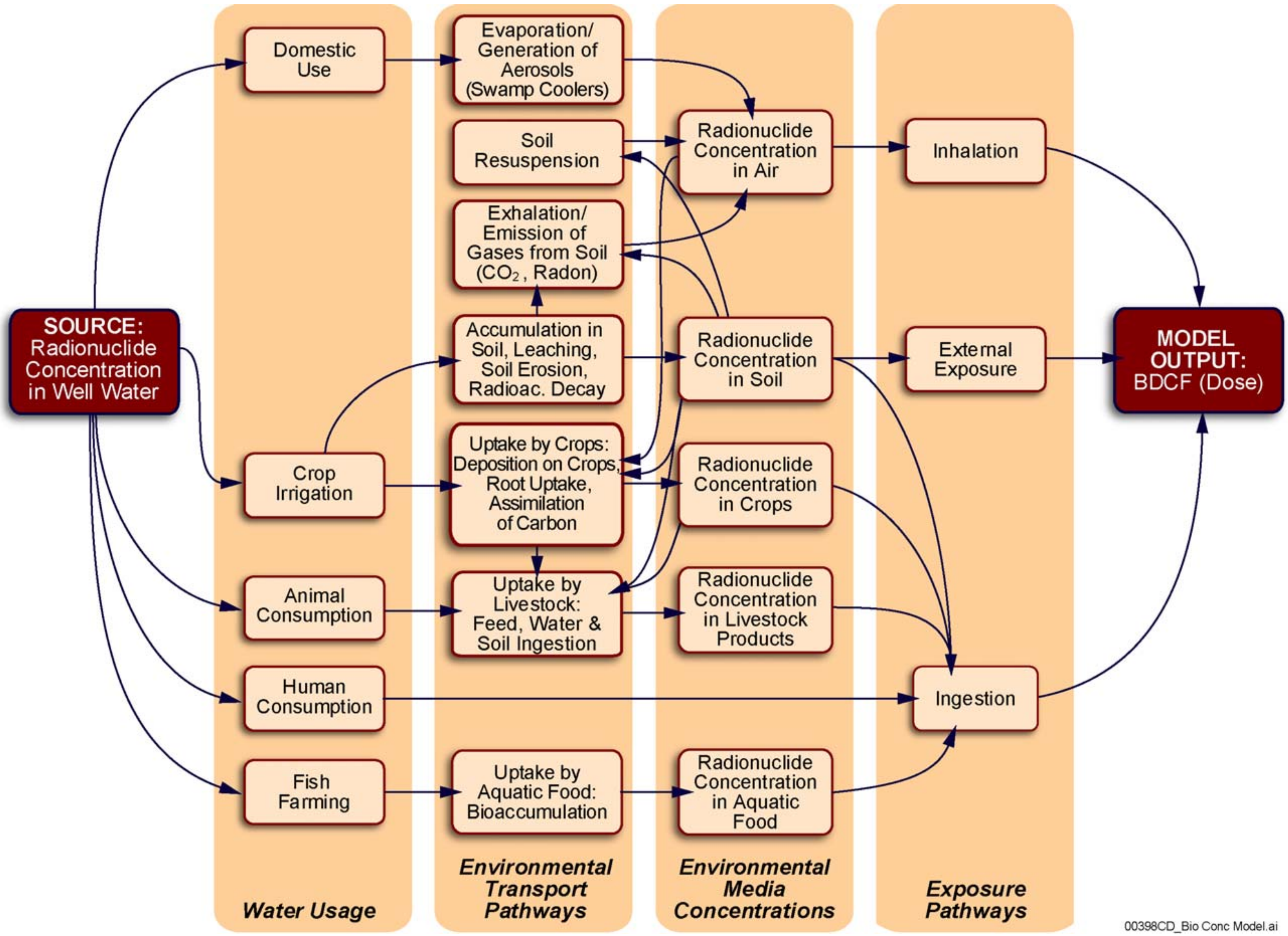


Figure 6.1-1. Conceptual Representation of the Biosphere Model for the Groundwater Exposure Scenario

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

- Radionuclide accumulation in soil as a result of long-term irrigation with contaminated water
- Resuspension of contaminated soil
- Radionuclide deposition on crop surfaces by dry processes (resuspension of contaminated soil and subsequent adhesion of soil particles onto vegetation surfaces)
- Radionuclide deposition on crop surfaces by wet processes resulting from using contaminated irrigation water
- Initial interception of deposited activity by vegetation surfaces
- Translocation of contaminants from the deposition site to the edible tissues of vegetation
- Post-deposition retention by vegetation (including weathering processes)
- Radionuclide uptake by plants through the roots
- Release of gaseous radionuclides (^{222}Rn, $^{14}CO_2$) from the soil
- Absorption of $^{14}CO_2$ by crops from the atmosphere
- Radionuclide uptake by animals through consumption of contaminated feed, water, and soil, followed by transfer to animal products
- Radionuclide transfer from water to air via evaporative coolers
- Radionuclide transfer from water to fish (aquatic food).

Exposure of humans 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 considered in the biosphere model, as well as environmental media and typical activities that may potentially lead to radiation exposure.

Table 6.1-1. Receptor Exposure Pathways for the Groundwater Exposure Scenario

Environmental Medium	Exposure Mode	Exposure Pathways	Examples of Typical Activities
Water	Ingestion	Water intake	Drinking as a component of diet or in other foods (cooking).
Soil	Ingestion	Inadvertent soil ingestion	Recreational activities, occupational activities, gardening, fresh fruit and vegetable consumption.
	External	External radiation exposure	Activities over or near contaminated soil.
Air	Inhalation	Breathing of airborne particulates Breathing of gases (^{222}Rn and progeny) Breathing of gases ($^{14}CO_2$) Breathing of aerosols from evaporative coolers	Any outdoor activities, including soil-disturbing activities related to work and recreation. Miscellaneous domestic activities, including sleeping.
Plants (crops for human and animal consumption)	Ingestion	Consumption of locally produced crops: Leafy vegetables Other vegetables Fruit Grain	Eating or drinking plant material as part of the diet.
Animals (animal products)	Ingestion	Consumption of locally produced animal products: Meat (beef and pork) Poultry Milk Eggs	Eating or drinking animal products as part of the diet.
Fish	Ingestion	Consumption of locally produced freshwater fish	Eating fish as part of the diet.

Source: BSC (2003 [DIRS 164186], Table 6.3-1).

6.1.3 Consideration of 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 evaluations in Owens Lake, California, and cores and calcite isotope records from Devils Hole, Death Valley National Park, Nevada. The sequence and duration of past climate periods are identified and applied to the Yucca Mountain site, which has a similar climate setting. Temperature and precipitation records from present-day meteorological stations at colder and wetter sites were selected to represent future climate states (USGS 2001 [DIRS 158378], Section 6.6.1).

For modeling climate change for TSPA, the climate shifts 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 modern climate), and glacial transition climate (colder than monsoon but similar precipitation) (BSC 2002 [DIRS 160146], p. 75). Within the TSPA model, these shifts require coordinating the coupled submodels because they must all simultaneously change to the appropriate climate state. To support climate change modeling for TSPA, BDCFs are developed for the three climate states (Section 6.2.1).

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 (10 CFR 63.312 [DIRS 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
- 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 physiologically consistent with present knowledge of adults.

To meet the requirements of 10 CFR 63.312(b) [DIRS 156605], the dietary and lifestyle characteristics of the RMEI were determined based on surveys of people living in the Amargosa Valley combined with national information on behavior patterns. Characteristics of the RMEI were developed in a separate analysis (BSC 2003 [DIRS 161241]).

6.1.5 Biosphere Model

The ERMYN model (BSC 2003 [DIRS 164186]), which this analysis uses to calculate BDCFs, models biosphere processes for radionuclides released from the repository to the biosphere, the environmental transport of these radionuclides, and human exposure. The *Biosphere Model Report* (BSC 2003 [DIRS 164186]), which describes the ERMYN model:

1. Describes the objectives, reference biosphere, human receptor, exposure scenarios, environmental transport pathways, and human exposure pathways (BSC 2003 [DIRS 164186], Section 6.1)

2. Develops the conceptual model based on 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. Describes the mathematical model and submodels based on the conceptual model and other published biosphere models (BSC 2003 [DIRS 164186], Sections 6.4 and 6.5)

4. Summarizes model input parameters and uncertainty distributions (BSC 2003 [DIRS 164186], Section 6.6)

5. Identifies model improvements compared with the previous biosphere model (BSC 2003 [DIRS 164186], Section 6.7)

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

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

8. Validates the ERMYN model by comparing the conceptual and mathematical models and by comparing the numerical results with results from other published biosphere models (BSC 2003 [DIRS 164186], Section 7).

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

The architecture of the biosphere model for the groundwater exposure scenario, including the submodels, is shown in Figure 6.1-2. The submodels address radionuclide transport to, and accumulation in, specific environmental media (e.g., soil, air, plants, animals, and fish) and the inhalation, ingestion, and external exposure pathways.

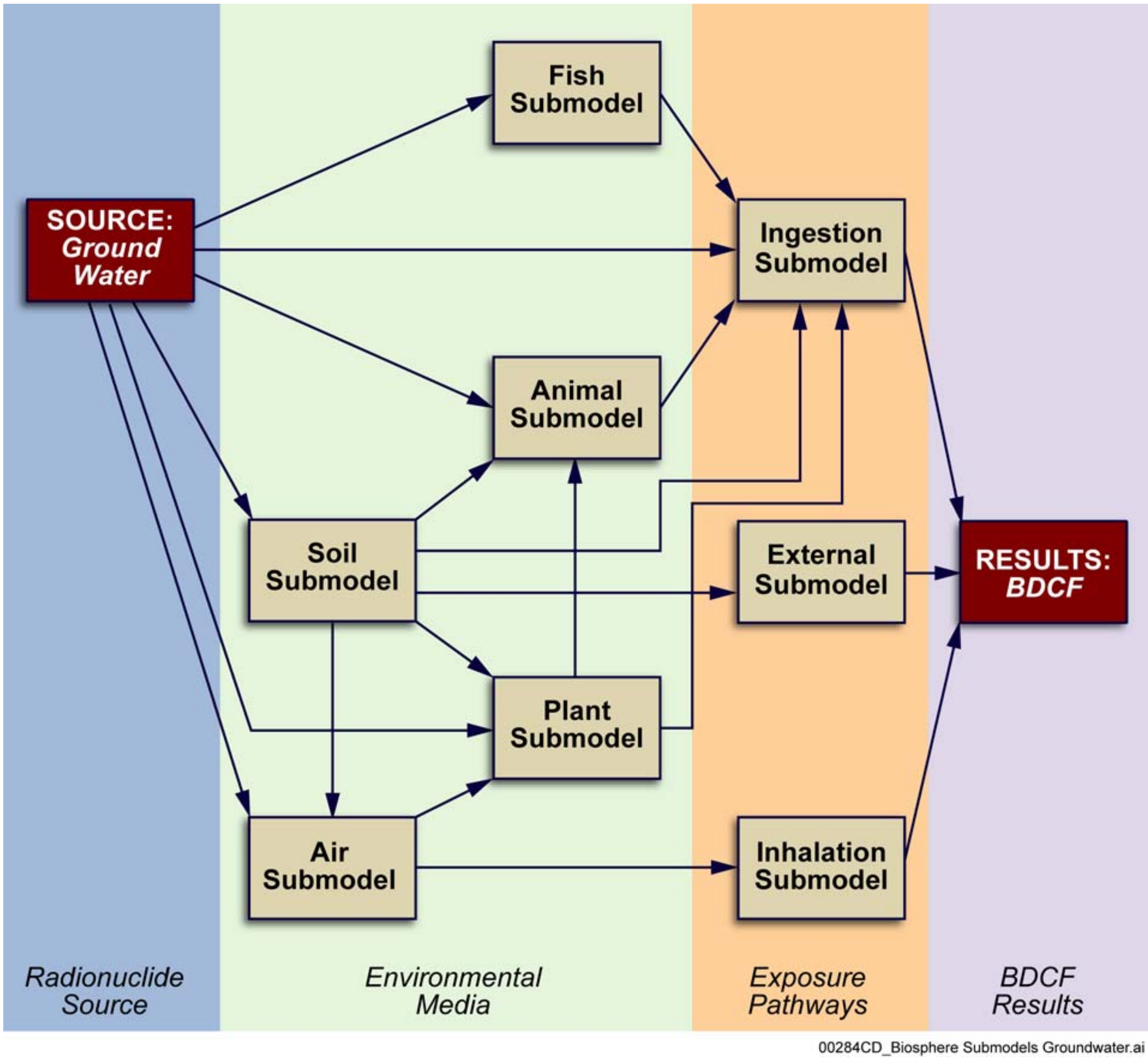


Figure 6.1-2. Relationships Among Submodels for the Groundwater Exposure Scenario

6.2 DEVELOPMENT OF BIOSPHERE DOSE CONVERSION FACTORS FOR THE GROUNDWATER EXPOSURE SCENARIO

BDCFs for groundwater exposure scenario were calculated, using probabilistic analysis, in a series of simulations for each of the 28 primary radionuclides and 2 long-lived decay products, ^{228}Th and ^{228}Ra (Section 6.1.1). 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 Modeling Methods: 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. 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. The value of the random seed was set to 1.

6.2.2 Modeling Methods: Incorporation of Climate Change

The biosphere model was constructed for a reference biosphere with an arid or semi-arid climate. The climate during the compliance period is projected to change from the modern (interglacial) climate, through a monsoon climate, to a glacial transition climate. Although the monsoon climate generally is wetter, and the glacial transition climate is wetter and cooler than the modern climate, the radionuclide environmental transport pathways and the human exposure pathways are expected to remain essentially unchanged. The conceptual and mathematical structure of the ERMYN model was designed such that it is appropriate for the entire 10,000-year postclosure period. Climate change is addressed through model input parameters, which use different values depending on the climate.

Detailed model input was developed for the anticipated extremes of climate, the modern climate and the upper bound of the glacial transition climate (which is predicted to start in about 2,000 years and last through the compliance period). For the upper bound of the glacial transition climate, climate-dependent model input parameters were based on future climate analog sites represented by meteorological conditions in east central Washington state. Although these are extremes in climate predictions, they remain arid to semi-arid. During the compliance period, the climate conditions are expected to be variable and may fall between the two extremes for which input data were developed. The approach adopted, to provide the TSPA-LA with BDCFs representing possible future climate variation between the two extremes, is provided below.

BDCFs were calculated for two climates (the modern climate and the average upper bound of the glacial transition climate) representing the upper and lower bounds of the expected range of the temperature and precipitation over the 10,000-year postclosure period. The mean values of the BDCFs for these two climate states, and the ratio of the two, are shown in Table 6.2-1.

Table 6.2-1. Differences Between Mean Biosphere Dose Conversion Factors for Climate Extremes

Radionuclide	**Mean BDCF, rem/yr per pCi/L**		**BDCF Ratio (Modern to Glacial Transition Climate)**
	Modern Climate	**Glacial Transition Climate- Upper Bound**	
^{14}C	9.06E-06	8.48E-06	1.07
^{36}Cl	1.95E-05	1.45E-05	1.34
^{79}Se	6.49E-05	4.23E-05	1.54
^{90}Sr	1.64E-04	1.43E-04	1.15
^{99}Tc	2.21E-06	1.89E-06	1.17
^{126}Sn	6.29E-03	3.51E-03	1.79
^{129}I	3.37E-04	2.92E-04	1.16
^{135}Cs	5.59E-05	3.41E-05	1.64
^{137}Cs	4.87E-04	2.89E-04	1.69
^{210}Pb	9.04E-03	7.48E-03	1.21
^{226}Ra	9.58E-02	5.71E-02	1.68
^{227}Ac	3.09E-02	1.75E-02	1.77
^{229}Th	3.37E-02	1.83E-02	1.84
^{230}Th	2.87E-02	1.70E-02	1.69
^{232}Th	4.41E-02	2.44E-02	1.81
^{231}Pa	9.91E-02	5.71E-02	1.74
^{232}U	5.78E-03	3.25E-03	1.78
^{233}U	1.74E-03	1.00E-03	1.74
^{234}U	1.21E-03	6.96E-04	1.74
^{236}U	1.08E-03	6.17E-04	1.75
^{238}U	1.08E-03	6.19E-04	1.74
^{237}Np	6.92E-03	5.09E-03	1.36
^{238}Pu	4.67E-03	3.38E-03	1.38
^{239}Pu	9.16E-03	5.94E-03	1.54
^{240}Pu	8.93E-03	5.81E-03	1.54
^{242}Pu	8.83E-03	5.71E-03	1.55
^{241}Am	6.78E-03	4.64E-03	1.46
^{243}Am	9.43E-03	6.09E-03	1.55

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: The mean BDCF values and their ratios were calculated using Excel (*BDCF Realizations for Groundwater MC and FC.xls*; Attachment I).

The BDCF values for the upper bound of the glacial transition climate are consistently lower than the corresponding values for the modern climate. The differences between the BDCFs are about a factor of less than two. For example, the factors for four radionuclides identified as important in the previous TSPA effort (BSC 2001 [DIRS 154659], Figures 4.1-8a and 4.1-8b) were 1.07 for ^{14}C, 1.17 for ^{99}Tc, 1.16 for ^{129}I, and 1.36 for ^{237}Np. Inspection of the BDCF distributions for the modern climate (Table 6.2-5) indicates that the BDCF variability, as measured by the 95- to the 5-percentile point, is a factor of about 4.2 for ^{14}C, 3.5 for ^{99}Tc, 2.2 for ^{129}I, and 2.6 for ^{237}Np. Variability in the BDCF values due to normal parametric uncertainty dominates the change in expected mean BDCF values caused by extreme climate change. It was therefore appropriate to use interpolation between the two extreme climate states, for which detailed information was available, to generate BDCFs for the expected distribution of climates in the future.

To evaluate this approach, the influence of climate change on the BDCF values was investigated. For the input parameters that are affected by climate change (Table 6.2-2), uniform distributions of parameter values were constructed ranging between the parameter averages for the extreme climates (i.e., the modern and the upper bound of the glacial transition climates). The uniform distribution was selected because it is the simplest distribution that captures the range of parameter values.

Table 6.2-2. Climate-dependent Input Parameters and Average Values for the Modern Climate and the Upper Bound of the Glacial Transition Climate

Parameter	Modern Climate	Glacial Transition Climate (Upper Bound)
Growing time, other vegetables	80 d	100 d
Growing time, fruits	160 d	105 d
Growing time, grains	200 d	185 d
Growing time, cattle forage	75 d	90 d
Irrigation application, leafy vegetables	14.7 mm	14.6 mm
Irrigation application, other vegetables	25.4 mm	25.0 mm
Irrigation application, fruits	33.9 mm	34.2 mm
Irrigation application, grains	56.8 mm	51.3 mm
Irrigation application, cattle forage	57.8 mm	53.5 mm
Average annual irrigation rate	0.94 m/yr	0.50 m/yr
Daily average irrigation rate, leafy vegetables	5.40 mm/d	3.81 mm/d
Daily average irrigation rate, other vegetables	7.55 mm/d	3.84 mm/d
Daily average irrigation rate, fruits	7.38 mm/d	3.90 mm/d
Daily average irrigation rate, grains	4.64 mm/d	3.36 mm/d
Daily average irrigation rate, cattle forage	6.54 mm/d	4.14 mm/d
Overwatering rate	0.079 m/yr	0.067 m/yr
Water concentration modifying factor (for fisheries)	4.15	2.4
Evaporative cooler use factor	0.39	0.085

Source: MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]

The model was executed using these distributions for the climate-dependent parameters with the other input parameter distributions and values left unchanged. BDCF values for 1,000 model realizations were calculated for each primary radionuclide (Section 6.1.1). The influence of climate-dependent input parameters on the model output was determined by calculating rank correlation coefficients for the BDCFs and climate-dependent input parameters (Table 6.2-3). The shaded cells contain correlation coefficients with values that differ from zero at the 99 percent confidence level (see Section 6.2.3 for discussion of the statistical test to determine values of correlation coefficients that represent true correlation at a given confidence level). The calculations were carried out using Excel (*Correlations for Climate Dependent Parameters.xls*; Attachments I and II).

The parameter for which rank correlation coefficients are consistently among the highest is the average annual irrigation rate (Table 6.2-3). The second highest correlation coefficients are for the evaporative cooler use factor. The relationships between the average annual irrigation rate and the BDCFs for ^{99}Tc, ^{129}I, and ^{237}Np are shown in Table 6.2-4. If the raw individual realization data are plotted, the stochastic variability among BDCFs from the multiple random inputs results in plots that show little discernable trend. To generate graphs illustrating the trend, averaging over realizations to minimize the impact of other variables was required. The results of model realizations were sorted by annual irrigation rate, and the irrigation rate and the corresponding BDCFs were averaged in blocks of 100 values. Graphical representations for selected radionuclides are shown in Table 6.2-4. The graphs were generated in Excel (*Dependence of BDCFs on Irrigation Rate.xls*; Attachments I and II).

BDCFs for 10 radionuclides also show a positive correlation with the evaporative cooler use factor, and BDCFs for 3 radionuclides show a positive correlation with the water concentration modifying factor. There is a positive correlation between the average annual irrigation rate, the evaporative cooler use factor, and the water concentration modifying factor because all these parameters have higher values in hotter climates. The annual average irrigation rate is a function of evapotranspiration (BSC 2003 [DIRS 160976], Section 6.5.2), which depends on temperature, as do the evaporative cooler use factor (BSC 2003 [DIRS 161241], Section 6.3.4.2) and the water concentration modifying factor ((BSC 2003 [DIRS 161241], Section 6.4.3). Therefore, the annual average irrigation rate was considered a surrogate parameter to represent the dependence of the BDCFs on the evaporative cooler use factor and the water concentration modifying factor.

The correlation between the irrigation rate and the BDCF for ^{14}C is negative. This is because the BDCF for ^{14}C depends on the concentration of ^{14}C in the air, which is proportional to the square root of the irrigated area; which, in turn, is inversely proportional to the amount of average annual irrigation (i.e., for a given volume of water, a greater area can be irrigated if the irrigation rate is lower). In spite of this, the BDCF for ^{14}C for the upper bound of the glacial transition climate is less than the BDCF for the modern climate due to the combined influence of other climate-dependent parameters, which reduce the BDCF value for ^{14}C for the upper bound of the glacial transition climate.

Table 6.2-3. Correlations (Rank Correlation Coefficients) Between BDCFs and Climate-dependent Input Parameters

Radio-nuclide	Growing time				Irrigation Application				
	Other Vegetables	Fruits	Grains	Cattle Forage	Leafy Vegetables	Other Vegetables	Fruits	Grains	Cattle Forage
^{14}C	0.0074	0.0617	0.0493	-0.0661	0.0162	0.0642	0.0286	0.0391	0.0426
^{36}Cl	0.0352	0.0597	0.0334	-0.0101	0.0718	0.0165	0.0171	0.0239	-0.0084
^{79}Se	0.0089	-0.0365	0.0158	-0.0297	-0.0265	0.0035	-0.0508	0.0119	-0.0194
^{90}Sr	-0.0073	0.0269	0.0113	-0.0250	0.0904	-0.0147	-0.0292	0.0557	0.0322
^{99}Tc	-0.0213	0.0192	-0.0373	-0.0004	0.0359	0.0388	-0.0847	0.0027	-0.0045
^{126}Sn	0.0361	-0.0172	0.0212	-0.0913	0.0535	0.0005	0.0065	-0.0151	-0.0103
^{129}I	-0.0256	0.0510	-0.0021	-0.0060	0.0664	0.0032	0.0087	0.0778	-0.0284
^{135}Cs	0.0717	0.0457	0.0268	-0.0237	0.0385	0.0145	-0.0025	0.0048	0.0565
^{137}Cs	0.0714	0.0334	0.0443	-0.0335	0.0146	0.0024	-0.0111	0.0081	0.0175
^{210}Pb	0.0048	0.0328	0.0080	0.0197	-0.0197	-0.0202	-0.0447	0.0202	-0.0157
^{226}Ra	0.0201	-0.0213	0.0408	-0.0442	0.0812	-0.0094	0.0121	-0.0467	0.0150
^{227}Ac	0.0444	-0.0430	-0.0008	-0.0280	0.0381	0.0250	-0.0671	-0.0363	0.0537
^{229}Th	0.0118	-0.0853	0.0346	-0.0660	0.0568	0.0391	0.0007	-0.0509	0.0344
^{230}Th	0.0185	-0.0235	0.0209	-0.0540	0.0534	-0.0068	0.0135	-0.0475	0.0185
^{232}Th	0.0157	-0.0759	0.0328	-0.0706	0.0524	0.0347	0.0013	-0.0569	0.0330
^{231}Pa	0.0047	-0.0925	0.0346	-0.0325	0.0402	0.0071	0.0404	-0.0496	0.0290
^{232}U	0.0334	-0.0256	0.0088	0.0140	0.0374	0.0037	-0.0821	-0.0303	0.0049
^{233}U	0.0272	-0.0010	-0.0123	0.0357	0.0391	-0.0080	-0.0511	-0.0215	-0.0108
^{234}U	0.0301	-0.0048	-0.0067	0.0352	0.0420	-0.0062	-0.0541	-0.0216	-0.0068
^{236}U	0.0291	-0.0077	-0.0035	0.0358	0.0425	-0.0037	-0.0561	-0.0188	-0.0050
^{238}U	0.0290	-0.0046	-0.0042	0.0365	0.0419	-0.0037	-0.0561	-0.0180	-0.0065
^{237}Np	0.0158	-0.0445	0.0094	0.0027	0.0025	0.0449	-0.0416	-0.0325	0.0402
^{238}Pu	0.0222	-0.0367	0.0184	-0.0214	0.0702	0.0344	-0.0265	-0.0137	0.0293
^{239}Pu	0.0006	-0.0725	0.0390	-0.0265	0.0720	0.0230	0.0120	-0.0439	0.0218
^{240}Pu	0.0007	-0.0715	0.0404	-0.0273	0.0729	0.0250	0.0111	-0.0435	0.0233
^{242}Pu	0.0008	-0.0723	0.0388	-0.0265	0.0717	0.0225	0.0120	-0.0442	0.0220
^{241}Am	0.0194	-0.0802	0.0083	-0.0205	0.0513	0.0334	-0.0307	-0.0335	0.0293
^{243}Am	0.0224	-0.0737	0.0059	-0.0098	0.0600	0.0165	-0.0214	-0.0396	0.0105

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: Values were calculated using Excel (*Correlations for climate dependent parameters.xls*; Attachment I). Correlation coefficients in shaded cells differ significantly from zero at the 99% confidence level.

Table 6.2-3. Correlations (Rank Correlation Coefficients) Between the BDCFs and Climate-dependent Input Parameters (continued)

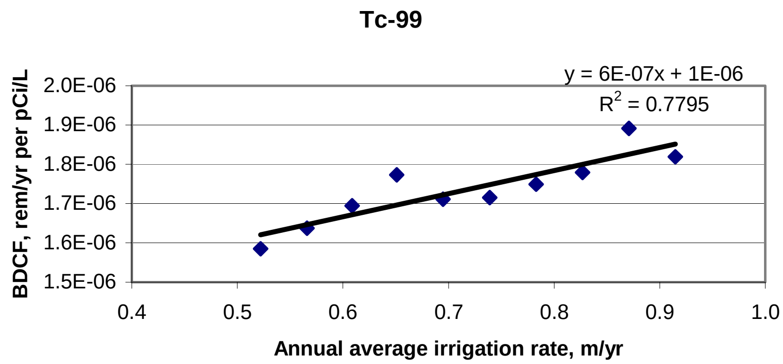
Radionuclide	Average Annual Irrigation Rate	Daily Average Irrigation Rate					Overwatering Rate	Water concentration modifying factor	Evaporative Cooler Use Factor
		Leafy Vegetables	Other Vegetables	Fruits	Grains	Cattle Forage			
^{14}C	-0.0800	-0.0247	0.0272	0.0461	0.0276	0.0969	-0.0489	0.0000	0.0337
^{36}Cl	0.1823	-0.0018	0.0362	-0.0311	-0.0054	0.0222	-0.0957	0.0486	0.0499
^{79}Se	0.1716	-0.0281	0.0010	0.0550	-0.0133	0.0327	-0.0380	-0.0312	-0.0166
^{90}Sr	0.2166	0.0122	0.0188	0.0262	0.0650	0.0607	-0.0628	0.0710	0.0091
^{99}Tc	0.1980	0.0327	-0.0254	0.0279	0.0175	0.0433	-0.0446	0.0566	0.0210
^{126}Sn	0.2660	-0.0288	-0.0101	0.0307	-0.0251	0.0153	-0.0349	0.0058	-0.0468
^{129}I	0.0758	-0.0141	-0.0213	0.0030	0.0372	0.0880	-0.0518	0.0243	0.0078
^{135}Cs	0.0965	-0.0291	0.0169	-0.0820	0.0053	0.0076	-0.0525	0.1242	0.0176
^{137}Cs	0.2233	-0.0251	0.0195	-0.0237	0.0214	0.0021	-0.0267	0.1342	0.0154
^{210}Pb	0.0027	0.0011	-0.0216	0.0124	-0.0601	0.0461	0.0310	0.1776	0.0367
^{226}Ra	0.3446	-0.0141	0.0155	0.0029	-0.0092	0.0205	-0.0601	0.0194	-0.0568
^{227}Ac	0.0942	0.0367	0.0184	0.0085	-0.0060	0.0081	0.0063	-0.0094	0.3785
^{229}Th	0.2291	-0.0032	0.0267	0.0306	0.0252	0.0268	-0.0201	0.0132	0.0843
^{230}Th	0.1848	-0.0194	0.0087	-0.0097	0.0079	0.0505	-0.0377	0.0013	-0.0201
^{232}Th	0.2691	-0.0140	0.0208	0.0175	0.0273	0.0316	-0.0232	0.0025	0.0587
^{231}Pa	0.2179	0.0247	0.0069	0.0413	0.0323	0.0195	-0.0070	-0.0066	-0.0020
^{232}U	0.1619	0.0230	0.0530	-0.0419	-0.0064	0.0045	-0.0013	-0.0211	0.2532
^{233}U	0.1086	0.0201	0.0386	-0.0313	0.0134	0.0275	-0.0054	-0.0209	0.1017
^{234}U	0.1159	0.0252	0.0393	-0.0363	0.0149	0.0249	-0.0026	-0.0253	0.1324
^{236}U	0.1173	0.0271	0.0425	-0.0342	0.0147	0.0230	-0.0026	-0.0275	0.1397
^{238}U	0.1191	0.0253	0.0429	-0.0365	0.0142	0.0232	-0.0028	-0.0258	0.1323
^{237}Np	0.1645	0.0553	0.0343	-0.0168	-0.0408	0.0159	-0.0427	0.0258	0.2337
^{238}Pu	0.1744	0.0288	0.0147	0.0634	-0.0024	-0.0181	-0.0022	0.0406	0.2309
^{239}Pu	0.2266	0.0022	0.0256	0.0373	0.0113	-0.0091	-0.0163	0.0208	0.0658
^{240}Pu	0.2304	0.0035	0.0262	0.0399	0.0119	-0.0102	-0.0172	0.0218	0.0693
^{242}Pu	0.2251	0.0016	0.0254	0.0362	0.0113	-0.0087	-0.0156	0.0203	0.0646
^{241}Am	0.2174	0.0662	0.0149	0.0376	0.0203	-0.0019	-0.0398	0.0292	0.1176
^{243}Am	0.2048	0.0509	0.0024	0.0289	0.0163	0.0178	-0.0574	0.0135	0.0460

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]

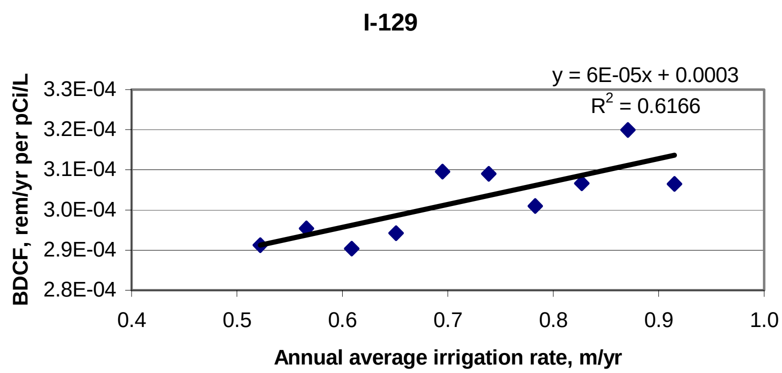
NOTE: Values were calculated using Excel (*Correlations for climate dependent parameters.xls*; Attachment I). Correlation coefficients in shaded cells differ significantly from zero at the 99% confidence level.

Table 6.2-4. Dependence of BDCFs for ^{99}Tc, ^{129}I, and ^{237}Np on Annual Average Irrigation Rate

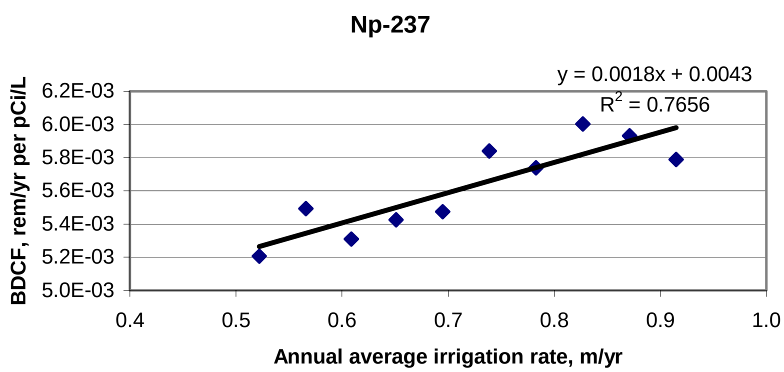
Realization Number [a]	Irrigation Rate [b]	BDCF [c]
Technetium – 99		
1-100	5.22E-01	1.58E-06
101-200	5.66E-01	1.64E-06
201-300	6.09E-01	1.69E-06
301-400	6.51E-01	1.77E-06
401-500	6.95E-01	1.71E-06
501-600	7.39E-01	1.72E-06
601-700	7.83E-01	1.75E-06
701-800	8.27E-01	1.78E-06
801-900	8.71E-01	1.89E-06
901-1000	9.15E-01	1.82E-06



Realization Number [a]	Irrigation Rate [b]	BDCF [c]
Iodine – 129		
1-100	5.28E-01	2.91E-04
101-200	5.84E-01	2.95E-04
201-300	6.40E-01	2.90E-04
301-400	6.96E-01	2.94E-04
401-500	7.52E-01	3.10E-04
501-600	8.08E-01	3.09E-04
601-700	8.64E-01	3.01E-04
701-800	9.20E-01	3.07E-04
801-900	9.76E-01	3.20E-04
901-1000	1.03E+00	3.06E-04



Realization Number [a]	Irrigation Rate [b]	BDCF [c]
Neptunium – 237		
1-100	5.28E-01	5.21E-03
101-200	5.84E-01	5.49E-03
201-300	6.40E-01	5.31E-03
301-400	6.96E-01	5.43E-03
401-500	7.52E-01	5.47E-03
501-600	8.08E-01	5.84E-03
601-700	8.64E-01	5.74E-03
701-800	9.20E-01	6.00E-03
801-900	9.76E-01	5.93E-03
901-1000	1.03E+00	5.79E-03



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:

Values were calculated using Excel (*Dependence of BDCFs on Irrigation Rate.xls*; Attachment I).

[a] Realization number after sorting by annual average irrigation rate

[b] Average of the long-term irrigation rate (annual average irrigation rate) for the range of realizations.

[c] Average of the BDCFs for the range of realizations.

Given that the BDCFs can be shown to increase linearly with the value of a climate-dependent parameter, the BDCFs for the average upper bound of the monsoon and the average lower bound of the glacial transition climates were calculated by interpolation between the BDCF values for the modern and the upper bound of the glacial transition climates. It was assumed that BDCFs can be scaled with the average annual irrigation rate. Based on the future climate analog sites (DTN: MO0306SPAAEIBM.001 [DIRS 163812]), values of the average annual irrigation rates are:

0.94 m/yr for the modern climate and the lower bound of the monsoon climate

0.88 m/yr for the lower bound of the glacial transition climate (based on Delta, Utah)

0.52 m/yr for the upper bound of the monsoon climate (based on Nogales, Arizona)

0.50 m/yr for the upper bound of the glacial transition climate (based on Spokane and other locations in east central Washington).

Because differences between the irrigation rates for the upper bound of the monsoon (0.52 m/yr) and the upper bound of the glacial transition climates (0.50 m/yr) are small, one value of 0.50 m/yr is used. The relationship between the average annual irrigation rates and the BDCFs for the climate states under consideration is shown in Figure 6.2-1.

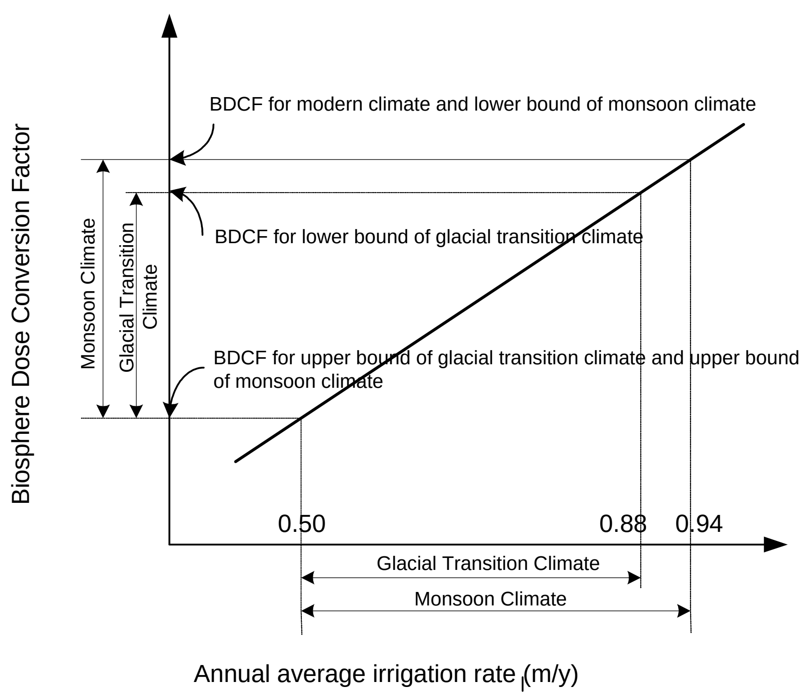


Figure 6.2-1. Scaling of the Biosphere Dose Conversion Factors

BDCF values for the lower bound of the glacial transition climate can be calculated as:

$$BDCF_{LBGT} = BDCF_{UBGT} + \frac{0.88 - 0.50}{0.94 - 0.50}(BDCF_{IC} - BDCF_{UBGT}) \qquad \text{(Eq. 6.2-1)}$$

where

$BDCF_{LBGT}$	=	BDCF for the lower bound of glacial transition climate
$BDCF_{UBGT}$	=	BDCF for the upper bound of glacial transition climate
$BDCF_{IC}$	=	BDCF for the modern climate (interglacial)
$\frac{0.88 - 0.50}{0.94 - 0.50}$	=	Scaling factor equal to the difference between the average annual irrigation rate for the modern climate and the lower bound of the glacial transition climates divided by the difference between the average annual irrigation rate for the modern climate and the upper bound of the glacial transition climate.

BDCF values for individual realizations for the monsoon and the glacial transition climates were then calculated by randomly sampling over the range of BDCF values for these climates. For the monsoon climate, the sampling was over the entire range between the two extreme BDCF values for an individual realization (i.e., the values for the modern climate and the upper bound of the glacial transition climate), and was calculated as

$$BDCF_{MC} = BDCF_{UBGT} + (BDCF_{IC} - BDCF_{UBGT})\ RAND \qquad \text{(Eq. 6.2-2)}$$

where

$BDCF_{MC}$	=	BDCF for the monsoon climate
$RAND$	=	random number greater than or equal to 0 and less than 1

For the glacial transition climate, the sampling was between the value for the lower and upper bounds of the glacial transition climate and was calculated as

$$BDCF_{GTC} = BDCF_{UBGT} + \frac{0.88 - 0.50}{0.94 - 0.50}(BDCF_{IC} - BDCF_{UBGT})\ RAND \qquad \text{(Eq. 6.2-3)}$$

where

$BDCF_{GTC}$	=	BDCF for the glacial transition climate

These calculations were performed using Excel (*BDCF Realizations for Groundwater MC and FC.xls*; Attachments I and II).

6.2.3 Modeling Results: Biosphere Dose Conversion Factors

BDCFs for the modern climate, monsoon climate, and glacial transition climate were calculated as described in the previous section. The BDCFs for a specific climate state consist of a set of 1,000 row vectors, with vector elements representing BDCFs for different radionuclides and a row (vector) number corresponding to a model realization. The full sets of BDCF vectors for the three climate states are given in *BDCF Realizations for Groundwater MC and FC.xls* (Attachment II). Summary statistics for the BDCFs are presented in Tables 6.2-5 to 6.2-7 for the modern climate, monsoon climate, and glacial transition climate, respectively. The statistics include the mean, standard deviation (STD), minimum, maximum, and percentiles of cumulative distribution in increments of 5%.

In all of the tables containing the results, the values for ^{232}Th include contributions from ^{228}Ra and ^{228}Th and their short-lived decay products. Similarly, values for ^{232}U include contributions from ^{228}Th and its short-lived decay products

Table 6.2-5. Biosphere Dose Conversion Factors Statistics for the Modern Climate, rem/yr per pCi/L.

	^{14}C	^{36}C	^{79}Se	^{90}Sr	^{99}Tc	^{126}Sn	^{129}I	^{135}Cs	^{137}Cs	^{210}Pb	^{226}Ra
Mean	9.06E-06	1.95E-05	6.49E-05	1.64E-04	2.21E-06	6.29E-03	3.37E-04	5.59E-05	4.87E-04	9.04E-03	9.58E-02
STD	6.05E-06	2.84E-05	1.29E-04	2.46E-05	1.48E-06	3.95E-03	1.17E-04	3.99E-05	2.54E-04	3.48E-03	4.65E-02
Minimum	4.15E-06	3.22E-06	9.26E-06	1.21E-04	1.16E-06	1.44E-04	2.20E-04	9.17E-06	1.70E-04	5.71E-03	2.20E-03
5%	4.90E-06	4.86E-06	1.44E-05	1.34E-04	1.30E-06	1.00E-03	2.39E-04	1.98E-05	2.28E-04	6.21E-03	3.93E-02
10%	5.15E-06	5.57E-06	1.69E-05	1.38E-04	1.35E-06	1.85E-03	2.47E-04	2.24E-05	2.57E-04	6.36E-03	4.70E-02
15%	5.38E-06	6.27E-06	1.97E-05	1.41E-04	1.41E-06	2.40E-03	2.55E-04	2.55E-05	2.77E-04	6.57E-03	5.27E-02
20%	5.61E-06	6.83E-06	2.16E-05	1.45E-04	1.45E-06	3.10E-03	2.62E-04	2.78E-05	3.00E-04	6.74E-03	5.75E-02
25%	5.80E-06	7.75E-06	2.35E-05	1.47E-04	1.50E-06	3.56E-03	2.70E-04	3.02E-05	3.19E-04	6.91E-03	6.22E-02
30%	6.00E-06	8.48E-06	2.50E-05	1.50E-04	1.55E-06	4.00E-03	2.77E-04	3.32E-05	3.35E-04	7.06E-03	6.60E-02
35%	6.24E-06	9.46E-06	2.71E-05	1.52E-04	1.60E-06	4.49E-03	2.82E-04	3.55E-05	3.58E-04	7.26E-03	7.09E-02
40%	6.44E-06	1.02E-05	2.97E-05	1.54E-04	1.65E-06	4.81E-03	2.90E-04	3.83E-05	3.77E-04	7.45E-03	7.50E-02
45%	6.74E-06	1.13E-05	3.30E-05	1.57E-04	1.70E-06	5.11E-03	2.97E-04	4.07E-05	4.02E-04	7.68E-03	8.00E-02
50%	7.10E-06	1.22E-05	3.63E-05	1.59E-04	1.76E-06	5.41E-03	3.05E-04	4.40E-05	4.23E-04	7.91E-03	8.51E-02
55%	7.48E-06	1.33E-05	3.94E-05	1.62E-04	1.82E-06	5.82E-03	3.13E-04	4.68E-05	4.53E-04	8.18E-03	9.28E-02
60%	7.84E-06	1.49E-05	4.33E-05	1.64E-04	1.90E-06	6.22E-03	3.25E-04	5.10E-05	4.77E-04	8.61E-03	9.98E-02
65%	8.34E-06	1.69E-05	4.80E-05	1.68E-04	2.00E-06	6.89E-03	3.35E-04	5.57E-05	5.07E-04	8.93E-03	1.06E-01
70%	8.99E-06	1.91E-05	5.35E-05	1.70E-04	2.12E-06	7.60E-03	3.49E-04	6.03E-05	5.36E-04	9.40E-03	1.14E-01
75%	9.83E-06	2.18E-05	6.21E-05	1.75E-04	2.30E-06	8.38E-03	3.67E-04	6.83E-05	5.75E-04	9.96E-03	1.23E-01
80%	1.07E-05	2.52E-05	7.36E-05	1.81E-04	2.52E-06	9.24E-03	3.89E-04	7.67E-05	6.19E-04	1.06E-02	1.33E-01
85%	1.22E-05	3.08E-05	8.93E-05	1.88E-04	2.90E-06	1.04E-02	4.12E-04	8.56E-05	6.85E-04	1.13E-02	1.44E-01
90%	1.48E-05	3.82E-05	1.19E-04	1.95E-04	3.36E-06	1.20E-02	4.58E-04	1.01E-04	7.86E-04	1.28E-02	1.59E-01
95%	2.04E-05	5.36E-05	1.81E-04	2.11E-04	4.60E-06	1.42E-02	5.22E-04	1.33E-04	9.83E-04	1.56E-02	1.83E-01
Maximum	6.09E-05	4.43E-04	2.72E-03	2.88E-04	1.89E-05	2.12E-02	1.39E-03	3.11E-04	2.14E-03	3.43E-02	3.37E-01

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]

Table 6.2-5. Biosphere Dose Conversion Factors Statistics for the Modern Climate, rem/yr per pCi/L (continued).

	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np
Mean	3.09E-02	3.37E-02	2.87E-02	4.41E-02	9.91E-02	5.78E-03	1.74E-03	1.21E-03	1.08E-03	1.08E-03	6.92E-03
STD	1.08E-02	1.77E-02	2.42E-02	2.21E-02	6.31E-02	2.36E-03	2.04E-03	1.02E-03	8.58E-04	8.55E-04	2.27E-03
Minimum	1.26E-02	6.36E-03	1.12E-03	7.59E-03	1.46E-02	1.78E-03	2.43E-04	2.29E-04	2.16E-04	2.15E-04	3.70E-03
5%	1.70E-02	1.31E-02	5.32E-03	1.79E-02	2.95E-02	2.72E-03	3.50E-04	3.26E-04	3.08E-04	3.04E-04	4.31E-03
10%	1.86E-02	1.60E-02	7.44E-03	2.13E-02	3.68E-02	3.15E-03	4.20E-04	3.91E-04	3.67E-04	3.61E-04	4.60E-03
15%	2.02E-02	1.76E-02	8.77E-03	2.33E-02	4.36E-02	3.53E-03	4.85E-04	4.46E-04	4.19E-04	4.12E-04	4.84E-03
20%	2.17E-02	1.93E-02	1.01E-02	2.60E-02	4.88E-02	3.86E-03	5.27E-04	4.97E-04	4.68E-04	4.57E-04	5.14E-03
25%	2.28E-02	2.11E-02	1.16E-02	2.82E-02	5.45E-02	4.08E-03	5.87E-04	5.40E-04	5.05E-04	4.97E-04	5.36E-03
30%	2.43E-02	2.25E-02	1.33E-02	3.05E-02	6.08E-02	4.35E-03	6.52E-04	5.87E-04	5.45E-04	5.36E-04	5.56E-03
35%	2.56E-02	2.44E-02	1.51E-02	3.28E-02	6.49E-02	4.62E-03	7.20E-04	6.52E-04	6.04E-04	5.93E-04	5.76E-03
40%	2.69E-02	2.63E-02	1.70E-02	3.49E-02	7.07E-02	4.93E-03	8.08E-04	7.05E-04	6.56E-04	6.39E-04	5.93E-03
45%	2.80E-02	2.84E-02	1.93E-02	3.70E-02	7.57E-02	5.12E-03	8.91E-04	7.69E-04	7.18E-04	7.02E-04	6.14E-03
50%	2.90E-02	2.97E-02	2.09E-02	3.93E-02	8.23E-02	5.35E-03	1.01E-03	8.42E-04	7.81E-04	7.69E-04	6.42E-03
55%	3.05E-02	3.20E-02	2.29E-02	4.14E-02	8.83E-02	5.61E-03	1.19E-03	9.55E-04	8.78E-04	8.76E-04	6.64E-03
60%	3.16E-02	3.38E-02	2.58E-02	4.44E-02	9.72E-02	5.98E-03	1.34E-03	1.06E-03	9.73E-04	9.80E-04	6.93E-03
65%	3.33E-02	3.58E-02	2.86E-02	4.69E-02	1.06E-01	6.26E-03	1.58E-03	1.21E-03	1.10E-03	1.10E-03	7.22E-03
70%	3.52E-02	3.86E-02	3.30E-02	5.05E-02	1.16E-01	6.53E-03	1.85E-03	1.38E-03	1.24E-03	1.24E-03	7.56E-03
75%	3.71E-02	4.15E-02	3.81E-02	5.43E-02	1.27E-01	7.05E-03	2.17E-03	1.50E-03	1.38E-03	1.38E-03	7.94E-03
80%	3.90E-02	4.54E-02	4.37E-02	5.91E-02	1.38E-01	7.48E-03	2.54E-03	1.79E-03	1.57E-03	1.57E-03	8.40E-03
85%	4.15E-02	5.05E-02	5.14E-02	6.60E-02	1.59E-01	8.06E-03	3.10E-03	2.11E-03	1.84E-03	1.83E-03	8.98E-03
90%	4.47E-02	5.74E-02	6.20E-02	7.44E-02	1.81E-01	8.83E-03	3.84E-03	2.45E-03	2.14E-03	2.14E-03	9.81E-03
95%	5.13E-02	6.86E-02	7.94E-02	8.80E-02	2.26E-01	1.01E-02	5.29E-03	3.15E-03	2.77E-03	2.74E-03	1.12E-02
Maximum	8.22E-02	1.22E-01	1.85E-01	1.51E-01	4.38E-01	1.78E-02	2.34E-02	8.99E-03	6.94E-03	6.78E-03	2.23E-02

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]

Table 6.2-5. Biosphere Dose Conversion Factors Statistics for the Modern Climate, rem/yr per pCi/L (continued).

	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	4.67E-03	9.16E-03	8.93E-03	8.83E-03	6.78E-03	9.43E-03
STD	1.13E-03	3.59E-03	3.37E-03	3.52E-03	1.93E-03	3.89E-03
Minimum	2.71E-03	3.73E-03	3.73E-03	3.55E-03	3.00E-03	3.03E-03
5%	3.32E-03	4.98E-03	4.95E-03	4.76E-03	4.32E-03	4.66E-03
10%	3.53E-03	5.48E-03	5.43E-03	5.23E-03	4.62E-03	5.31E-03
15%	3.68E-03	5.89E-03	5.85E-03	5.63E-03	4.93E-03	5.77E-03
20%	3.80E-03	6.31E-03	6.24E-03	6.03E-03	5.15E-03	6.24E-03
25%	3.91E-03	6.62E-03	6.55E-03	6.35E-03	5.43E-03	6.55E-03
30%	4.00E-03	7.03E-03	6.96E-03	6.74E-03	5.63E-03	6.98E-03
35%	4.12E-03	7.34E-03	7.23E-03	7.03E-03	5.86E-03	7.37E-03
40%	4.25E-03	7.70E-03	7.57E-03	7.38E-03	6.00E-03	7.86E-03
45%	4.35E-03	8.05E-03	7.89E-03	7.73E-03	6.20E-03	8.32E-03
50%	4.45E-03	8.43E-03	8.30E-03	8.11E-03	6.45E-03	8.72E-03
55%	4.57E-03	8.80E-03	8.61E-03	8.44E-03	6.66E-03	9.08E-03
60%	4.72E-03	9.21E-03	9.03E-03	8.89E-03	6.92E-03	9.69E-03
65%	4.86E-03	9.64E-03	9.40E-03	9.28E-03	7.18E-03	1.01E-02
70%	5.02E-03	1.01E-02	9.83E-03	9.74E-03	7.49E-03	1.06E-02
75%	5.18E-03	1.07E-02	1.04E-02	1.03E-02	7.84E-03	1.12E-02
80%	5.39E-03	1.13E-02	1.10E-02	1.09E-02	8.15E-03	1.20E-02
85%	5.69E-03	1.23E-02	1.20E-02	1.19E-02	8.60E-03	1.33E-02
90%	6.02E-03	1.38E-02	1.33E-02	1.32E-02	9.31E-03	1.47E-02
95%	6.64E-03	1.65E-02	1.58E-02	1.60E-02	1.05E-02	1.72E-02
Maximum	1.52E-02	2.90E-02	2.63E-02	2.87E-02	1.66E-02	2.95E-02

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: STD = standard deviation. See Excel file *BDCF Realizations for Groundwater MC and FC.xls* in Attachments I and II for details of calculations.

Table 6.2-6. Biosphere Dose Conversion Factors Statistics for the Monsoon Climate, rem/yr per pCi/L.

	^{14}C	^{36}C	^{79}Se	^{90}Sr	^{99}Tc	^{126}Sn	^{129}I	^{135}Cs	^{137}Cs	^{210}Pb	^{226}Ra
Mean	8.78E-06	1.71E-05	5.33E-05	1.54E-04	2.06E-06	4.89E-03	3.13E-04	4.54E-05	3.89E-04	8.23E-03	7.67E-02
STD	6.04E-06	2.62E-05	1.01E-04	2.06E-05	1.37E-06	3.08E-03	9.65E-05	3.31E-05	2.05E-04	2.71E-03	3.94E-02
Minimum	3.99E-06	3.20E-06	8.76E-06	1.20E-04	1.15E-06	1.09E-04	2.17E-04	7.55E-06	1.19E-04	5.67E-03	1.92E-03
5%	4.66E-06	4.38E-06	1.28E-05	1.29E-04	1.26E-06	7.88E-04	2.32E-04	1.55E-05	1.75E-04	5.94E-03	2.89E-02
10%	4.92E-06	5.02E-06	1.50E-05	1.32E-04	1.30E-06	1.41E-03	2.38E-04	1.85E-05	1.99E-04	6.11E-03	3.60E-02
15%	5.11E-06	5.39E-06	1.67E-05	1.35E-04	1.34E-06	2.03E-03	2.44E-04	2.10E-05	2.18E-04	6.27E-03	4.10E-02
20%	5.34E-06	5.93E-06	1.81E-05	1.37E-04	1.38E-06	2.39E-03	2.51E-04	2.29E-05	2.38E-04	6.40E-03	4.43E-02
25%	5.56E-06	6.53E-06	1.96E-05	1.39E-04	1.41E-06	2.74E-03	2.57E-04	2.48E-05	2.53E-04	6.52E-03	4.81E-02
30%	5.77E-06	7.19E-06	2.15E-05	1.41E-04	1.45E-06	3.03E-03	2.62E-04	2.65E-05	2.68E-04	6.66E-03	5.10E-02
35%	5.93E-06	8.02E-06	2.31E-05	1.43E-04	1.49E-06	3.38E-03	2.68E-04	2.89E-05	2.85E-04	6.81E-03	5.55E-02
40%	6.14E-06	8.80E-06	2.48E-05	1.45E-04	1.54E-06	3.68E-03	2.75E-04	3.15E-05	3.04E-04	6.97E-03	5.92E-02
45%	6.37E-06	9.48E-06	2.71E-05	1.47E-04	1.59E-06	4.03E-03	2.80E-04	3.32E-05	3.21E-04	7.14E-03	6.28E-02
50%	6.76E-06	1.02E-05	2.97E-05	1.49E-04	1.63E-06	4.27E-03	2.86E-04	3.52E-05	3.43E-04	7.34E-03	6.79E-02
55%	7.16E-06	1.11E-05	3.32E-05	1.52E-04	1.68E-06	4.57E-03	2.94E-04	3.79E-05	3.61E-04	7.56E-03	7.25E-02
60%	7.63E-06	1.27E-05	3.64E-05	1.54E-04	1.76E-06	4.87E-03	3.03E-04	4.05E-05	3.81E-04	7.85E-03	7.84E-02
65%	8.08E-06	1.42E-05	3.95E-05	1.56E-04	1.86E-06	5.31E-03	3.12E-04	4.41E-05	4.06E-04	8.24E-03	8.50E-02
70%	8.72E-06	1.64E-05	4.44E-05	1.59E-04	1.98E-06	5.78E-03	3.25E-04	4.89E-05	4.33E-04	8.52E-03	9.21E-02
75%	9.56E-06	1.88E-05	4.97E-05	1.62E-04	2.11E-06	6.34E-03	3.39E-04	5.41E-05	4.57E-04	8.94E-03	9.74E-02
80%	1.05E-05	2.25E-05	6.02E-05	1.67E-04	2.31E-06	7.29E-03	3.52E-04	6.05E-05	5.03E-04	9.48E-03	1.06E-01
85%	1.20E-05	2.65E-05	7.39E-05	1.72E-04	2.62E-06	8.27E-03	3.75E-04	6.96E-05	5.52E-04	1.02E-02	1.16E-01
90%	1.46E-05	3.29E-05	9.65E-05	1.81E-04	3.18E-06	9.37E-03	4.13E-04	8.30E-05	6.40E-04	1.13E-02	1.31E-01
95%	1.99E-05	4.64E-05	1.45E-04	1.94E-04	4.16E-06	1.09E-02	4.76E-04	1.11E-04	7.81E-04	1.33E-02	1.54E-01
Maximum	6.03E-05	4.27E-04	2.03E-03	2.69E-04	1.77E-05	1.69E-02	1.34E-03	2.65E-04	1.68E-03	2.69E-02	2.89E-01

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]

Table 6.2-6. Biosphere Dose Conversion Factors Statistics for the Monsoon Climate, rem/yr per pCi/L (continued).

	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np
Mean	2.40E-02	2.62E-02	2.29E-02	3.39E-02	7.78E-02	4.51E-03	1.39E-03	9.52E-04	8.56E-04	8.47E-04	6.00E-03
STD	8.18E-03	1.43E-02	1.97E-02	1.71E-02	4.96E-02	1.82E-03	1.66E-03	7.86E-04	7.11E-04	6.73E-04	1.86E-03
Minimum	1.21E-02	5.14E-03	6.97E-04	6.58E-03	1.26E-02	1.73E-03	2.32E-04	2.24E-04	2.12E-04	2.10E-04	3.57E-03
5%	1.48E-02	9.64E-03	4.32E-03	1.37E-02	2.39E-02	2.29E-03	3.01E-04	2.90E-04	2.71E-04	2.66E-04	4.00E-03
10%	1.57E-02	1.16E-02	5.35E-03	1.65E-02	2.98E-02	2.61E-03	3.48E-04	3.22E-04	3.03E-04	2.97E-04	4.18E-03
15%	1.65E-02	1.30E-02	6.67E-03	1.78E-02	3.49E-02	2.85E-03	3.83E-04	3.54E-04	3.35E-04	3.25E-04	4.37E-03
20%	1.71E-02	1.47E-02	7.77E-03	2.00E-02	3.85E-02	3.04E-03	4.22E-04	3.82E-04	3.58E-04	3.55E-04	4.53E-03
25%	1.79E-02	1.60E-02	9.13E-03	2.16E-02	4.21E-02	3.23E-03	4.62E-04	4.16E-04	3.95E-04	3.83E-04	4.70E-03
30%	1.89E-02	1.74E-02	1.02E-02	2.32E-02	4.64E-02	3.42E-03	5.12E-04	4.55E-04	4.34E-04	4.14E-04	4.88E-03
35%	1.98E-02	1.87E-02	1.16E-02	2.50E-02	4.99E-02	3.59E-03	5.53E-04	4.95E-04	4.68E-04	4.61E-04	5.04E-03
40%	2.06E-02	2.00E-02	1.31E-02	2.64E-02	5.56E-02	3.77E-03	6.05E-04	5.38E-04	5.04E-04	5.09E-04	5.19E-03
45%	2.14E-02	2.14E-02	1.47E-02	2.81E-02	6.07E-02	3.99E-03	6.92E-04	5.99E-04	5.57E-04	5.55E-04	5.37E-03
50%	2.23E-02	2.29E-02	1.66E-02	2.99E-02	6.45E-02	4.17E-03	8.11E-04	6.69E-04	6.20E-04	6.11E-04	5.57E-03
55%	2.32E-02	2.45E-02	1.88E-02	3.18E-02	7.04E-02	4.36E-03	9.36E-04	7.48E-04	6.84E-04	6.80E-04	5.72E-03
60%	2.40E-02	2.63E-02	2.11E-02	3.47E-02	7.50E-02	4.55E-03	1.06E-03	8.40E-04	7.70E-04	7.83E-04	5.98E-03
65%	2.52E-02	2.81E-02	2.36E-02	3.69E-02	8.30E-02	4.75E-03	1.26E-03	9.74E-04	8.57E-04	8.55E-04	6.22E-03
70%	2.63E-02	2.98E-02	2.64E-02	3.97E-02	8.92E-02	4.98E-03	1.45E-03	1.08E-03	9.36E-04	9.31E-04	6.50E-03
75%	2.78E-02	3.21E-02	3.03E-02	4.22E-02	1.00E-01	5.27E-03	1.70E-03	1.21E-03	1.07E-03	1.06E-03	6.81E-03
80%	2.99E-02	3.50E-02	3.42E-02	4.58E-02	1.10E-01	5.71E-03	2.02E-03	1.39E-03	1.21E-03	1.28E-03	7.21E-03
85%	3.21E-02	3.85E-02	4.12E-02	5.14E-02	1.24E-01	6.23E-03	2.48E-03	1.61E-03	1.42E-03	1.46E-03	7.68E-03
90%	3.42E-02	4.63E-02	5.09E-02	5.75E-02	1.45E-01	6.81E-03	3.14E-03	1.96E-03	1.66E-03	1.69E-03	8.49E-03
95%	3.93E-02	5.62E-02	6.29E-02	6.63E-02	1.80E-01	7.90E-03	4.04E-03	2.54E-03	2.23E-03	2.24E-03	9.62E-03
Maximum	7.19E-02	9.49E-02	1.71E-01	1.26E-01	3.24E-01	1.68E-02	2.00E-02	6.56E-03	6.80E-03	6.59E-03	2.09E-02

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]

Table 6.2-6. Biosphere Dose Conversion Factors Statistics for the Monsoon Climate, rem/yr per pCi/L (continued).

	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	4.04E-03	7.55E-03	7.38E-03	7.20E-03	5.69E-03	7.75E-03
STD	9.60E-04	2.93E-03	2.76E-03	2.83E-03	1.61E-03	3.17E-03
Minimum	2.61E-03	3.12E-03	3.21E-03	3.12E-03	2.97E-03	2.98E-03
5%	2.98E-03	4.25E-03	4.22E-03	3.99E-03	3.71E-03	3.98E-03
10%	3.10E-03	4.60E-03	4.63E-03	4.39E-03	3.99E-03	4.47E-03
15%	3.20E-03	4.94E-03	4.94E-03	4.67E-03	4.18E-03	4.89E-03
20%	3.31E-03	5.25E-03	5.21E-03	4.96E-03	4.40E-03	5.15E-03
25%	3.40E-03	5.49E-03	5.49E-03	5.25E-03	4.56E-03	5.49E-03
30%	3.49E-03	5.81E-03	5.68E-03	5.51E-03	4.71E-03	5.84E-03
35%	3.58E-03	6.14E-03	5.92E-03	5.74E-03	4.85E-03	6.10E-03
40%	3.68E-03	6.36E-03	6.15E-03	6.00E-03	5.01E-03	6.41E-03
45%	3.77E-03	6.64E-03	6.44E-03	6.28E-03	5.20E-03	6.74E-03
50%	3.87E-03	6.92E-03	6.74E-03	6.53E-03	5.36E-03	7.03E-03
55%	3.95E-03	7.17E-03	7.10E-03	6.84E-03	5.54E-03	7.32E-03
60%	4.05E-03	7.46E-03	7.39E-03	7.11E-03	5.75E-03	7.76E-03
65%	4.18E-03	7.86E-03	7.70E-03	7.47E-03	5.98E-03	8.19E-03
70%	4.31E-03	8.28E-03	8.08E-03	7.82E-03	6.20E-03	8.67E-03
75%	4.44E-03	8.87E-03	8.54E-03	8.42E-03	6.50E-03	9.19E-03
80%	4.64E-03	9.41E-03	9.18E-03	8.90E-03	6.85E-03	9.78E-03
85%	4.83E-03	1.01E-02	9.83E-03	9.70E-03	7.20E-03	1.08E-02
90%	5.07E-03	1.10E-02	1.09E-02	1.08E-02	7.64E-03	1.21E-02
95%	5.56E-03	1.30E-02	1.29E-02	1.30E-02	8.89E-03	1.38E-02
Maximum	1.40E-02	2.65E-02	2.29E-02	2.20E-02	1.46E-02	2.27E-02

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: STD = standard deviation. See Excel file *BDCF Realizations for Groundwater MC and FC.xls* in Attachments I and II for details of calculations.

Table 6.2-7. Biosphere Dose Conversion Factors Statistics for the Glacial Transition Climate, rem/yr per pCi/L.

	^{14}C	^{36}C	^{79}Se	^{90}Sr	^{99}Tc	^{126}Sn	^{129}I	^{135}Cs	^{137}Cs	^{210}Pb	^{226}Ra
Mean	8.73E-06	1.65E-05	5.19E-05	1.52E-04	2.03E-06	4.68E-03	3.12E-04	4.39E-05	3.74E-04	8.16E-03	7.34E-02
STD	6.04E-06	2.29E-05	1.06E-04	2.02E-05	1.32E-06	3.02E-03	9.74E-05	3.08E-05	2.02E-04	2.64E-03	3.64E-02
Minimum	4.04E-06	3.01E-06	9.09E-06	1.21E-04	1.15E-06	1.15E-04	2.17E-04	8.71E-06	1.22E-04	5.56E-03	2.01E-03
5%	4.58E-06	4.30E-06	1.27E-05	1.29E-04	1.25E-06	8.20E-04	2.32E-04	1.51E-05	1.72E-04	5.96E-03	2.79E-02
10%	4.86E-06	4.93E-06	1.47E-05	1.31E-04	1.30E-06	1.41E-03	2.38E-04	1.81E-05	1.92E-04	6.12E-03	3.43E-02
15%	5.08E-06	5.46E-06	1.66E-05	1.34E-04	1.33E-06	1.83E-03	2.45E-04	2.04E-05	2.11E-04	6.26E-03	3.91E-02
20%	5.31E-06	5.88E-06	1.80E-05	1.37E-04	1.37E-06	2.30E-03	2.49E-04	2.28E-05	2.24E-04	6.40E-03	4.34E-02
25%	5.49E-06	6.45E-06	1.95E-05	1.38E-04	1.40E-06	2.59E-03	2.55E-04	2.46E-05	2.41E-04	6.51E-03	4.71E-02
30%	5.71E-06	7.04E-06	2.10E-05	1.40E-04	1.45E-06	2.90E-03	2.61E-04	2.64E-05	2.55E-04	6.63E-03	5.07E-02
35%	5.92E-06	7.59E-06	2.26E-05	1.42E-04	1.49E-06	3.25E-03	2.66E-04	2.86E-05	2.70E-04	6.76E-03	5.46E-02
40%	6.14E-06	8.36E-06	2.47E-05	1.44E-04	1.53E-06	3.54E-03	2.73E-04	3.06E-05	2.89E-04	6.90E-03	5.84E-02
45%	6.41E-06	9.04E-06	2.70E-05	1.46E-04	1.56E-06	3.75E-03	2.79E-04	3.24E-05	3.06E-04	7.11E-03	6.23E-02
50%	6.70E-06	1.01E-05	2.90E-05	1.47E-04	1.61E-06	4.07E-03	2.86E-04	3.43E-05	3.23E-04	7.29E-03	6.63E-02
55%	7.11E-06	1.08E-05	3.19E-05	1.50E-04	1.66E-06	4.29E-03	2.92E-04	3.64E-05	3.41E-04	7.53E-03	7.06E-02
60%	7.48E-06	1.24E-05	3.49E-05	1.52E-04	1.73E-06	4.58E-03	3.00E-04	3.94E-05	3.61E-04	7.82E-03	7.58E-02
65%	8.03E-06	1.39E-05	3.84E-05	1.55E-04	1.82E-06	4.98E-03	3.12E-04	4.34E-05	3.83E-04	8.09E-03	8.05E-02
70%	8.61E-06	1.56E-05	4.37E-05	1.57E-04	1.94E-06	5.59E-03	3.21E-04	4.78E-05	4.04E-04	8.44E-03	8.56E-02
75%	9.52E-06	1.80E-05	4.96E-05	1.60E-04	2.09E-06	6.09E-03	3.33E-04	5.28E-05	4.40E-04	8.93E-03	9.24E-02
80%	1.04E-05	2.15E-05	5.81E-05	1.66E-04	2.28E-06	6.81E-03	3.50E-04	6.01E-05	4.81E-04	9.39E-03	1.01E-01
85%	1.19E-05	2.60E-05	6.83E-05	1.71E-04	2.67E-06	7.82E-03	3.73E-04	6.73E-05	5.34E-04	1.01E-02	1.10E-01
90%	1.45E-05	3.28E-05	9.13E-05	1.78E-04	3.10E-06	8.76E-03	4.09E-04	7.92E-05	6.08E-04	1.11E-02	1.24E-01
95%	2.00E-05	4.69E-05	1.49E-04	1.88E-04	4.01E-06	1.10E-02	4.64E-04	1.02E-04	7.56E-04	1.34E-02	1.45E-01
Maximum	6.04E-05	3.24E-04	2.36E-03	2.74E-04	1.81E-05	1.84E-02	1.33E-03	2.60E-04	1.79E-03	2.83E-02	2.53E-01

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]

Table 6.2-7. Biosphere Dose Conversion Factors Statistics for the Glacial Transition Climate, rem/yr per pCi/L (continued).

	^{227}Ac	^{229}Th	^{230}Th	^{232}Th	^{231}Pa	^{232}U	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np
Mean	2.32E-02	2.51E-02	2.19E-02	3.33E-02	7.58E-02	4.33E-03	1.31E-03	9.11E-04	8.19E-04	8.20E-04	5.90E-03
STD	7.45E-03	1.36E-02	1.88E-02	1.77E-02	4.88E-02	1.67E-03	1.54E-03	7.80E-04	6.64E-04	6.56E-04	1.76E-03
Minimum	1.23E-02	4.98E-03	9.09E-04	6.33E-03	1.10E-02	1.72E-03	2.34E-04	2.23E-04	2.11E-04	2.12E-04	3.54E-03
5%	1.44E-02	9.83E-03	3.95E-03	1.30E-02	2.41E-02	2.26E-03	2.95E-04	2.77E-04	2.65E-04	2.64E-04	3.98E-03
10%	1.54E-02	1.15E-02	5.40E-03	1.53E-02	2.92E-02	2.55E-03	3.30E-04	3.17E-04	2.93E-04	2.86E-04	4.14E-03
15%	1.63E-02	1.27E-02	6.70E-03	1.73E-02	3.34E-02	2.74E-03	3.70E-04	3.51E-04	3.24E-04	3.14E-04	4.32E-03
20%	1.69E-02	1.40E-02	7.67E-03	1.90E-02	3.71E-02	2.93E-03	4.05E-04	3.79E-04	3.57E-04	3.43E-04	4.48E-03
25%	1.76E-02	1.53E-02	8.86E-03	2.07E-02	4.11E-02	3.08E-03	4.47E-04	4.08E-04	3.85E-04	3.77E-04	4.61E-03
30%	1.83E-02	1.68E-02	9.93E-03	2.27E-02	4.54E-02	3.28E-03	4.98E-04	4.40E-04	4.13E-04	4.06E-04	4.81E-03
35%	1.89E-02	1.79E-02	1.13E-02	2.38E-02	4.92E-02	3.48E-03	5.54E-04	4.80E-04	4.44E-04	4.38E-04	4.97E-03
40%	1.97E-02	1.92E-02	1.27E-02	2.53E-02	5.36E-02	3.66E-03	6.21E-04	5.18E-04	4.80E-04	4.92E-04	5.12E-03
45%	2.06E-02	2.05E-02	1.46E-02	2.73E-02	5.78E-02	3.79E-03	6.97E-04	5.77E-04	5.44E-04	5.37E-04	5.29E-03
50%	2.13E-02	2.22E-02	1.58E-02	2.93E-02	6.25E-02	3.96E-03	7.67E-04	6.48E-04	5.97E-04	6.09E-04	5.47E-03
55%	2.26E-02	2.37E-02	1.77E-02	3.09E-02	6.78E-02	4.17E-03	8.81E-04	7.07E-04	6.67E-04	6.61E-04	5.70E-03
60%	2.37E-02	2.50E-02	1.94E-02	3.28E-02	7.33E-02	4.43E-03	1.05E-03	8.05E-04	7.38E-04	7.31E-04	5.98E-03
65%	2.47E-02	2.69E-02	2.15E-02	3.53E-02	7.90E-02	4.67E-03	1.21E-03	8.88E-04	8.17E-04	8.26E-04	6.14E-03
70%	2.58E-02	2.88E-02	2.59E-02	3.78E-02	8.67E-02	4.91E-03	1.41E-03	1.03E-03	9.21E-04	8.99E-04	6.33E-03
75%	2.71E-02	3.11E-02	2.87E-02	4.10E-02	9.83E-02	5.18E-03	1.67E-03	1.16E-03	1.03E-03	1.05E-03	6.59E-03
80%	2.87E-02	3.43E-02	3.37E-02	4.53E-02	1.07E-01	5.60E-03	1.97E-03	1.31E-03	1.18E-03	1.21E-03	6.95E-03
85%	3.08E-02	3.82E-02	3.99E-02	5.04E-02	1.21E-01	5.98E-03	2.27E-03	1.54E-03	1.37E-03	1.39E-03	7.45E-03
90%	3.28E-02	4.29E-02	4.75E-02	5.75E-02	1.39E-01	6.49E-03	2.81E-03	1.86E-03	1.60E-03	1.64E-03	8.20E-03
95%	3.78E-02	5.20E-02	6.19E-02	6.80E-02	1.72E-01	7.41E-03	3.71E-03	2.41E-03	2.07E-03	2.05E-03	9.59E-03
Maximum	6.71E-02	1.08E-01	1.44E-01	1.36E-01	3.35E-01	1.35E-02	1.99E-02	7.93E-03	6.37E-03	5.88E-03	1.76E-02

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]

Table 6.2-7. Biosphere Dose Conversion Factors Statistics for the Glacial Transition Climate, rem/yr per pCi/L (continued).

	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
Mean	3.93E-03	7.35E-03	7.19E-03	7.09E-03	5.57E-03	7.45E-03
STD	8.77E-04	2.89E-03	2.70E-03	2.74E-03	1.52E-03	2.93E-03
Minimum	2.61E-03	3.34E-03	3.28E-03	2.95E-03	2.98E-03	2.95E-03
5%	2.99E-03	4.24E-03	4.13E-03	3.98E-03	3.74E-03	4.01E-03
10%	3.10E-03	4.53E-03	4.55E-03	4.35E-03	3.98E-03	4.46E-03
15%	3.20E-03	4.80E-03	4.83E-03	4.66E-03	4.16E-03	4.79E-03
20%	3.27E-03	5.10E-03	5.12E-03	4.90E-03	4.31E-03	5.08E-03
25%	3.35E-03	5.41E-03	5.31E-03	5.16E-03	4.48E-03	5.35E-03
30%	3.44E-03	5.64E-03	5.58E-03	5.37E-03	4.63E-03	5.58E-03
35%	3.50E-03	5.87E-03	5.86E-03	5.66E-03	4.78E-03	5.86E-03
40%	3.57E-03	6.19E-03	6.10E-03	5.97E-03	4.94E-03	6.16E-03
45%	3.65E-03	6.45E-03	6.35E-03	6.23E-03	5.08E-03	6.48E-03
50%	3.74E-03	6.73E-03	6.63E-03	6.48E-03	5.25E-03	6.84E-03
55%	3.84E-03	7.04E-03	6.93E-03	6.74E-03	5.42E-03	7.06E-03
60%	3.93E-03	7.26E-03	7.18E-03	7.07E-03	5.62E-03	7.42E-03
65%	4.03E-03	7.54E-03	7.51E-03	7.40E-03	5.82E-03	7.85E-03
70%	4.17E-03	7.86E-03	7.80E-03	7.83E-03	6.10E-03	8.35E-03
75%	4.30E-03	8.35E-03	8.24E-03	8.17E-03	6.40E-03	8.94E-03
80%	4.42E-03	8.99E-03	8.76E-03	8.64E-03	6.60E-03	9.61E-03
85%	4.64E-03	9.86E-03	9.57E-03	9.65E-03	6.97E-03	1.04E-02
90%	4.94E-03	1.11E-02	1.06E-02	1.07E-02	7.46E-03	1.13E-02
95%	5.48E-03	1.32E-02	1.24E-02	1.27E-02	8.55E-03	1.32E-02
Maximum	1.21E-02	2.72E-02	2.24E-02	2.33E-02	1.39E-02	2.60E-02

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: STD = standard deviation. See Excel file *BDCF Realizations for Groundwater MC and FC.xls* in Attachments I and II for details of calculations.

Some of the BDCFs for the groundwater scenario are correlated (Table 6.2-8). To show correlations between the BDCFs, rank correlation coefficients for modern climate BDCFs were calculated for selected radionuclides. These calculations were done using Excel (*Correlations for Groundwater BDCFs MC.xls*; Attachments I and II). Certain correlation coefficients in Table 6.2-8 are shown as zero. The lack of correlation was determined by performing a statistical test on the correlation coefficients. The null hypothesis was that the (true) population correlation coefficient is zero. If the calculated value of the correlation coefficient for the sampling distribution is r, values of t can be calculated as

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

where n is the number of data points in the sampling distribution (i.e., 1,000). The t-values then can be compared with Student's t-values for $n - 2$ degrees of freedom (Steel and Torrie 1980 [DIRS 150857], pp. 278 to 279). Values of t calculated for different values of r are listed in Table 6.2-9. The null hypothesis that the population correlation coefficient is equal to zero (no correlation) can be rejected at the 99 percent confidence level if the value of t is less than 2.576 (Lide and Frederikse 1997 [DIRS 103178], p. A-105) because the one-tail area under the probability distribution function for t is equal to 0.995 for $t = 2.576$.) This corresponds to the value of r equal to 0.0813. The distribution of t approaches a normal distribution when the degrees of freedom are large, which is the case here. Thus, for correlation coefficients less than 0.0813, the value is set to zero in Table 6.2-8.

Table 6.2-8. Rank Correlation Coefficients for the Modern Climate Biosphere Dose Conversion Factors for Individual Radionuclides

	^{14}C	^{36}Cl	^{79}Se	^{90}Sr	^{99}Tc	^{126}Sn	^{129}I	^{135}Cs	^{137}Cs	^{210}Pb	^{226}Ra	^{227}Ac	^{229}Th	^{230}Th
^{14}C	1.000													
^{36}Cl	0.091	1.000												
^{79}Se	0.086	0.273	1.000											
^{90}Sr	0.140	0.382	0.214	1.000										
^{99}Tc	0	0.519	0.268	0.455	1.000									
^{126}Sn	0	0.218	0.214	0.162	0.226	1.000								
^{129}I	0.095	0.303	0.281	0.417	0.418	0.140	1.000							
^{135}Cs	0.151	0.110	0.113	0.220	0	0.161	0.115	1.000						
^{137}Cs	0.150	0.082	0	0.345	0	0	0.105	0.711	1.000					
^{210}Pb	0.120	0	0	0.196	0	0	0.103	0.199	0.221	1.000				
^{226}Ra	0	0	0.175	0.153	0.086	0.427	0	0.233	0.175	0	1.000			
^{227}Ac	0	0	0	0.132	0	0	0	0	0.148	0	0	1.000		
^{229}Th	0	0	0.165	0.097	0.086	0.358	0	0.126	0	0	0.405	0.358	1.000	
^{230}Th	0	0.095	0.227	0	0.099	0.456	0	0.205	-0.116	0	0.693	0	0.680	1.000
^{232}Th	0	0.095	0.227	0	0.099	0.456	0	0.205	-0.116	0	0.693	0	0.680	1.000
^{231}Pa	0	0.109	0.151	0	0.109	0.372	0	0.140	0	0	0.415	0.213	0.755	0.542
^{232}U	0	0.095	0.168	0.090	0.102	0.388	0	0.141	0	0	0.436	0.304	0.936	0.651
^{233}U	0	0.174	0.155	0.101	0.195	0.136	0.083	0	0	0	0.139	0.296	0.318	0.252
^{234}U	0	0.166	0.141	0.113	0.186	0.109	0.086	0	0	0	0.133	0.371	0.292	0.196
^{236}U	0	0.163	0.134	0.120	0.184	0.098	0.086	0	0	0	0.116	0.394	0.289	0.166
^{238}U	0	0.166	0.135	0.121	0.188	0.099	0.089	0	0	0	0.117	0.377	0.277	0.165
^{237}Np	0	0.399	0.244	0.314	0.389	0.210	0.254	0.118	0	0	0.110	0.501	0.380	0.177
^{238}Pu	0	0	0	0.237	0	0.096	0.117	0	0.257	0	0.140	0.773	0.478	0
^{239}Pu	0	0.088	0.175	0.132	0.121	0.379	0.104	0.172	0	0	0.427	0.361	0.813	0.544
^{240}Pu	0	0.087	0.173	0.139	0.122	0.372	0.106	0.169	0	0	0.421	0.377	0.813	0.527
^{242}Pu	0	0.088	0.176	0.129	0.121	0.381	0.103	0.172	0	0	0.429	0.356	0.813	0.550
^{241}Am	0	0.103	0	0.230	0.159	0.229	0.132	0.112	0.171	0	0.276	0.549	0.662	0.239
^{243}Am	0	0.117	0.112	0.132	0.163	0.334	0.106	0.139	0	0	0.367	0.311	0.689	0.455

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: See Excel file *Correlations for Groundwater BDCFs MC.xls* in Attachments I and II for details of calculations.

Table 6.2-8. Rank Correlations (Correlation Coefficients) Between the External Exposure/Ingestion/Radon BDCF Components for Individual Radionuclides

	^{232}Th	^{231}Pa	^{232}U	^{233}U	^{234}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu	^{242}Pu	^{241}Am	^{243}Am
^{14}C														
^{36}Cl														
^{79}Se														
^{90}Sr														
^{99}Tc														
^{126}Sn														
^{129}I														
^{135}Cs														
^{137}Cs														
^{210}Pb														
^{226}Ra														
^{227}Ac														
^{229}Th														
^{230}Th														
^{232}Th	1.000													
^{231}Pa	0.542	1.000												
^{232}U	0.651	0.936	1.000											
^{233}U	0.252	0.251	0.304	1.000										
^{234}U	0.196	0.229	0.278	0.990	1.000									
^{236}U	0.166	0.227	0.276	0.984	0.998	1.000								
^{238}U	0.165	0.217	0.264	0.986	0.998	0.999	1.000							
^{237}Np	0.177	0.328	0.377	0.333	0.354	0.362	0.354	1.000						
^{238}Pu	0.019	0.358	0.444	0.238	0.296	0.318	0.302	0.468	1.000					
^{239}Pu	0.544	0.771	0.844	0.312	0.303	0.305	0.292	0.421	0.609	1.000				
^{240}Pu	0.527	0.768	0.843	0.312	0.305	0.307	0.294	0.426	0.630	0.999	1.000			
^{242}Pu	0.550	0.772	0.845	0.313	0.303	0.304	0.291	0.419	0.600	1.000	0.999	1.000		
^{241}Am	0.239	0.608	0.676	0.290	0.313	0.328	0.314	0.448	0.642	0.674	0.685	0.670	1.000	
^{243}Am	0.455	0.675	0.726	0.295	0.288	0.288	0.278	0.372	0.414	0.694	0.695	0.694	0.907	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]

NOTE: See Excel file *Correlations for Groundwater BDCFs MC.xls* in Attachments I and II for details of calculations.

Table 6.2-9. 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

NOTE: See Excel file *Correlations for Groundwater BDCFs MC.xls* in Attachments I and II for details of calculations.

6.2.4 TSPA Use of Biosphere Dose Conversion Factors

The assessment of annual doses will be carried out in the TSPA model, which uses BDCFs as input parameters. The TSPA model calculates annual fluxes of individual radionuclides at a specified distance from the repository, which, when divided by the annual water demand, yield radionuclide concentrations in the groundwater used by the receptor. The total annual dose is the sum of the annual doses from the 28 radionuclides tracked in the TSPA model. The total annual dose is calculated (BSC 2003 [DIRS 164186], Sections 6.4.10.2 and 6.4.10.4) as

$$D_{total}(t) = \sum_i BDCF_i \times Cw_i(t) \qquad \text{(Eq. 6.2-5)}$$

where

$D_{total}(t)$ = time-dependent total annual dose to a defined receptor resulting from the release of radionuclides from the repository; includes contributions from all radionuclides considered in the TSPA-LA (mrem/y)

$BDCF_i$ = biosphere dose conversion factor for radionuclide *i* (mrem/yr) per (pCi/L)

$Cw_i(t)$ = time dependent activity concentration of radionuclide *i* in the groundwater (pCi/L).

Equation 6.2-5 is based on a linear relationship between groundwater concentrations and dose. The BDCFs are calculated for constant activity concentration of radionuclides in the soil, which occurs after the saturation concentration of radionuclides in soil has been reached. Saturation conditions are reached if irrigation is sustained for a sufficiently long period of time, which varies among radionuclides from years to thousands of years, depending on the effective removal rate of the radionuclide from soil.

Some radionuclides, such as isotopes of thorium, plutonium, and americium, have low removal rates from soils. These radionuclides build up slowly in the soil and it may take on the order of thousands of years to reach saturation concentrations. In the event that equilibrium conditions for a radionuclide have not been reached and groundwater concentrations are increasing, this assumption will result in overestimating the dose for that radionuclide (BSC 2003 164186], Section 5.1). If concentrations in groundwater are decreasing, the dose may be underestimated (BSC 2003 164186], Section 5.1). However, it is unlikely that groundwater concentrations will decrease until long after the period of 20,000 years used for the TSPA. The annual dose for a point in time, *t*, is calculated using the activity concentration in water at time *t*, *Cw(t)*. The product of the radionuclide concentration and the BDCF represents the dose that would prevail if the radionuclide concentration in water, *Cw(t)*, persisted prior to time *t* long enough for this radionuclide to reach saturation in the soil.

6.2.5 Pathway Analysis

Pathway analysis was conducted to determine the relative importance of individual exposure pathways in terms of contributions to BDCFs for various radionuclides. The biosphere model explicitly addresses 15 exposure pathways, and percent contributions to the BDCF were calculated using the mean values of the BDCFs. The results for the modern climate BDCFs are presented in Table 6.2-10. These calculations were performed using Excel (*Groundwater BDCF Pathway Analysis.xls*; Attachments I and II).

Pathway contributions differ among radionuclides. Inhalation of particulate matter tends to dominate doses for actinides (e.g., isotopes of thorium, uranium, plutonium, and americium). Inhalation of radioactive aerosols generated by evaporative coolers also is an important inhalation exposure pathway for these radionuclides. Ingestion of water is a consistently high contributor to dose. Other pathways are only important for a few radionuclides. For instance, external exposure is a dominant pathway for ^{126}Sn and ^{137}Cs, inhalation of radon decay products for ^{226}Ra and ^{230}Th, and fish consumption for isotopes of cesium, ^{210}Pb, and ^{237}Np. Consumption pathways generally are more important for radionuclides with atomic numbers less than about 88.

For the future climate, the importance of the evaporative cooler pathway is greatly reduced, and for most radionuclides, the inhalation of particulate matter and the consumption of water are dominant pathways (Table 6.2-11). These calculations were performed using Excel (*Groundwater BDCF Pathway Analysis FC.xls*; Attachments I and II).

Table 6.2-10. Exposure Pathway Contributions (Percent) for the Modern Climate Biosphere Dose Conversion Factors

RN	External exposure	Inhalation			Ingestion										
		Particul. Matter	Evap. Cooler	Radon	Water	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs	Fish	Soil
^{14}C	0.0	0.0	0.0	0.0	16.8	2.8	5.0	13.1	0.6	7.1	3.4	0.6	5.5	45.1	0.0
^{36}Cl	0.1	0.0	0.2	0.0	11.3	3.4	5.0	17.6	2.6	23.7	19.1	0.0	4.8	12.0	0.0
^{79}Se	0.0	0.1	0.0	0.0	9.8	0.7	0.5	1.7	0.1	56.4	3.0	1.9	21.6	3.7	0.6
^{90}Sr	0.5	0.1	0.3	0.0	68.2	6.8	3.7	6.1	0.6	2.9	3.6	0.0	1.6	5.2	0.4
^{99}Tc	0.0	0.0	0.7	0.0	48.3	11.0	2.2	8.2	0.5	4.5	11.9	0.1	10.8	1.6	0.0
^{126}Sn	98.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.0	0.0
^{129}I	0.1	0.1	0.1	0.0	59.8	2.6	0.7	3.0	0.4	5.0	7.4	0.2	14.6	5.3	0.8
^{135}Cs	0.0	0.1	0.0	0.0	9.2	1.7	0.9	4.0	0.2	10.1	5.8	7.7	3.3	55.9	1.1
^{137}Cs	42.2	0.0	0.0	0.0	7.5	0.4	0.1	0.5	0.0	1.7	0.9	0.8	0.4	45.4	0.1
^{210}Pb	0.0	0.2	0.5	0.0	58.8	2.5	0.6	2.3	0.3	0.3	0.2	0.0	1.3	32.6	0.4
^{226}Ra	6.8	0.3	0.0	89.3	1.0	0.3	0.1	0.6	0.0	0.1	0.1	0.0	0.7	0.1	0.6
^{227}Ac	0.3	16.4	42.8	0.0	34.8	1.4	0.3	1.2	0.1	0.1	0.0	0.0	0.0	2.3	0.2
^{229}Th	3.1	71.5	12.6	0.0	8.7	0.5	0.1	0.4	0.0	0.1	0.0	0.0	0.1	1.9	0.9
^{230}Th	5.7	13.6	2.2	74.3	1.4	0.3	0.1	0.5	0.0	0.1	0.1	0.0	0.6	0.3	0.6
^{232}Th	25.2	53.4	8.9	0.0	8.2	0.7	0.2	0.6	0.1	0.1	0.1	0.0	0.0	1.6	0.9
^{231}Pa	1.3	84.5	2.6	0.0	7.8	0.6	0.2	0.8	0.1	0.1	0.0	0.0	0.0	0.2	1.8
^{232}U	12.4	20.0	34.2	0.0	26.8	1.1	0.3	0.9	0.1	0.1	0.1	0.2	0.8	2.8	0.3
^{233}U	1.4	66.4	15.3	0.0	12.1	0.7	0.2	0.6	0.1	0.1	0.1	0.3	1.6	0.4	0.9
^{234}U	0.4	50.2	21.5	4.8	17.1	0.8	0.2	0.8	0.1	0.1	0.1	0.4	2.2	0.5	0.7
^{236}U	0.0	52.7	22.9	0.0	18.1	0.9	0.2	0.8	0.1	0.1	0.2	0.4	2.3	0.6	0.8
^{238}U	3.8	49.9	21.7	0.0	18.2	0.9	0.2	0.8	0.1	0.1	0.2	0.4	2.4	0.6	0.8
^{237}Np	2.6	21.8	15.4	0.0	46.9	2.6	1.0	4.3	0.2	0.8	0.0	0.0	0.0	3.1	1.2
^{238}Pu	0.0	20.2	16.5	0.0	50.0	2.1	0.5	1.8	0.2	0.0	0.0	0.0	0.0	7.4	1.1
^{239}Pu	0.0	52.1	9.2	0.0	28.2	1.5	0.3	1.3	0.2	0.0	0.0	0.0	0.1	4.2	2.9
^{240}Pu	0.0	51.1	9.5	0.0	28.9	1.5	0.3	1.3	0.2	0.0	0.0	0.0	0.1	4.3	2.8
^{242}Pu	0.0	52.6	9.2	0.0	27.8	1.5	0.3	1.3	0.1	0.0	0.0	0.0	0.1	4.1	2.9
^{241}Am	0.1	37.8	12.9	0.0	39.2	1.8	0.4	1.6	0.2	0.1	0.0	0.0	0.0	3.7	2.1
^{243}Am	5.6	48.4	9.2	0.0	28.1	1.5	0.3	1.3	0.1	0.1	0.0	0.0	0.0	2.6	2.7

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: See Excel file *Groundwater BDCFs Pathway Analysis.xls* in Attachments I and II for details of calculations.

Table 6.2-11. Exposure Pathway Contributions (Percent) for the Upper Bound of Glacial Transition Climate Biosphere Dose Conversion Factors

RN	External exposure	Inhalation			Ingestion										
		Particul. Matter	Evap. Cooler	Radon	Water	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs	Fish	Soil
^{14}C	0.0	0.0	0.0	0.0	18.0	2.9	3.7	10.1	0.7	6.4	3.1	0.7	6.2	48.2	0.0
^{36}Cl	0.1	0.0	0.1	0.0	15.2	3.3	4.9	17.4	2.7	23.4	18.8	0.0	4.8	9.3	0.0
^{79}Se	0.0	0.1	0.0	0.0	15.0	0.7	0.4	1.5	0.1	53.8	2.9	1.7	20.0	3.3	0.5
^{90}Sr	0.3	0.1	0.1	0.0	78.4	4.9	2.4	3.9	0.5	2.0	2.5	0.0	1.2	3.4	0.2
^{99}Tc	0.0	0.0	0.2	0.0	56.4	9.5	1.8	7.0	0.5	3.7	9.8	0.1	9.9	1.1	0.0
^{126}Sn	97.9	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	1.0	0.0
^{129}I	0.1	0.1	0.0	0.0	69.0	2.1	0.5	2.0	0.3	3.9	5.7	0.1	12.1	3.5	0.6
^{135}Cs	0.0	0.1	0.0	0.0	15.1	1.6	0.8	3.6	0.2	9.4	5.3	7.0	3.0	53.0	1.0
^{137}Cs	37.9	0.0	0.0	0.0	12.6	0.4	0.1	0.4	0.0	1.7	1.0	0.9	0.4	44.2	0.1
^{210}Pb	0.0	0.1	0.1	0.0	71.1	2.2	0.4	1.4	0.2	0.2	0.1	0.0	1.1	22.7	0.3
^{226}Ra	6.1	0.3	0.0	89.6	1.7	0.3	0.1	0.5	0.0	0.1	0.1	0.0	0.6	0.1	0.5
^{227}Ac	0.3	15.5	16.5	0.0	61.6	1.8	0.3	1.1	0.2	0.1	0.0	0.0	0.0	2.3	0.2
^{229}Th	3.1	71.5	5.1	0.0	16.1	0.6	0.1	0.4	0.1	0.1	0.0	0.0	0.1	2.0	0.9
^{230}Th	5.3	12.5	0.8	76.5	2.4	0.3	0.1	0.5	0.0	0.1	0.0	0.0	0.6	0.3	0.6
^{232}Th	24.7	52.5	3.5	0.0	14.9	0.7	0.2	0.6	0.1	0.1	0.1	0.0	0.0	1.6	0.9
^{231}Pa	1.3	80.5	1.0	0.0	13.5	0.7	0.2	0.7	0.1	0.1	0.0	0.0	0.0	0.2	1.8
^{232}U	12.2	19.8	13.3	0.0	47.5	1.4	0.2	0.9	0.2	0.1	0.1	0.2	1.0	2.8	0.3
^{233}U	1.4	66.6	5.8	0.0	21.1	0.8	0.2	0.6	0.1	0.1	0.1	0.3	1.7	0.4	0.9
^{234}U	0.4	49.9	8.2	5.4	29.7	1.0	0.2	0.7	0.1	0.1	0.2	0.4	2.4	0.5	0.7
^{236}U	0.0	52.7	8.7	0.0	31.8	1.1	0.2	0.8	0.1	0.1	0.2	0.4	2.5	0.6	0.8
^{238}U	3.8	49.6	8.2	0.0	31.7	1.1	0.2	0.7	0.1	0.1	0.2	0.4	2.5	0.6	0.8
^{237}Np	2.2	18.2	4.6	0.0	63.7	2.5	0.8	3.6	0.3	0.8	0.0	0.0	0.0	2.4	1.0
^{238}Pu	0.0	15.1	5.0	0.0	69.2	2.1	0.4	1.3	0.2	0.0	0.0	0.0	0.0	5.9	0.8
^{239}Pu	0.0	44.1	3.1	0.0	43.5	1.5	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.7	2.5
^{240}Pu	0.0	43.0	3.2	0.0	44.4	1.6	0.3	1.1	0.2	0.0	0.0	0.0	0.1	3.8	2.4
^{242}Pu	0.0	44.7	3.1	0.0	43.0	1.5	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.7	2.5
^{241}Am	0.1	30.0	4.1	0.0	57.4	1.9	0.3	1.2	0.2	0.1	0.0	0.0	0.0	3.1	1.7
^{243}Am	4.7	40.9	3.1	0.0	43.5	1.5	0.3	1.0	0.2	0.1	0.0	0.0	0.0	2.3	2.3

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: See Excel file *Groundwater BDCFs Pathway Analysis.xls* in Attachments I and II for details of calculations.

6.3 DOSE FACTORS FOR GROUNDWATER PROTECTION STANDARD

The groundwater protection standard (10 CFR 63.331 [DIRS 156605]) prohibits releasing radionuclides from the repository to the accessible environment in excess of the values in Table 6.3-1 in 3,000-acre feet of water (representative volume) (10 CFR 63.332 [DIRS 156605]).

Table 6.3-1 Limits on Radionuclides in the Representative Volume

Radionuclide or type of radiation emitted	Limit	Is natural background included?
Combined radium-226 and radium-228	5 picocuries per liter	Yes
Gross alpha activity (including radium-226 but excluding radon and uranium)	15 picocuries per liter	Yes
Combined beta and photon emitting radionuclides	0.04 mSv (4 mrem) per year to the whole body or any organ, based on drinking 2 liters of water per day from the representative volume	No

Source: 10 CFR 63.331 and 10 CFR 63.332 [DIRS 156605].

Gross alpha particle activity means the total radioactivity due to alpha particle emission as inferred from measurements on a dry sample (40 CFR 141.2 [DIRS 103999]). For this analysis, evaluation of gross alpha activity for consideration in TSPA is based on calculation, rather than measurement, of total alpha emissions from the primary radionuclides and their decay products (Section 6.1.1). The calculation of radionuclide concentrations in water are based on the representative volume, which contains 3,000 acre-feet of water (about 3,714,450,000 liters) (10 CFR 63.332 [DIRS 156605]).

Table 6.3-2 lists primary radionuclides (Section 6.1.1), short-lived decay products, radionuclide emissions, and applicable limits from the groundwater protection standard.

Table 6.3-2. Primary Radionuclides, Decay Products, and Applicable Groundwater Protection Limits

Primary Radionuclide and Mode of Decay		**Short-lived Decay Product and Mode of Decay**		**BF**	**Type and Energy of Radiation (MeV per nuclear transformation)**			**Half-life [a]**	**Applicable Limit**
					Alpha	Electron	Photon		
Carbon-14	β-			1	-	0.049	-	5730 yr	0.04 mSv (4 mrem) per year; β, γ
Chlorine-36	EC β+ β-			1	-	0.274	<	3.01E+05 yr	0.04 mSv (4 mrem) per year; β, γ
Selenium-79	β-			1	-	0.056	-	6.50E+04 yr	0.04 mSv (4 mrem) per year; β, γ
Strontium-90	β-			1	-	0.196	-	29.12 yr	0.04 mSv (4 mrem) per year; β, γ
		Yttrium-90	β-	1	-	0.935	<	64.0 h	0.04 mSv (4 mrem) per year; β, γ
Technetium-99	β-			1	-	0.101	-	2.13E+05 yr	0.04 mSv (4 mrem) per year; β, γ
Tin-126	β-			1	-	0.172	0.057	1.0E+05 yr	0.04 mSv (4 mrem) per year; β, γ
		Antimony-126m	IT β-	1	-	0.591	1.548	19.0 min	0.04 mSv (4 mrem) per year; β, γ
		Antimony-126	β-	0.14	-	0.283	2.834	12.4 d	0.04 mSv (4 mrem) per year; β, γ
Iodine-129	β-			1	-	0.064	0.025	1.57E+07 yr	0.04 mSv (4 mrem) per year; β, γ
Cesium-135	β-			1	-	0.067	-	2.3E+06 yr	0.04 mSv (4 mrem) per year; β, γ
Cesium-137	β-			1	-	0.187	-	30.0 yr	0.04 mSv (4 mrem) per year; β, γ
		Barium-137m	IT	0.946	-	0.065	0.597	2.552 min	0.04 mSv (4 mrem) per year; β, γ
Thorium Series (4n)									
Plutonium-240	SF α			1	5.156	0.011	0.002	6.537E+03 yr	15 pCi/L; α
Uranium-236	α			1	4.505	0.011	0.002	2.3415E+07 yr	excluded
Thorium-232	α			1	3.996	0.012	0.001	1.405E+10 yr	15 pCi/L; α
Radium-228	β-			1	-	0.017	<	5.75E+00 yr	5 pCi/L of Ra-226 + Ra-228 0.04 mSv (4 mrem) per year; β, γ
		Actinium-228	β-	1	-	0.475	0.971	6.13 hr	0.04 mSv (4 mrem) per year; β, γ
Uranium-232	α			1	5.302	0.017	0.002	72 yr	excluded
Thorium-228	α			1	5.400	0.021	0.003	1.9131 yr	15 pCi/L; α
		Radium-224	α	1	5.674	0.002	0.010	3.66 d	15 pCi/L; α
		Radon-220	α	1	6.288	<	<	55.6 s	excluded
		Polonium-216	α	1	6.779	<	<	0.15 s	15 pCi/L; α
		Lead-212	β-	1	-	0.176	0.148	10.64 h	0.04 mSv (4 mrem) per year; β, γ
		Bismuth-212	β- α	1	2.174	0.472	0.186	60.55 min	15 pCi/L; α

Table 6.3-2. Primary Radionuclides, Decay Products, and Applicable Groundwater Protection Limits (Continued)

Primary Radionuclide		Short-lived Decay Product		BF	Type and Energy of Radiation (MeV per nuclear transformation)			Half-life [a]	Applicable Limit
					Alpha	Electron	Photon		
									0.04 mSv (4 mrem) per year; β, γ
		Polonium-212	α	0.6407	8.785	-	-	0.305 µs	15 pCi/L; α
		Thallium-208	β-	0.3593	-	0.598	3.375	3.07 min	0.04 mSv (4 mrem) per year; β, γ
Neptunium Series (4n + 1)									
Americium-241	α			1	5.479	0.052	0.033	432.2 yr	15 pCi/L; α
Neptunium-237	α			1	4.769	0.070	0.035	2.14E+06 yr	15 pCi/L; α
		Protactinium-233	β-	1	-	0.196	0.204	27.0 d	0.04 mSv (4 mrem) per year; β, γ
Uranium-233	α			1	4.817	0.006	0.001	1.585E+05 yr	excluded
Thorium-229	α			1	4.873	0.116	0.096	7340 yr	15 pCi/L; α
		Radium-225	β-	1	-	0.107	0.014	14.8 d	0.04 mSv (4 mrem) per year; β, γ
		Actinium-225	α	1	5.787	0.022	0.018	10.0 d	15 pCi/L; α
		Francium-221	α	1	6.304	0.010	0.031	4.8 min	15 pCi/L; α
		Astatine-217	α	1	7.067	<	<	32.3 ms	15 pCi/L; α
		Bismuth-213	β- α	1	0.126	0.442	0.133	45.65 min	15 pCi/L; α 0.04 mSv (4 mrem) per year; β, γ
		Polonium-213	α	0.9784	8.376	-	-	4.2 µs	15 pCi/L; α
		Thallium-209	β-	0.0216	-	0.688	2.032	2.20 min	0.04 mSv (4 mrem) per year; β, γ
		Lead-209	β-	-	-	0.198	-	3.253 h	0.04 mSv (4 mrem) per year; β, γ
Uranium Series (4n + 2)									
Plutonium-242	SF α			1	4.891	0.009	0.001	3.763E+05 yr	15 pCi/L; α
Uranium-238	SF α			1	4.187	0.010	0.001	4.468E+09 yr	excluded
		Thorium-234	β-	1	-	0.060	0.009	24.10 d	0.04 mSv (4 mrem) per year; β, γ
		Protactinium-234m	β- IT	99.80	-	0.822	0.012	1.17 min	0.04 mSv (4 mrem) per year; β, γ
		Protactinium-234	β-	0.33	-	0.494	1.919	6.70 h	0.04 mSv (4 mrem) per year; β, γ
Plutonium-238	SF α			1	5.487	0.011	0.002	87.74 yr	15 pCi/L; α
Uranium-234	α			1	4.758	0.013	0.002	2.445E+05 yr	excluded
Thorium-230	α			1	4.671	0.015	0.002	7.7E+04 yr	15 pCi/L; α

Table 6.3-2. Primary Radionuclides, Decay Products, and Applicable Groundwater Protection Limits (Continued)

Primary Radionuclide		Short-lived Decay Product		BF	Type and Energy of Radiation (MeV per nuclear transformation)			Half-life [a]	Applicable Limit
					Alpha	Electron	Photon		
Radium-226	α			1	4.774	0.004	0.007	1600 yr	5 pCi/L of Ra-226 + Ra-228 15 pCi/L; α
		Radon-222	α	1	5.489	<	<	3.8235 d	excluded
		Polonium-218	α	1	6.001	<	<	3.05 min	15 pCi/L; α
		Lead-214	β-	0.9998	-	0.293	0.250	26.8 min	0.04 mSv (4 mrem) per year; β, γ
		Astatine-218	α	0.0002	6.697	0.040	0.007	2 s	15 pCi/L; α
		Bismuth-214	β-	1	-	0.659	1.508	19.9 min	15 pCi/L; α 0.04 mSv (4 mrem) per year; β, γ
		Polonium-214	α	0.9998	7.687	<	<	164.3 μs	15 pCi/L; α
		Thallium-210	β-	0.0002	-			1.3 min	0.04 mSv (4 mrem) per year; β, γ
Lead-210	β-			1	-	0.038	0.005	22.3 yr	0.04 mSv (4 mrem) per year; β, γ
		Bismuth-210	β-	1	-	0.389	-	5.012 d	0.04 mSv (4 mrem) per year; β, γ
		Polonium-210	α	1	5.297	<	<	138.38 d	15 pCi/L; α
Actinium Series (4n + 3)									
Americium-243	α			1	5.270	0.022	0.056	7380 yr	15 pCi/L; α
		Neptunium-239	β-	1	-	0.260	0.173	2.355 d	0.04 mSv (4 mrem) per year; β, γ
Plutonium-239	α			1	5.148	0.007	<	2.4065E+04 yr	15 pCi/L; α
Uranium-235	α			1	4.396	0.049	0.156	703.8E6 yr	excluded
		Thorium-231	β-	1	-	0.165	0.026	25.52 hr	0.04 mSv (4 mrem) per year; β, γ
Protactinium-231	α			1	4.969	0.065	0.048	3.276E+04 yr	15 pCi/L; α
Actinium-227	β- α			1	0.068	0.016	<	21.773 yr	15 pCi/L; α 0.04 mSv (4 mrem) per year; β, γ
		Thorium-227	α	0.9862	5.884	0.053	0.110	18.718 d	15 pCi/L; α
		Francium-223	β-	0.0138	-	0.400	0.059	21.8 min	0.04 mSv (4 mrem) per year; β, γ
		Radium-223	α	1	5.667	0.076	0.134	11.434 d	15 pCi/L; α
		Radon-219	α	1	6.757	0.006	0.056	3.96 s	excluded
		Polonium-215	α	1	7.386	<	<	1.78 ms	15 pCi/L; α
		Lead-211	β-	1	-	0.456	0.051	36.1 min	0.04 mSv (4 mrem) per year; β, γ

Table 6.3-2. Primary Radionuclides, Decay Products, and Applicable Groundwater Protection Limits (Continued)

Primary Radionuclide	Short-lived Decay Product		BF	Type and Energy of Radiation (MeV per nuclear transformation)			Half-life [a]	Applicable Limit
				Alpha	Electron	Photon		
	Bismuth-211	α β-	1	6.550	0.010	0.047	2.14 min	15 pCi/L; α
	Thallium-207	β-	0.9972	-	0.493	0.002	4.77 min	0.04 mSv (4 mrem) per year; β, γ
	Polonium-211	α	0.0028	7.442	<	0.008	0.516 s	15 pCi/L; α

Source: Eckerman and Ryman (1993 [DIRS 107684], Table A.1) except for ^{210}Tl for which Lide and Frederikse (1997 [DIRS 103178], p. 11-125) was used

NOTE: Short-lived decay products of primary radionuclides are assumed to be in secular equilibrium with their parents.

BF = branching fraction; EC = electron capture; SF = spontaneous fission; IT = isomeric transformation.

The combined activity concentration of ^{226}Ra and ^{228}Ra in the groundwater is calculated based on the annual mass flux of these radionuclides and the representative volume. The natural background concentrations of ^{226}Ra and ^{228}Ra in groundwater must be included with the calculated activity (10 CFR 63.331 [DIRS 156605]) for comparison to the limit of 5 pCi/L.

For determining alpha activity concentration (including ^{226}Ra but excluding radon and uranium) for comparison with the limit for gross alpha activity of 15 pCi/L, the activity concentration of primary radionuclides in groundwater is calculated based on the annual mass flux of these radionuclides and the representative volume. Alpha particle activity is calculated as the total of alpha emissions from all primary radionuclides and decay products included in the model (Section 6.1.1). Consistent with the approach used in the biosphere model (BSC 2003 [DIRS 164186], Section 5.2), short-lived decay products of a primary radionuclide are assumed to be in secular equilibrium with the primary radionuclide. After the activity concentration of a primary radionuclide in the groundwater is calculated, the value is multiplied by the number of alpha particles included in the decay chain to calculate the total number of alpha particles associated with the decay of the primary radionuclide. The number of alpha particles is shown in Table 6.3-3. For example, if the calculated activity concentration of ^{229}Th in groundwater is 2 pCi/L, the alpha activity associated with the decay of ^{229}Th is 2 pCi/L $\times$ 5 alpha particles per decay = 10 pCi/L. The natural background concentrations of alpha emitters in groundwater (including ^{226}Ra but excluding radon and uranium) (10 CFR 63.331 [DIRS 156605]) must be included in the calculation of alpha activity concentration.

Table 6.3-3. Number of Alpha Particles Emitted per One Decay of a Primary Radionuclide Considered in the Gross Alpha Activity Limit of the Groundwater Protection Standard

Primary Radionuclide		Short-lived Decay Products		Number of Alpha Particles
Thorium Series (4n)				
Plutonium-240	100%			1
Uranium-236 [a]	(100%)			0 [a]
Thorium-232 [b]	100%			1
Uranium-232 [a, c]	(100%)			0 [a]
Thorium-228 [b, c]	100%			4 [a]
		Radium-224	100%	
		Radon-220 [a]	(100%)	
		Polonium-216	100%	
		Bismuth-212	35.93%	
		Polonium-212	64.07%	
Neptunium Series (4n + 1)				
Americium-241	100%			1
Neptunium-237	100%			1
Uranium-233 [a]	(100%)			0
Thorium-229	100%			5
		Actinium-225	100%	
		Francium-221	100%	
		Astatine-217	100%	
		Bismuth-213	2.16%	
		Polonium-213	97.84%	

Table 6.3-3. Number of Alpha Particles Emitted per One Decay of a Primary Radionuclide Considered in the Gross Alpha Activity Limit of the Groundwater Protection Standard (continued)

Primary Radionuclide		Short-lived Decay Products		Number of Alpha Particles
Uranium Series (4n + 2)				
Plutonium-242	100%			1
Uranium-238 [a]	(100%)			0 [a]
Plutonium-238	100%			1
Uranium-234 [a]	(100%)			0 [a]
Thorium-230	100%			1
Radium-226	100%			3
		Radon-222 [a]	(100%)	
		Polonium-218	99.98%	
		Astatine-218	0.02%	
		Bismuth-214	0.02%	
		Polonium-214	99.98%	
Lead-210	β-			1 [b]
		Polonium-210	100%	
Actinium Series (4n + 3)				
Americium-243	100%			1
Plutonium-239	100%			1
Uranium-235 [a]	(100%)			0 [a]
Protactinium-231	100%			1
Actinium-227	1.38%			4 [a]
		Thorium-227	98.62%	
		Radium-223	100%	
		Radon-219 [a]	(100%)	
		Polonium-215	100%	
		Bismuth-211	99.73%	
		Polonium-211	0.273%	

NOTES:

[a] Isotopes of radon and uranium have been excluded, per 10 CFR 63.331 [DIRS 156605].

[b] ^{232}Th is accompanied in the groundwater by its relatively long-lived decay products, ^{228}Ra and ^{228}Th (and their short-lived decay products), which are not being tracked in TSPA. If radioactive equilibrium between ^{232}Th, ^{228}Ra and ^{228}Th is assumed, the number of alpha particles for ^{228}Th should be added to that for ^{232}Th (^{228}Ra and its decay product ^{228}Ac are beta-emitters).

[c] ^{232}U is accompanied in the groundwater by its relatively long-lived decay product, ^{228}Th (and its short-lived decay products). If radioactive equilibrium between ^{232}U and ^{228}Th is assumed, the number of alpha particles for ^{228}Th should be added to that for ^{232}U.

The alpha particle activity concentration in water is calculated as

$$C_\alpha = \sum_i Cw_i \ N_{\alpha,i} \qquad \text{(Eq. 6.3-1)}$$

where

C_α = total alpha particle activity concentration in groundwater

Cw_i = activity concentration of a primary radionuclide i in groundwater (Bq/m^3 or pCi/L)

$N_{\alpha, i}$ = number of alpha particles emitted per one decay of a primary radionuclide *i*

The annual dose limit for beta and photon emitting radionuclides is 0.04 mSv (4 mrem) per year, based on the consumption of 2 liters of water per day (10 CFR 63.331 [DIRS 156605]). This limit applies to radionuclides other than alpha emitters. Alpha emitters are covered under the gross alpha limit of the groundwater protection standard. If a radionuclide decays with emissions of alpha and beta radiation, this analysis considers the radionuclide for both gross alpha and annual dose. This is the case for several radionuclides (Table 6.3-2). Such an approach is conservative and ensures that all types of radiation emitted from a radionuclide are considered.

Dose contributions for beta-photon emitters were calculated using dose conversion factors from *Characteristics of the Receptor for the Biosphere Model* (DTN: MO0306SPACRBSM.001 [DIRS 163813]). These dose conversion factors include contributions from all emissions for each radionuclide. For example, if the fraction of decays of a radionuclide that primarily is a beta emitter undergoes an alpha decay, the dose from alpha particles is included in the dose conversion factor. Radionuclides such as ^{212}Bi that have large fractions of alpha and beta decays are thus "double-counted" (i.e., they are included in the gross alpha component and the dose component to ensure that all radionuclide emissions are counted). Radionuclides classified as alpha-beta emitters (Eckerman and Ryman 1993 [DIRS 107684], Table A.1), with a large fraction of alpha emission (about 99% or more; e.g., ^{218}Po, 99.98% α; ^{211}Bi, 99.73% α), are not included in calculating beta-photon dose.

The annual dose for a given concentration of a primary beta-photon-emitting radionuclide in groundwater is calculated as

$$D_i\,(Sv/yr) = Cw_i\;(Bq/m^3)\;CF_i\left(\frac{Sv/yr}{Bq/L}\right)$$

or (Eq. 6.3-2)

$$D_i\,(mrem/yr) = Cw_i\;(pCi/L)\;CF_i\left(\frac{mrem/yr}{pCi/L}\right)$$

where

D_i = annual dose (committed effective dose equivalent) from intake of radionuclide *i* by ingestion resulting from daily consumption of 2 liters of water (Sv/yr or mrem/yr, depending on the set of units used)

Cw_i = activity concentration of radionuclide *i* in groundwater (Bq/L or pCi/L, depending on the set of units used)

CF_i = conversion factor for calculating beta-photon dose (Sv/yr per Bq/L or mrem/yr per pCi/L, depending on the set of units used).

The conversion factor, *CF*, is numerically equal to the annual dose resulting from daily consumption of 2 liters of water containing a unit activity concentration of a given primary radionuclide and associated short-lived decay products. Conversion factors are calculated as

$$CF_i\left(\frac{Sv/yr}{Bq/m^3}\right) = 2\frac{L}{d}\times 365.25\frac{d}{yr}\times 10^{-3}\,\frac{m^3}{L}\times EDCF_i\left(\frac{Sv}{Bq}\right)$$

or

$$CF_i\left(\frac{mrem/yr}{pCi/L}\right) = 2\frac{L}{d}\times 365.25\frac{d}{yr}\times\frac{3.7\times 10^{-2}\,Bq}{pCi}\times EDCF_i\left(\frac{Sv}{Bq}\right)\times\frac{100\,rem}{Sv}\times\frac{1000\;mrem}{rem}$$

(Eq. 6.3-3)

where

$EDCF_i$ = effective dose conversion factor for ingestion of primary radionuclide *i* (Sv/Bq)

The total dose from beta-gamma emitters in the groundwater water is calculated as

$$D = \sum_i Cw_i\; CF_i \qquad \text{(Eq. 6.3-4)}$$

The effective dose conversion factor for the ingestion of a primary radionuclide includes contributions from dose conversion factors for the short-lived decay products. The effective dose conversion factor is calculated as the sum, or the weighted sum, of the dose conversion factors for a primary radionuclide and the short-lived decay products. Dose conversion factors, effective dose conversion factors, and conversion factors for calculating annual beta-photon dose resulting from consumption of 2 liters of water per day are summarized in Table 6.3-4. The calculations were carried out in Excel (*Conversion Factors for Groundwater Protection Standard.xls*; Attachments I and II).

Table 6.3-4. Conversion Factors for Calculating Annual Beta-Gamma Dose to Demonstrate Compliance with the Groundwater Protection Standard

Primary Radionuclide and Mode of Decay		Short-lived Decay Product and Mode of Decay		DCF [a] Sv/Bq	Effective DCF [b] Sv/Bq	Conversion Factor	
						Sv/y per Bq/L	mrem/y per pCi/L
Carbon-14	β-			5.64E-10	5.64E-10	4.12E-10	1.52E-03
Chlorine-36	EC β+ β-			8.18E-10	8.18E-10	5.98E-10	2.21E-03
Selenium-79	β-			2.35E-09	2.35E-09	1.72E-09	6.35E-03
Strontium-90	β-			3.85E-08	4.14E-08	3.02E-08	1.12E-01
		Yttrium-90	β-	2.91E-09			
Technetium-99	β-			3.95E-10	3.95E-10	2.89E-10	1.07E-03
Tin-126	β-			5.27E-09	5.70E-09	4.16E-09	1.54E-02
		Antimony-126m	IT β-	2.54E-11			
		Antimony-126	β-	2.89E-09			
Iodine-129	β-			7.46E-08	7.46E-08	5.45E-08	2.02E-01
Cesium-135	β-			1.91E-09	1.91E-09	1.40E-09	5.16E-03
Cesium-137	β-			1.35E-08	1.35E-08	9.86E-09	3.65E-02
		Barium-137m	IT	0			
Thorium Series (4n)							
Radium-228 [c]	β-			3.88E-07	3.89E-07	2.84E-07	1.05E+00
		Actinium-228	β-	5.85E-10			
Thorium-228 [c, d]	α			-	1.26E-08	9.20E-09	3.41E-02
		Lead-212	β-	1.23E-08			
		Bismuth-212 [a]	β- α	2.87E-10			
		Thallium-208	β-	0			
Neptunium Series (4n + 1)							
Neptunium-237	α			-	9.81E-10	7.17E-10	2.65E-03
		Protactinium-233	β-	9.81E-10			
Thorium-229	α			-	1.04E-07	7.60E-08	2.81E-01
		Radium-225	β-	1.04E-07			
		Bismuth-213	β- α	1.95E-10			
		Thallium-209	β-	0			
		Lead-209	β-	5.75E-11			
Uranium Series (4n + 2)							
Uranium-238	SF α			-	3.69E-09	2.70E-09	9.97E-03
		Thorium-234	β-	3.69E-09			
		Protactinium-234m	β- IT	0			
		Protactinium-234	β- (0.33%)	5.84E-10			
Radium-226	α			-	2.45E-10	1.79E-10	6.62E-04
		Lead-214	β-	1.69E-10			
		Bismuth-214	β-	7.64E-11			
		Thallium-210	β-	0			
Lead-210	β-			1.45E-06	1.45E-06	1.06E-06	3.92E+00
		Bismuth-210	β-	1.73E-09			

Table 6.3-4. Conversion Factors for Calculating Annual Beta-Gamma Dose to Demonstrate Compliance with the Groundwater Protection Standard (continued)

Primary Radionuclide and Mode of Decay		Short-lived Decay Product and Mode of Decay		DCF [a] Sv/Bq	Effective DCF [b] Sv/Bq	Conversion Factor	
						Sv/y per Bq/L	mrem/y per pCi/L
Actinium Series (4n + 3)							
Americium-243	α			-	8.82E-10	6.44E-10	2.38E-03
		Neptunium-239	β-	8.82E-10			
Actinium-227	β- α			3.80E-06	3.80E-06	2.78E-06	1.03E+01
		Francium-223	β- (1.38%)	2.33E-09			
		Lead-211	β-	1.42E-10			
		Thallium-207	β-	0			

Source: [a] MO0306SPACRBSM.001 [DIRS 163813]

NOTES: [b] Effective dose conversion factors (DCFs) include contributions from short-lived decay products of primary radionuclides, where applicable. The short-lived decay products are assumed to be in secular equilibrium with the parent primary radionuclide.

[c] ^{232}Th is accompanied in the groundwater by its relatively long-lived decay products, ^{228}Ra and ^{228}Th (and their short-lived decay products), which are not being tracked in TSPA. If radioactive equilibrium between ^{232}Th, ^{228}Ra and ^{228}Th is assumed, the beta-gamma dose attributable to ^{232}Th should be calculated by multiplying activity concentration of ^{232}Th in the water by the sum of conversion factors for ^{228}Th and ^{228}Ra (Equation 6.3-2).

[d] ^{232}U is accompanied in the groundwater by its relatively long-lived decay product, ^{228}Th (and its short-lived decay products). If radioactive equilibrium between ^{232}U and ^{228}Th is assumed, the beta-gamma dose attributable to ^{232}U should be calculated by multiplying activity concentration of ^{232}U in the water by the conversion factor for ^{228}Th (Equation 6.3-2).

α β- emitting radionuclides with fraction of alpha of 99% or more (Po-218 99.98% α and Bi-211 99.73% α) are not included in the beta-photon dose.

EC = electron capture, IT = isomeric transformation, SF = spontaneous fission.

^{232}Th is accompanied in the groundwater by its relatively long-lived decay products, ^{228}Ra and ^{228}Th (and their short-lived decay products), which are not primary radionuclides (Section 6.1.1). If radioactive equilibrium between ^{232}Th, ^{228}Ra, and ^{228}Th exists, the beta-gamma dose attributable to ^{232}Th should be calculated by multiplying activity concentration of ^{232}Th in the groundwater by the sum of conversion factors for ^{228}Th and ^{228}Ra (Equation 6.3-2). Similarly, ^{232}U is accompanied in the groundwater by its relatively long-lived decay product, ^{228}Th (and its short-lived decay products). If radioactive equilibrium between ^{232}U and ^{228}Th exists, the beta-gamma dose attributable to ^{232}U should be calculated by multiplying activity concentration of ^{232}U in the groundwater by the conversion factor for ^{228}Th (Equation 6.3-2).

7. CONCLUSIONS

This section contains the summary of recommendations concerning BDCFs for the groundwater exposure scenario and the methods for calculating values for comparison with the groundwater protection standard. The output of this analysis, including the BDCFs as well as the methods and conversion factors supporting calculations for comparison with the groundwater protection standard, are included in the dataset Nominal Performance Biosphere Dose Conversion Factors (DTN: MO0307MWDNPBDC.001).

The applicable acceptance criteria listed in Section 4.2 have been addressed. This report describes the results of biosphere modeling for the groundwater exposure scenario. The acceptance criteria that were considered during development of the model and its input parameters are implicitly included in the modeling results. The results reflect consideration of 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 groundwater 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 IN BIOSPHERE DOSE CONVERSION FACTORS

BDCFs were calculated in a series of biosphere model realizations using a probabilistic approach that allows statistical sampling of parameter values defined by their probability distribution functions. Such an approach provides a quantitative evaluation of the parameter uncertainties and their impacts on the modeling outcome, the BDCFs. Uncertainty in the model outcome is represented by the probability distribution functions of the BDCFs. The BDCFs were developed for three climate states: the modern climate, the monsoon climate, and the glacial transition climate. BDCFs for each climate are in the format of 1,000 row vectors. Rows represent individual model realizations, while the vector elements correspond to the BDCFs for individual radionuclides of interest for a given model realization. The BDCFs were calculated for 28 radionuclides, so each row vector has 28 elements. The full set of BDCFs consists of 84,000 values (3 climate states × 28 radionuclides × 1,000 model realizations). 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.

7.2 BIOSPHERE DOSE CONVERSION FACTORS FOR GROUNDWATER EXPOSURE SCENARIO AND THEIR USE IN TSPA

The full set of BDCFs for the groundwater exposure scenario is included in the dataset Nominal Performance Biosphere Dose Conversion Factors (DTN: MO0307MWDNPBDC.001).

Some BDCFs (radionuclide specific) include contributions from decay products (Section 6.1.1). The primary radionuclides and the decay products, which were included in the BDCF with the primary radionuclides, are presented in Table 7-1.

Table 7-1. Primary Radionuclides and Decay Products Included in the Biosphere Dose Conversion Factors

Primary Radionuclide	Short-lived Decay Products Included in BDCF
^{14}C	
^{36}Cl	
^{79}Se	
^{90}Sr	^{90}Y
^{99}Tc	
^{126}Sn	
^{129}I	
^{135}Cs	
^{137}Cs	^{137m}Ba
^{210}Pb	^{210}Bi, ^{210}Po
^{226}Ra	^{222}Rn, ^{218}Po, ^{214}Pb, ^{218}At, ^{214}Bi, ^{214}Po, ^{210}Tl
^{227}Ac	^{227}Th, ^{223}Fr, ^{223}Ra, ^{219}Rn, ^{215}Po, ^{211}Pb, ^{211}Bi, ^{207}Tl, ^{211}Po
^{229}Th	^{225}Ra, ^{225}Ac, ^{221}Fr, ^{223}At, ^{213}Bi, ^{213}Po, ^{209}Tl, ^{209}Pb
^{230}Th	
^{232}Th	^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl
^{231}Pa	
^{232}U	^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl
^{233}U	
^{234}U	
^{236}U	
^{238}U	^{234}Th, ^{234m}Pa, ^{234}Pa
^{237}Np	^{233}Pa
^{238}Pu	
^{239}Pu	
^{240}Pu	
^{242}Pu	
^{241}Am	
^{243}Am	^{239}Np

The total annual dose is the sum of the annual doses from individual radionuclides. The total annual dose is calculated in TSPA as

$$D_{total}(t) = \sum_i BDCF_i \times Cw_i(t) \qquad \text{(Eq. 7-1)}$$

where

$D_{total}(t)$ = time-dependent total annual dose to a defined receptor resulting from the release of radionuclides from the repository; includes contributions from all radionuclides considered in the TSPA (Sv/y)

$BDCF_i$ = biosphere dose conversion factor for radionuclide *i* (Sv/yr) per (Bq/L)

$Cw_i(t)$ = time dependent activity concentration of radionuclide *i* the groundwater (Bq/m^3).

Equation 7-1 uses a linear relationship between radionuclide concentrations in groundwater and the resulting doses. Calculations of the total dose for a given point in time should use the set of BDCFs corresponding to the climate at that time.

7.3 LIMITATIONS OF BIOSPHERE MODELING

The ERMYN model applies to the specific environments identified in 10 CFR 63.305 [DIRS 156605]. It uses certain assumptions and simplifications. Therefore, the ERMYN model only applies within a certain assessment context (BSC 2003 [DIRS 164186], Section 6.1). The radionuclide sources for the biosphere model are specific to the groundwater exposure scenario. The ERMYN model focuses on the radionuclides that were screened for the TSPA (BSC 2002 [DIRS 160059]). The model applies to assessing chronic radiation doses and is valid for all values of input parameters reasonably expected to occur in the arid to semi-arid region surrounding Yucca Mountain.

For the contaminated groundwater scenario, the ERMYN model applies to an agricultural situation with long-term irrigation and soil contamination at long-term saturation conditions. If soils are not at saturation concentrations of radionuclides, the ERMYN model might overestimate the radiation dose. The biosphere model applies to an arid or semi-arid climate, and it is valid only for limited groundwater discharge to the surface and limited surface water transport, as long as the radionuclide concentration in the surface water is the same as in the groundwater and the reference biosphere is not greatly altered. For example, if permanent surface waters such as rivers or lakes are present, the environment would be sufficiently different to change the reference biosphere, and other pathways would have to be added for the ERMYN model to remain valid.

7.4 PERFORMANCE ASSESSMENT CALCULATIONS FOR GROUNDWATER PROTECTION STANDARD

For calculating activity concentration and dose for comparison with the groundwater protection standard, the methods and the conversion factor values described in Section 6.3 should be used (DTN: MO0307MWDNPBDC.001). Natural background activity concentrations must be added to calculated values for comparison with the combined ^{226}Ra and ^{228}Ra and the gross alpha activity limits. The alpha particle activity concentration in the groundwater should be calculated using Equation 6.3-1 and the number of alpha particles from Table 6.3-3. The beta-gamma dose should be calculated using Equation 6.3-4 and conversion factors from Table 6.3-4.

7.5 CORRELATIONS AND PATHWAY ANALYSIS

Rank correlation coefficients for the groundwater exposure scenario BDCF for individual radionuclides are listed in Table 6.2-8. Correlation coefficients generally are the highest for the isotopes of actinides.

Results of pathway analysis are presented in Tables 6.2-10 and 6.2-11 for the modern climate and the upper bound of the glacial transition climate, respectively. For both climates, inhalation of particulate matter tends to dominate doses for actinides (e.g., isotopes of thorium, uranium, plutonium, and americium). Inhalation of radioactive aerosols generated by evaporative coolers also is an important inhalation exposure pathway for these radionuclides, especially for the modern climate. For the upper bound of the glacial transition climate, the importance of the evaporative cooler pathway is greatly reduced. Ingestion of water is a consistently high contributor to dose for all radionuclides and for both climates. Other pathways are only important for a few radionuclides. For instance, external exposure is a dominant pathway for ^{126}Sn and ^{137}Cs, inhalation of radon decay products for ^{226}Ra and ^{230}Th, and fish consumption for isotopes of cesium, ^{210}Pb, and ^{237}Np. Consumption pathways generally are more important for radionuclides with atomic numbers less than about 88.

8. INPUTS AND REFERENCES

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163813 MO0306SPACRBSM.001. Characteristics of the Receptor for the Biosphere Model. Submittal date: 06/11/2003.

163814 MO0306SPAETPBM.001. Environmental Transport Input Parameters for the Biosphere Model. Submittal date: 06/11/2003.

8.3 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

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103999 40 CFR 141. Protection of Environment: National Primary Drinking Water Regulations. Readily available.

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8.4 ANALYSIS OUTPUT

MO0307MWDNPBDC.001. Nominal Performance Biosphere Dose Conversion Factors. Submittal date: 07/8/2003

ATTACHMENT I

CALCULATION OF BIOSPHERE DOSE CONVERSION FACTORS FOR GROUNDWATER EXPOSURE SCENARIO

This attachment contains descriptions of the EXCEL files that were used for calculations in this analysis.

BDCF Realizations for Groundwater MC and FC.xls–Excel file *BDCF Realizations for Groundwater MC and FC.xls* contains two worksheets: *BDCF Calculations* and *BDCF Values*. The first worksheet contains the results of 1,000 biosphere model realizations for the groundwater exposure scenario from files shown in Figures II-1 and II-2. These realizations generated BDCFs for the modern climate and the upper bound of the glacial transition climate. The worksheet also contains the calculated values of BDCFs for the monsoon and the glacial transition climates. The BDCFs are arranged by radionuclide in columns B to AG for the modern climate (average interglacial) and in columns AJ to BO for the average upper bound of the glacial transition climate. The results of individual model realizations are in rows 31 to 1,030. The values from the modern climate and the upper bound of the glacial transition climate were copied from the GoldSim results summaries and pasted into the worksheet.

Columns BR to CW and rows 31 to 1,030 contain calculated BDCF values for the monsoon climate. Each BDCF value was calculated as

$$BDCF_{MC,i\,j} = BDCF_{UBGT,i,j} + (BDCF_{IC,i,j} - BDCF_{UBGT,i,j})\; RAND(0,1) \qquad \text{(Eq. I-1)}$$

where

$BDCF_{MC,\,i,\,j}$	=	BDCF for model realization *i* and radionuclide *j* for monsoon climate
$BDCF_{UBGT,\,i,\,j}$	=	BDCF for model realization *i* and radionuclide *j* for upper bound of glacial transition climate
$BDCF_{IC,\,i,\,j}$	=	BDCF for model realization *i* and radionuclide *j* for modern (interglacial) climate
$RAND(0,\,1)$	=	random number between 0 and 1.

Columns CZ to EE and rows 31 to 1,030 contain calculated BDCF values for the glacial transition climate. Each BDCF value was calculated as

$$BDCF_{GTC,i\,j} = BDCF_{UBGT,i,j} + (BDCF_{IC,i,j} - BDCF_{UBGT,i,j})\,\frac{0.88-0.50}{0.94-0.50}\,RAND(0,1) \qquad \text{(Eq. I-2)}$$

where

$BDCF_{GTC,\,i,\,j}$	=	BDCF for model realization *i* and radionuclide *j* for glacial transition climate
$BDCF_{UBGT,\,i,\,j}$	=	BDCF for model realization *i* and radionuclide *j* for upper bound of glacial transition climate
$\frac{0.88-0.50}{0.94-0.50}$	=	scaling factor, which is a fraction of the BDCF interval that is being sampled; scaling factor is calculated using the values of average annual irrigation rate for the modern interglacial climate, and lower

and upper bounds of the glacial transition climate, as explained in Section 6.2.2

RAND(0, 1) = random number between 0 and 1.

For all climates, the BDCF values for ^{232}Th and its decay products were calculated by adding the values for ^{232}Th, ^{228}Ra, and ^{228}Th. The BDCF values for ^{232}U and its decay products were calculated by adding the values for ^{232}U and ^{228}Th.

Row 5 contains the means of the values in rows 31 to 1,030 of the corresponding columns, calculated using the Excel AVERAGE function for the specified cell range.

Row 6 contains standard deviations of the values in rows 31 to 1,030 of the corresponding columns, calculated using the Excel STDEV function the specified cell range.

Row 7 contains the minima of the values in rows 31 to 1,030 of the corresponding columns, calculated using the Excel MIN function the specified cell range.

Row 27 contains the maxima of the values in rows 31 to 1,030 of the corresponding columns, calculated using the Excel MAX function the specified cell range.

Rows 8 to 26 contain the percentiles in the increments of 5 of the values in rows 31 to 1,030 of the corresponding columns, calculated using the Excel PERCENTILE function for the specified cell range.

The second worksheet, *BDCF Values*, contains values copied from the first worksheet, *BDCF Calculations*. This was done to stabilize the results of random sampling executed in the first worksheet.

The *BDCF Values* worksheet also contains calculation of the ratio of the mean BDCFs for the modern climate and the upper bound of the glacial transition climate in rows 1039 and 1040.

Correlations for Groundwater BDCFs MC.xls–Excel file *Correlations for Groundwater BDCFs MC.xls* contains calculations of the rank correlation coefficients for groundwater exposure scenario BDCFs for different radionuclides for the modern climate. The BDCF values were copied from files shown in Figure II-1.

The BDCFs and the ranks are arranged by radionuclide in sets of 2 columns per radionuclide in columns B to BI. The BDCF values were taken from the model output. The rank of each BDCF was calculated using the Excel RANK function for the specified range of cells. The BDCF values and the ranks for individual model realizations are in rows 7 to 1,006.

Rows 1,013 to 1,040 and columns C to AD contain the 28 by 28 table of rank correlation coefficients for the BDCFs for 28 primary radionuclides, calculated using the Excel CORREL function for the specified range of cells containing ranks for the BDCFs.

The rows beneath row 1,040 contain supplementary calculations of the Student's *t* values for the range of correlation coefficient values.

Groundwater BDCFs Pathway Analysis.xls and **Groundwater BDCFs Pathway Analysis FC.xls–**Excel files *Groundwater BDCFs Pathway Analysis* and *Groundwater BDCFs Pathway Analysis FC* contain calculations of pathway contributions to BDCFs for the modern climate and upper bound of the glacial transition climate, respectively. The files contains 33 worksheets, a summary and pathway BDCFs for 30 individual radionuclides (28 primary radionuclides plus ^{228}Ra and ^{228}Th) and individual realizations and 2 additional worksheets for ^{232}Th and ^{232}U combined with their long-lived decay products. The first worksheet (*Pathway Summary*) contains the summary of the mean pathway BDCFs, the second to the thirty-third worksheets contain the pathway BDCFs from individual realizations for 32 radionuclides, as well as their mean values. The pathway BDCFs for 1,000 realizations are in rows 10 to 1,009 of each worksheet for an individual radionuclide. The values were copied from GoldSim pathway results summary (files shown in Figures II-1 and II-2) and pasted into the worksheets for the corresponding radionuclides, following each run of the model. Row 6 contains the mean values of BDCFs from individual model realizations (rows 10 to 1,009) calculated using the Excel AVERAGE function.

The *Pathway Summary* worksheet contains the summary of the mean values of pathway BDCFs for the individual radionuclides copied from the radionuclide worksheets (worksheets 2 to 31). These values are in rows 9 to 40 for individual radionuclides, and in columns C to Q for individual exposure pathways. Column S contain the all-pathway BDCF for each radionuclide, which is a sum of individual pathway BDCFs.

Rows 48 to 79 contain the calculated percent values of the individual pathway contributions to the all-pathway BDCF. These values were calculated by dividing the mean pathway BDCFs by the all-pathway BDCF for a given radionuclide. Rows 84 to 111 contain the percent pathway contributions for the primary radionuclides for pasting into the main document.

Correlations for Climate Dependent Parameters.xls–Excel file *Correlations for Climate Dependent Parameters* contains calculations of rank correlations between the climate-dependent parameters and the BDCFs calculated by replacing the values of climate-dependent parameters with uniform distributions between the values for the extreme climates (i.e., for the modern climate and the upper bound of the glacial transition climate). The workbook consists of two worksheets: *Summary* and *Raw Data*. The *Raw Data* worksheet contains the results of sampling of individual climate-dependent model input parameters (there are 18 such parameters) and the ranks. The results are in columns B to AK and rows 39 to 1,038. Columns AM to CX and rows 39 to 1,038 contain BDCF values and ranks for individual radionuclides and model realizations. The BDCFs were generated using modified distributions for climate-dependent parameters, as described in Section 6.2.2. In rows 4 to 33, and in every other column from C to AK, there are values of rank correlation coefficients for the climate-dependent model input parameters and the BDCFs, calculated using the Excel CORREL function. Worksheet *Summary* contains the rank correlation coefficients for the primary radionuclides copied from the worksheet *Raw Data*. They appear in columns C to T and in rows 8 to 35 of the worksheet.

Dependence of BDCFs on Irrigation Rate.xls–Excel file *Dependence of BDCFs on Irrigation Rate* is used to generate graphs showing the linear dependence of BDCFs on annual average irrigation rate. First, the columns containing the sampling results for annual average irrigation rate and the BDCFs for ^{14}C, ^{99}Tc, ^{129}I, and ^{237}Np were copied from file *Correlations for Climate*

Dependent Parameters, worksheet *Raw Data*. The values are in columns C to G of the worksheet. The values then were sorted by average annual irrigation rate. The irrigation rates and the BDCFs were then averaged in groups of 100 (columns K to O, rows 8 to 17). The average values were used to produce four graphs, one for each of the four radionuclides.

Conversion Factors for Groundwater Protection Standard.xls–Excel file *Conversion Factors for Groundwater Protection Standard* contains calculations of conversion factors for demonstrating compliance with the groundwater protection standard. The conversion factors are calculated in units of Sv/yr per Bq/m^3 or in mrem/yr per pCi/L using Equation 6.3-2. The calculations are performed for 18 radionuclides of importance during the compliance period. Column C contains the effective dose conversion factors for ingestion of radionuclides calculated in rows 33 to 111; columns E and F contain the conversion factors for the two sets of units.

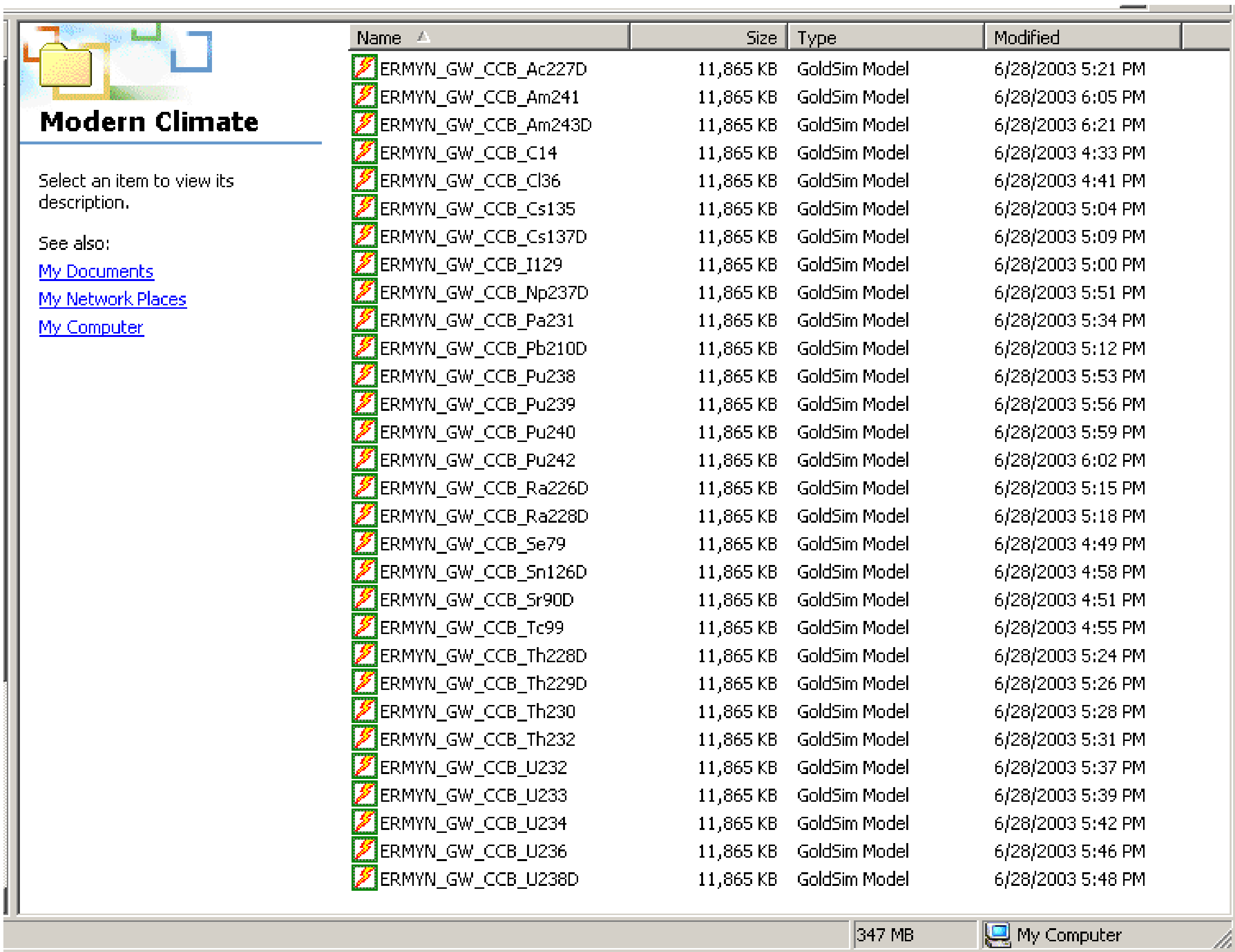
Rows 33 to 111 contain calculations of the effective dose conversion factors for the beta-gamma emitting radionuclides (Table 6.3-4). The effective dose conversion factors are calculated by adding the dose conversion factors weighted by their branching fractions, if branching fractions are different than 1.

ATTACHMENT II

LIST OF FILES GENERATED IN THE ANALYSIS

This attachment contains the listing of files generated in this analysis. The files are included on the compact disks (i.e., CD-ROMs), which are a part of this attachment. Figure II-1 shows the list of GoldSim files for the modern climate (file names ERMYN_GW_CCB_<radionuclide symbol>), Figure II-2 shows the list of GoldSim files for the upper bound of the glacial transition climate (file names ERMYN_GW_FCB_<radionuclide symbol>), and Figure II-3 shows the listing of the GoldSim files with modified climate-dependent input parameters (file names ERMYN_GW_Climates_<radionuclide symbol>), as described in Section 6.2.2 and in Attachment I. The GoldSim files contain the stochastic results of the model runs. The results are summarized in the *Results* container.

In addition, 7 Excel files shown in Figure II-4 contain calculations for this analysis, as described in Attachment I.



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Name	Size	Type	Modified
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ERMYN_GW_CCB_Am241	11,865 KB	GoldSim Model	6/28/2003 6:05 PM
ERMYN_GW_CCB_Am243D	11,865 KB	GoldSim Model	6/28/2003 6:21 PM
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Figure II-1. GoldSim Files for Calculating BDCFs for the Modern Climate

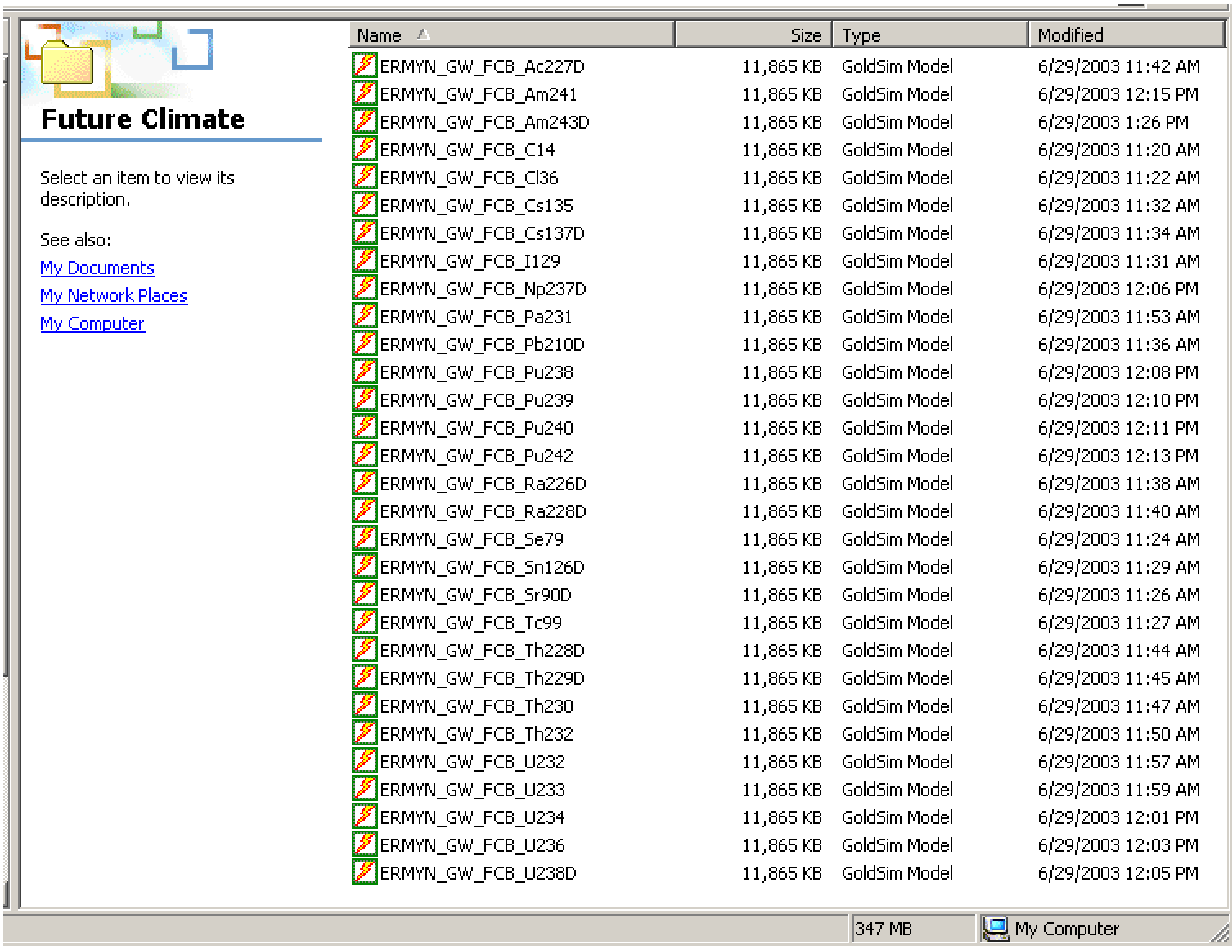
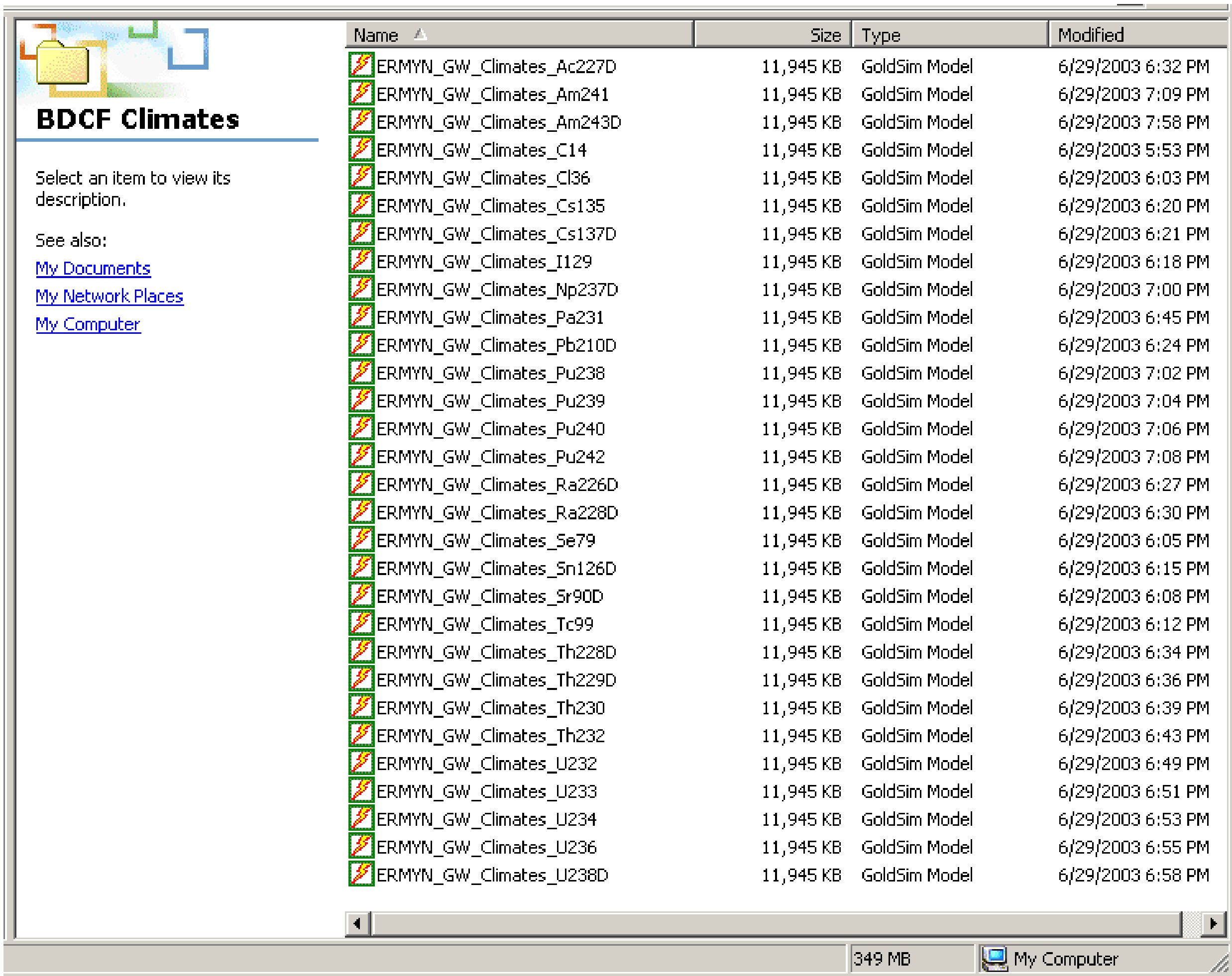


Figure II-2. GoldSim Files for Calculating BDCFs for the Upper Bound of Glacial Transition Climate



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ERMYN_GW_Climates_Am241	11,945 KB	GoldSim Model	6/29/2003 7:09 PM
ERMYN_GW_Climates_Am243D	11,945 KB	GoldSim Model	6/29/2003 7:58 PM
ERMYN_GW_Climates_C14	11,945 KB	GoldSim Model	6/29/2003 5:53 PM
ERMYN_GW_Climates_Cl36	11,945 KB	GoldSim Model	6/29/2003 6:03 PM
ERMYN_GW_Climates_Cs135	11,945 KB	GoldSim Model	6/29/2003 6:20 PM
ERMYN_GW_Climates_Cs137D	11,945 KB	GoldSim Model	6/29/2003 6:21 PM
ERMYN_GW_Climates_I129	11,945 KB	GoldSim Model	6/29/2003 6:18 PM
ERMYN_GW_Climates_Np237D	11,945 KB	GoldSim Model	6/29/2003 7:00 PM
ERMYN_GW_Climates_Pa231	11,945 KB	GoldSim Model	6/29/2003 6:45 PM
ERMYN_GW_Climates_Pb210D	11,945 KB	GoldSim Model	6/29/2003 6:24 PM
ERMYN_GW_Climates_Pu238	11,945 KB	GoldSim Model	6/29/2003 7:02 PM
ERMYN_GW_Climates_Pu239	11,945 KB	GoldSim Model	6/29/2003 7:04 PM
ERMYN_GW_Climates_Pu240	11,945 KB	GoldSim Model	6/29/2003 7:06 PM
ERMYN_GW_Climates_Pu242	11,945 KB	GoldSim Model	6/29/2003 7:08 PM
ERMYN_GW_Climates_Ra226D	11,945 KB	GoldSim Model	6/29/2003 6:27 PM
ERMYN_GW_Climates_Ra228D	11,945 KB	GoldSim Model	6/29/2003 6:30 PM
ERMYN_GW_Climates_Se79	11,945 KB	GoldSim Model	6/29/2003 6:05 PM
ERMYN_GW_Climates_Sn126D	11,945 KB	GoldSim Model	6/29/2003 6:15 PM
ERMYN_GW_Climates_Sr90D	11,945 KB	GoldSim Model	6/29/2003 6:08 PM
ERMYN_GW_Climates_Tc99	11,945 KB	GoldSim Model	6/29/2003 6:12 PM
ERMYN_GW_Climates_Th228D	11,945 KB	GoldSim Model	6/29/2003 6:34 PM
ERMYN_GW_Climates_Th229D	11,945 KB	GoldSim Model	6/29/2003 6:36 PM
ERMYN_GW_Climates_Th230	11,945 KB	GoldSim Model	6/29/2003 6:39 PM
ERMYN_GW_Climates_Th232	11,945 KB	GoldSim Model	6/29/2003 6:43 PM
ERMYN_GW_Climates_U232	11,945 KB	GoldSim Model	6/29/2003 6:49 PM
ERMYN_GW_Climates_U233	11,945 KB	GoldSim Model	6/29/2003 6:51 PM
ERMYN_GW_Climates_U234	11,945 KB	GoldSim Model	6/29/2003 6:53 PM
ERMYN_GW_Climates_U236	11,945 KB	GoldSim Model	6/29/2003 6:55 PM
ERMYN_GW_Climates_U238D	11,945 KB	GoldSim Model	6/29/2003 6:58 PM

Figure II-3. GoldSim Files for Calculating BDCF Correlations with Climate-dependent Parameters

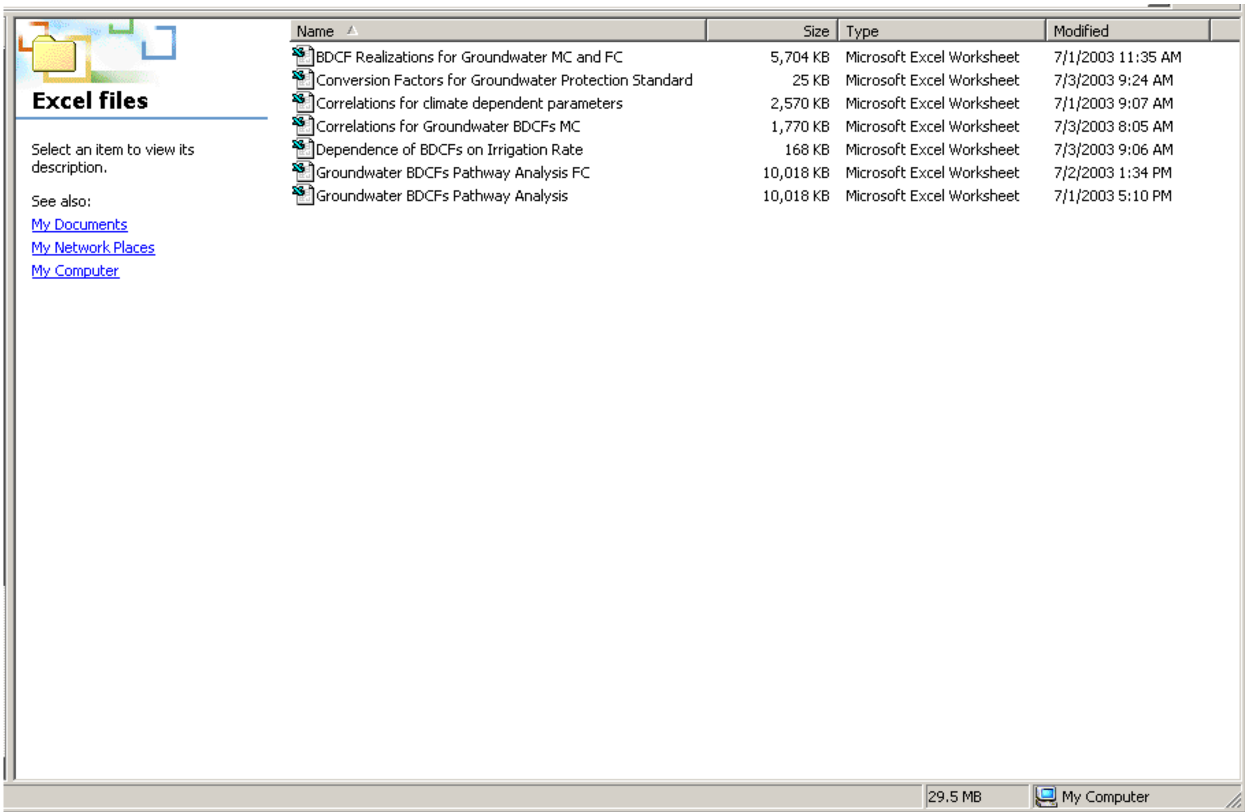
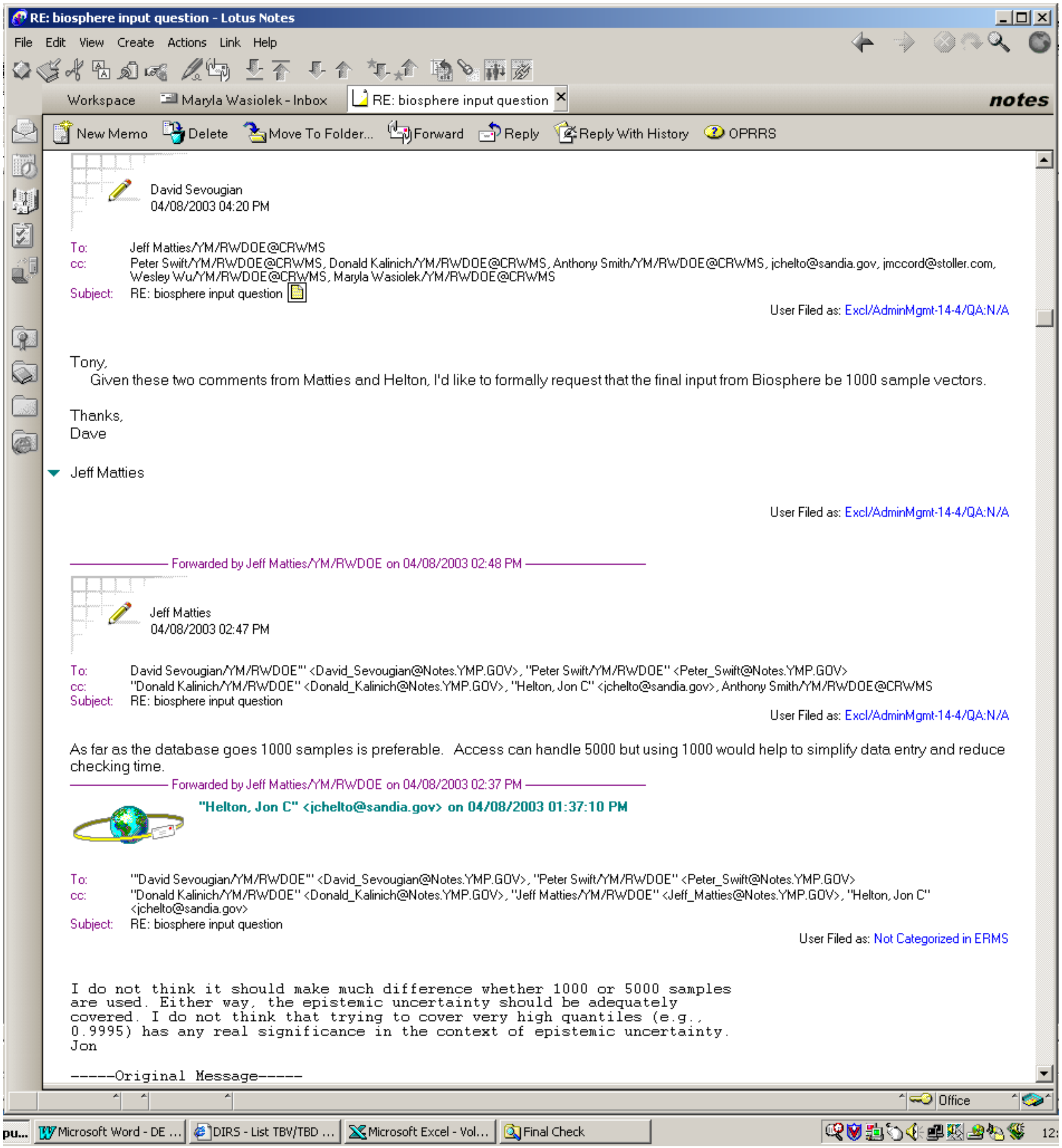


Figure II-4. Excel Files used for Calculations Supporting this Analysis

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

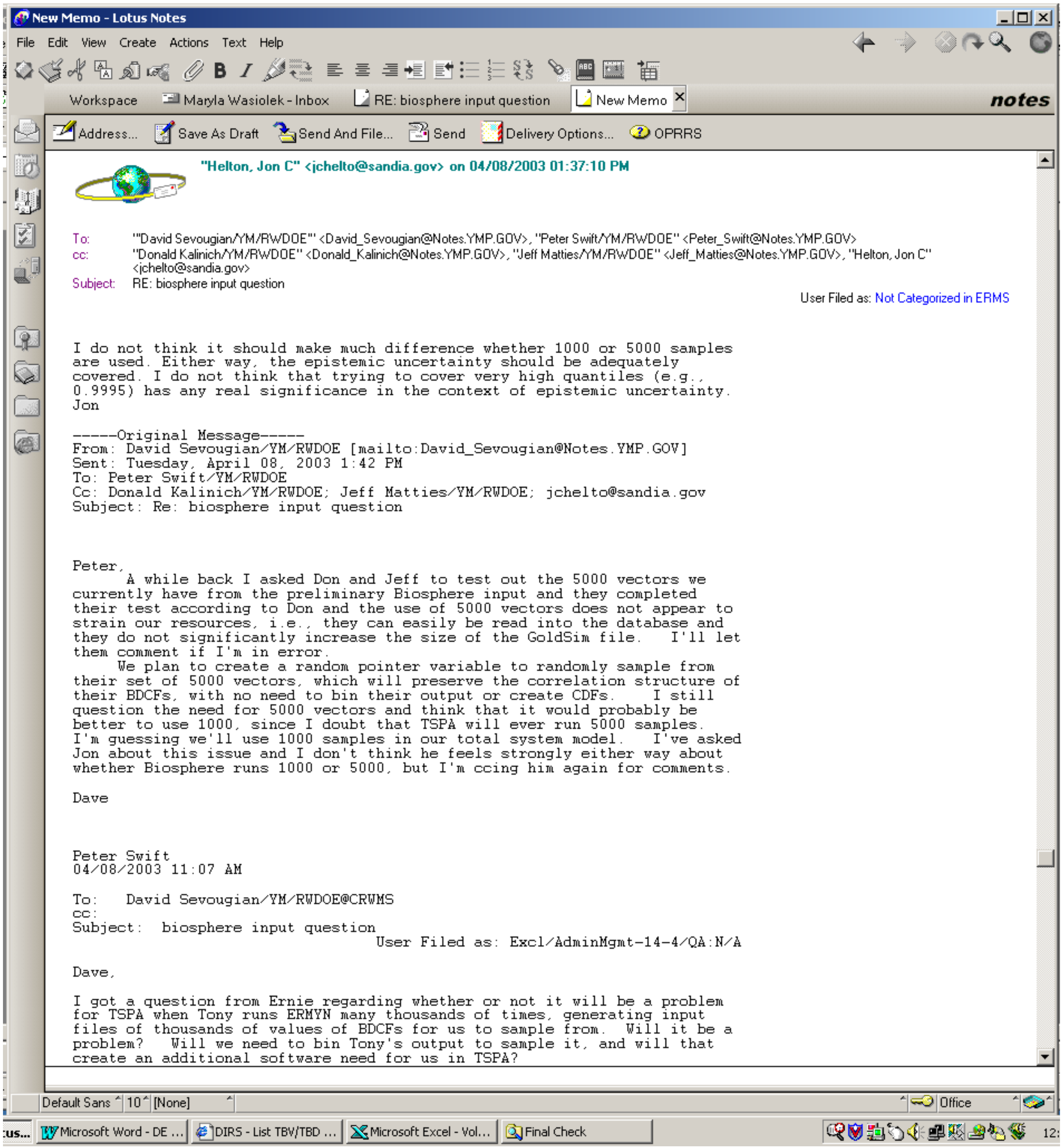
To: "David Sevougian/YM/RWDOE" <David_Sevougian@Notes.YMP.GOV>, "Peter Swift/YM/RWDOE" <Peter_Swift@Notes.YMP.GOV>
cc: "Donald Kalinich/YM/RWDOE" <Donald_Kalinich@Notes.YMP.GOV>, "Jeff Matties/YM/RWDOE" <Jeff_Matties@Notes.YMP.GOV>, "Helton, Jon C" <jchelto@sandia.gov>
Subject: RE: biosphere input question

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)