DOC.20040909.0003
QA: QA

ANL-MGR-MD-000009 REV 03

September 2004

BECHTEL
SAIC COMPANY LLC

Nominal Performance Biosphere Dose Conversion Factor Analysis

Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
1551 Hillshire Drive
Las Vegas, Nevada 89134-6321

Prepared by:
Bechtel SAIC Company, LLC
1180 Town Center Drive
Las Vegas, Nevada 89144

Under Contract Number
DE-AC28-01RW12101

DISCLAIMER

QA: QA

Nominal Performance Biosphere Dose Conversion Factor Analysis

ANL-MGR-MD-000009 REV 03

September 2004

OCRWM	Scientific Analysis Signature Page/ Change History	Page iii 1. Total Pages: 180

2. Scientific Analysis Title Nominal Performance Biosphere Dose Conversion Factor Analysis			
3. DI (including Revision Number) ANL-MGR-MD-000009 REV 03			
4. Total Appendices 5		5. Number of Pages in Each Appendix A – 8 pages, B – 8 pages, C – 24 pages, D – 4 pages, E – 6 pages	
	Printed Name	Signature	Date
6. Originator	M. A. Wasiolek	[illegible]	9/7/2004
7. Checker	E. Faillace	[illegible]	9/7/2004
8. QER	K. O. Gilkerson	J.E. Gebhart	9/8/2004
9. Responsible Manager/Lead	M. A. Wasiolek	[illegible]	9/8/2004
10. Responsible Manager	M. Zhu	[illegible]	9/8/04
11. Remarks			

Change History

12. Revision No.	13. Description of Change
REV 00 ICN 00	Initial issue
REV 01 ICN 00	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 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.
REV 02 ICN 00	Complete revision following development of the new biosphere model.
REV 03 ICN 00	Revision to incorporate Regulatory Integration Team review comments and to address Condition Report No. 2222 (implementation of Action No. 2222-001) concerning Latin Hypercube sampling scheme in GoldSim. The analysis is a complete revision; no change bars were used.

CONTENTS

FIGURES

INTENTIONALLY LEFT BLANK

TABLES

Page

ACRONYMS

AC	acceptance criterion
BDCF	biosphere dose conversion factor
ERMYN	Environmental Radiation Model for Yucca Mountain, Nevada
FEP	feature, event, or process
FGR	Federal Guidance Report
LA	license application
QA	quality assurance
RMEI	reasonably maximally exposed individual
SP	service pack
TSPA	total system performance assessment
TWP	technical work plan

INTENTIONALLY LEFT BLANK

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-LA model. The *Biosphere Model Report* (BSC 2004 [DIRS 169460]) describes in detail the ERMYN conceptual model and mathematical model. The input parameter reports, shown to the right of the *Biosphere Model Report* in Figure 1-1, contain detailed description of the model input parameters, their development, and the relationship between the parameters and specific features events and processes (FEPs). This report describes biosphere model calculations and their output, the BDCFs, for the groundwater exposure scenario. This analysis receives direct input from the outputs of the *Biosphere Model Report* (BSC 2004 [DIRS 169460]) and the five analyses that develop parameter values for the biosphere model (BSC 2004 [DIRS 169671]; BSC 2004 [DIRS 169672]; BSC 2004 [DIRS 169673]; BSC 2004 [DIRS 169458]; BSC 2004 [DIRS 169459]). The results of this report are further analyzed in the *Biosphere Dose Conversion Factor Importance and Sensitivity Analysis* (Figure 1-1).

This analysis is a revision of the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403]). The analysis was performed in accordance with the *Technical Work Plan for Biosphere Modeling and Expert Support* (TWP) (BSC 2004 [DIRS 169573]).

The objectives of this analysis are to develop BDCFs for the groundwater exposure scenario for the three climate states considered in the TSPA-LA as well as conversion factors for evaluating compliance with the groundwater protection standard. The BDCFs will be used in performance assessment for calculating all-pathway 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 drinking water for beta- and photon-emitting radionuclides. Another objective of this analysis was to re-qualify the output of the previous revision (BSC 2003 [DIRS 164403]).

For the groundwater exposure scenario, radionuclides enter the biosphere from a well that extracts contaminated groundwater from an aquifer. BDCFs for the groundwater scenario apply to the TSPA-LA 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).

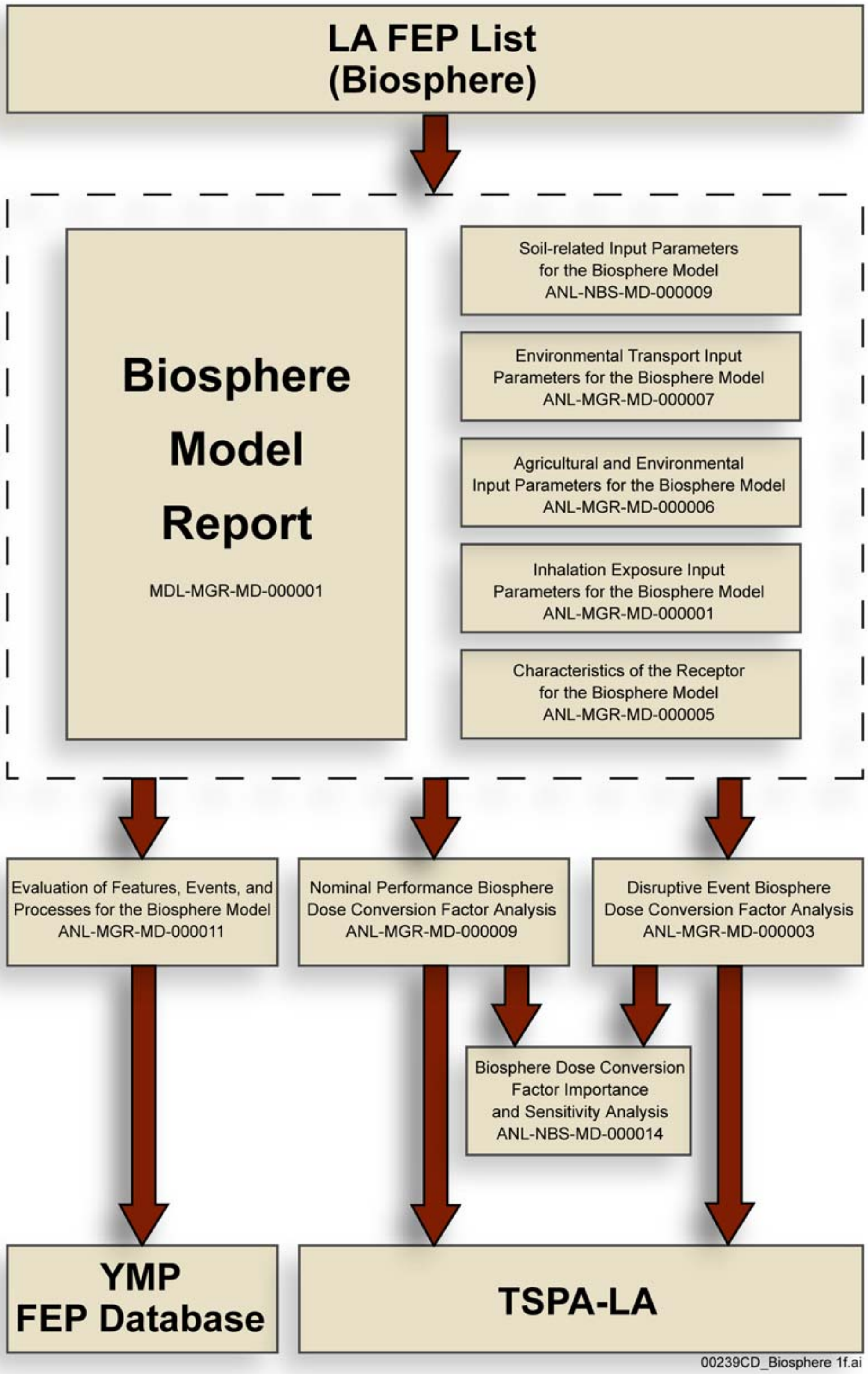


Figure 1-1. Biosphere Model Documentation and Total System Performance Assessment Feeds

The biosphere model considers features, events, and processes (FEPs) applicable to the Yucca Mountain biosphere (DTN: MO0407SEPFEPLA.000 [DIRS 170760]). Consideration of the *LA FEPs List* (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) constitutes a deviation from the TWP (BSC 2004 [DIRS 169573]), which referred to an earlier revision of the FEPs list (DTN: MO0307SEPFEPS4.000 [DIRS 164527]). Table 1-1 lists FEPs that are included in the biosphere model for the groundwater exposure scenario (BSC 2004 [DIRS 169460], Tables 6.2-1 and 6.3-6).

The BDCFs developed as output of this report, and used as direct inputs to the TSPA, are the results of the biosphere model and are based on the inputs from the supporting parameter reports. The BDCFs, therefore, implicitly include the FEPs that are related to the model and to the model inputs taken from the supporting parameter reports. Consequently, explicit mapping of individual FEPs listed in Table 1-1 to specific sections of this report and BDCFs is not possible. All FEPs considered in the biosphere model and its input parameters are collectively included in BDCFs. Relationships among the biosphere-related FEPs, the biosphere conceptual model, and the exposure scenarios are examined in Section 6.3 of the *Biosphere Model Report* (BSC 2004 [DIRS 169460]). The disposition of the included FEPs within the mathematical model, and their explicit relationship to the model equations and input parameters, is presented in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Table 6.7-1).

In addition to producing the BDCFs for the groundwater exposure scenario, this analysis develops conversion factor values for evaluating compliance with the groundwater protection standard of 10 CFR 63 [DIRS 156605]. These conversion factors are used by TSPA to calculate gross alpha particle activity in groundwater and the organ and whole-body annual dose from beta- and photon-emitting radionuclides resulting from drinking 2 liters of water per day. The FEPs considered in the development of conversion factors are listed in Table 1-2. The disposition of these FEPs in TSPA is through the conversion factors that are inputs for the TSPA-LA.

Table 1-1. Biosphere-Related Features, Events, and Processes Implicitly Included in TSPA Through the Use Of Biosphere Dose Conversion Factors for the Groundwater Exposure Scenario

FEP Name	LA FEP Number
Climate change	1.3.01.00.0A
Water table rise affects SZ	1.3.07.02.0A
Water management activities	1.4.07.01.0A
Wells	1.4.07.02.0A
Chemical characteristics of groundwater in the SZ	2.2.08.01.0A
Soil type	2.3.02.01.0A
Radionuclide accumulation in soils	2.3.02.02.0A
Soil and sediment transport in the biosphere	2.3.02.03.0A
Surface water transport and mixing	2.3.04.01.0A
Precipitation	2.3.11.01.0A
Biosphere characteristics	2.3.13.01.0A
Radionuclide alteration during biosphere transport	2.3.13.02.0A
Human characteristics (physiology, metabolism)	2.4.01.00.0A
Human lifestyle	2.4.04.01.0A
Dwellings	2.4.07.00.0A
Wild and natural land and water use	2.4.08.00.0A
Agricultural land use and irrigation	2.4.09.01.0B
Animal farms and fisheries	2.4.09.02.0A
Urban and industrial land and water use	2.4.10.00.0A
Radioactive decay and ingrowth	3.1.01.01.0A
Atmospheric transport of contaminants	3.2.10.00.0A
Contaminated drinking water, foodstuffs and drugs	3.3.01.00.0A
Plant uptake	3.3.02.01.0A
Animal uptake	3.3.02.02.0A
Fish uptake	3.3.02.03.0A
Contaminated nonfood products and exposure	3.3.03.01.0A
Ingestion	3.3.04.01.0A
Inhalation	3.3.04.02.0A
External exposure	3.3.04.03.0A
Radiation doses	3.3.05.01.0A
Radon and radon daughter exposure	3.3.08.00.0A

Source: DTN: MO0407SEPFEPLA.000 [DIRS 170760].
SZ = saturated zone

Table 1-2. Features, Events and Processes Considered in the Development of Conversion Factors

FEP Number	FEP Name	Description of FEP Disposition
1.4.07.02.0A	Wells	A well is the 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).
3.1.01.01.0A	Radioactive decay and ingrowth	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 ingestion (Table 6.3-5) 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.

Source: DTN: MO0407SEPFEPLA.000 [DIRS 170760].

INTENTIONALLY LEFT BLANK

2. QUALITY ASSURANCE

This analysis involved development of data to support performance assessment, as identified in TWP (BSC 2004 [DIRS 169573]), and thus, it was a quality affecting activity in accordance with AP-2.27Q, *Planning for Science Activities*. Approved quality assurance procedures identified in TWP (BSC 2004 [DIRS 169573], Section 4) were used to conduct and document the activities described in this report. Specifically, the procedure governing development of this document was AP-SIII.9Q, *Scientific Analyses*. Electronic data used in this analysis were controlled in accordance with methods specified in TWP (BSC 2004 [DIRS 169573], Section 8).

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

INTENTIONALLY LEFT BLANK

3. USE OF SOFTWARE

This analysis was performed using a verified and validated model, the ERMYN model, which is described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460]). 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]).

The analysis was conducted using two versions of the software that was qualified under the Office of Civilian Radioactive Waste Management, Quality Assurance program for use on the Yucca Mountain Project.

- GoldSim V7.50.100 (STN: 10344-7.5.100-00) (BSC 2003 [DIRS 161572])
- GoldSim V8.01 Service Pack (SP) 4 (STN: 10344-8.01SP4-00) (BSC 2004 [DIRS 169695])

The software was appropriate for the application of running ERMYN model, which was implemented using GoldSim software, as described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.8), and was used within the range of validation in accordance with procedure LP-SI.11Q-BSC, *Software Management*. The GoldSim files generated in this analysis are shown in Appendix A. The original verification of the model was performed using GoldSim version 7.50.100. Verification of the model for the use with GoldSim version 8.01 SP4 is described in Appendix E.

Both versions of GoldSim were installed by Software Configuration Management on a DELL Precision Workstation 530 computer (CPU# 151554) and were ran under the Windows 2000 operating system.

In addition, the commercial off-the-shelf product Microsoft® Excel 2000 (Version 9.0.3821 SR-1) was used for data reduction. Standard functions of Excel were used to calculate values presented in the tables in Section 6. The use of these functions, including formulas or algorithms, inputs, and outputs, is described in Appendix B.

INTENTIONALLY LEFT BLANK

4. INPUTS

4.1 DIRECT INPUTS

4.1.1 Calculation of Biosphere Dose Conversion Factors

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. The appropriateness for the intended use in this analysis and uncertainty in the input parameters is discussed in the individual analysis reports that document parameter development (BSC 2004 [DIRS 169672]; BSC 2004 [DIRS 169458]; BSC 2004 [DIRS 169673]; BSC 2004 [DIRS 169459]; BSC 2004 [DIRS 169671]).

The parameters were used as input for the ERMYN model for the groundwater exposure scenario (DTN: MO0306MWDBGSMF.001 [DIRS 163816]). Where applicable, Table 4.1-1 includes parameter values and distributions for two climate extremes: the present-day climate and one future climate state represented by the upper bound of the glacial transition climate. The BDCFs are calculated in this analysis for three climate states by interpolation between these two extremes. 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.

The output of Revision 02 of this analysis (DTN: MO0307MWDNPBDC.001 [DIRS 164615]) is also a direct input to this analysis. This DTN is re-qualified within this analysis (see Appendix C) using a corroborating data approach as a qualification method, per AP-SIII.2Q, *Qualification of Unqualified Data*. The Data Qualification Plan is included in Appendix D. In the qualification process, the DTN: MO0307MWDNPBDC.001 [DIRS 164615] is compared with the results of biosphere modeling generated in this analysis to determine the impact of software and input changes, and to qualify the data. Table 4.1-5 lists the input DTNs used by both analyses and summarizes differences between the inputs.

The direct inputs described in this section are used in Sections 6.2 and in Appendix C.

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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
S U R F A C E S O I L S U B M O D E L								
Activity concentration of a radionuclide in well water		Fixed	Bq/m^3	1	–	–	–	Source of contamination
Annual average irrigation rate	Present-day climate	Normal	m/yr	0.95	0.08	0.74	1.16	MO0403SPAAEIBM.002 [DIRS 169392]
	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	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
Soil bulk density		Triangular	kg/m^3	1500	–	1300	1700	MO0407SPASRPBM.002 [DIRS 170755]
Surface soil depth (tillage depth)		Uniform	m	–	–	0.05	0.30	MO0403SPAAEIBM.002 [DIRS 169392]
Surface soil erosion rate		Triangular	$kg/(m^2\ yr)$	0.19	–	0.19	1.1	MO0407SPASRPBM.002 [DIRS 170755]
Soil solid/liquid partition coefficient	Carbon	Lognormal[a]	L/kg	1.8E+01	6.0E+00	–	–	MO0407SPASRPBM.002 [DIRS 170755]
	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	Minimum or Value for CD	Maximum or Percentile for CD	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	Present-day climate	Cumulative	m/yr	–	–	0.009 0.030 0.045 0.077 0.129 0.233 0.275	0% 19% 38% 57% 76% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]
	Future climate	Cumulative	m/yr	–	–	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	MO0407SPASRPBM.002 [DIRS 170755]
AIR SUBMODEL								
Mass loading for crops at nominal conditions		Triangular	mg/m^3	0.12	–	0.025	0.200	MO0407SPAINEXI.002 [DIRS 170597]
Mass loading for receptor environments at nominal conditions	Active outdoors	Triangular	mg/m^3	5.00	–	1.000	10.000	MO0407SPAINEXI.002 [DIRS 170597]
	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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
Enhancement factor at nominal conditions	Active outdoors	Cumulative	–	–	–	2.2 4.0 6.5	0% 50% 100%	MO0407SPASRPBM.002 [DIRS 170755]
	Inactive outdoors Active indoors Asleep indoors	Cumulative	–	–	–	0.21 0.7 1.04	0% 50% 100%	
Evaporative cooler water transfer fraction		Uniform	–	–	–	0	1	MO0406SPAETPBM.002 [DIRS 170150]
Evaporative cooler water use (evaporation) rate		Lognormal[a]	L/hr	17	1.7	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Evaporative cooler air flow rate		Cumulative	m^3/hr	–	–	1,700 8,300 10,200	0% 50% 100%	MO0406SPAETPBM.002 [DIRS 170150]
Correlation coefficient for evaporative cooler water use (evaporation) and air flow rates		Fixed	–	0.8	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Radon release factor		Fixed	$(Bq/m^3)/(Bq/kg)$	0.25	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
House ventilation rate	Average	Lognormal[b]	1/hr	1.0	1.1	0.35	2.9	MO0406SPAETPBM.002 [DIRS 170150]
	Evap. cooler on	Uniform		–	–	1	30	
Fraction of radon from soil entering the house		Uniform	–	–	–	0.1	0.25	MO0406SPAETPBM.002 [DIRS 170150]
Ratio of Rn-222 concentration in air to flux density from soil		Fixed	$(Bq\ m^{-3})/(Bq\ m^{-2}\ s^{-1})$	300	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
PLANT SUBMODEL								
Soil-to-plant transfer factor for leafy vegetables	Chlorine	Lognormal[a]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	6.4E+01	2.0	1.1E+01	3.8E+02	MO0406SPAETPBM.002 [DIRS 170150]
	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			8.5E−02	2.5	7.7E−03	9.4E−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	Minimum or Value for CD	Maximum or Percentile for CD	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[a]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	6.4E+01	2.0	1.1E+01	3.8E+02	MO0406SPAETPBM.002 [DIRS 170150]
	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[a]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	6.4E+01	2.0	1.1E+01	3.8E+02	MO0406SPAETPBM.002 [DIRS 170150]
	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	Minimum or Value for CD	Maximum or Percentile for CD	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[a]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	2.4E+01	8.4	1.0E−01	5.8E+03	MO0406SPAETPBM.002 [DIRS 170150]
	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[a]	$(Bq/kg_{plant})/(Bq/kg_{soil})$	7.5E+01	2.0	1.3E+01	4.5E+02	MO0406SPAETPBM.002 [DIRS 170150]
	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	Minimum or Value for CD	Maximum or Percentile for CD	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	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
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%	MO0403SPAAEIBM.002 [DIRS 169392]
	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	Minimum or Value for CD	Maximum or Percentile for CD	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	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
		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	MO0403SPAAEIBM.002 [DIRS 169392]
		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	days	14	–	5 14 30	0% 50% 100%	MO0406SPAETPBM.002 [DIRS 170150]
Crop growing time	Present-day climate	Leafy vegetables	Fixed	days	75	–	–	–	MO0403SPAAEIBM.002 [DIRS 169392]
		Other vegetables			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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
	Future climate	Leafy vegetables	Fixed	days	75	–	–	–	
		Other vegetables			100	–	–	–	
		Fruit			105	–	–	–	
		Grain			185	–	–	–	
		Forage			90	–	–	–	
Crop wet yield		Leafy vegetables	Cumulative	kg/m^2	–	–	1.08	0%	MO0403SPAAEIBM.002 [DIRS 169392]
							1.46	5%	
							1.78	20%	
							2.01	35%	
							2.98	50%	
							3.25	65%	
							3.83	80%	
							7.79	95%	
							7.85	100%	
		Other vegetables	Cumulative	kg/m^2	–	–	2.8	0%	
							3.37	5%	
							3.56	28%	
							3.64	51%	
							4.92	72%	
							5.15	95%	
							6.61	100%	
		Fruit	Cumulative	kg/m^2	–	–	0.73	0%	
							1.51	5%	
							2.67	28%	
							2.92	51%	
							3.00	72%	
							3.63	95%	
							6.89	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	Minimum or Value for CD	Maximum or Percentile for CD	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 vegetables	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%	MO0403SPAAEIBM.002 [DIRS 169392]
	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	Minimum or Value for CD	Maximum or Percentile for CD	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, present-day climate	Leafy vegetables	Cumulative	mm/day	–	–	4.00 5.11 5.19 5.21 5.38 5.48 6.00 7.08	0% 5% 20% 35% 50% 80% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]

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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
	Other vegetables	Cumulative	mm/day	–	–	5.00 6.07 6.65 6.93 7.67 8.36 9.03 9.26 10.93	0% 5% 20% 35% 50% 65% 80% 95% 100%	
	Fruit	Cumulative	mm/day	–	–	4.00 5.40 7.02 7.59 8.38 8.67 10.23	0% 5% 28% 51% 72% 95% 100%	
	Grain	Cumulative	mm/day	–	–	3.00 3.44 3.58 3.87 7.69 9.07	0% 5% 35% 65% 95% 100%	
	Forage	Cumulative	mm/day	–	–	5.00 5.85 6.18 9.02 10.64	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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
Daily average irrigation rate, future climate	Leafy vegetables	Cumulative	mm/day	–	–	3.00 3.34 3.51 3.86 3.92 4.02 4.18 4.93	0% 5% 20% 50% 65% 80% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]
	Other vegetables	Cumulative	mm/day	–	–	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/day	–	–	2.00 2.51 3.48 4.33 4.38 4.79 5.65	0% 5% 28% 51% 72% 95% 100%	
	Grain	Cumulative	mm/day	–	–	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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
	Forage	Cumulative	mm/day	–	–	3.00 3.64 4.01 5.03 5.94	0% 5% 73% 95% 100%	
Irrigation amount per application, present-day climate	Leafy vegetables	Cumulative	mm	–	–	6.0 7.5 8.4 10.0 10.9 20.8 22.0 23.5 27.7	0% 5% 20% 35% 50% 65% 80% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]
	Other vegetables	Cumulative	mm	–	–	8.0 9.1 18.9 19.8 21.2 33.3 34.8 44.7 52.7	0% 5% 20% 35% 50% 65% 80% 95% 100%	
	Fruit	Cumulative	mm	–	–	5.0 6.0 30.3 35.4 48.4 49.4 58.3	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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
	Grain	Cumulative	mm	–	–	43.0	0%	
						48.6	5%	
						50.1	35%	
						50.4	65%	
						77.9	95%	
						91.9	100%	
	Forage	Cumulative	mm	–	–	50.0	0%	
						56.3	5%	
						57.6	72%	
						60.0	95%	
						71.0	100%	
Irrigation amount per application, future climate	Leafy vegetables	Cumulative	mm	–	–	7.0	0%	MO0403SPAAEIBM.002 [DIRS 169392]
						7.8	5%	
						8.0	20%	
						9.0	35%	
						10.1	50%	
						19.3	65%	
						22.0	80%	
						26.1	95%	
						30.8	100%	
	Other vegetables	Cumulative	mm	–	–	10.0	0%	
						11.3	5%	
						14.4	20%	
						17.7	35%	
						20.1	50%	
						34.1	65%	
						37.2	80%	
						40.3	95%	
						47.6	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	Minimum or Value for CD	Maximum or Percentile for CD	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	MO0403SPAAEIBM.002 [DIRS 169392]
Dry deposition velocity		Cumulative	m/s	–	–	3E−4 1E−3 8E−3 3E−2 3E−1	0 % 16 % 50 % 84 % 100 %	MO0406SPAETPBM.002 [DIRS 170150]

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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
ANIMAL SUBMODEL								
Animal product transfer coefficients for meat	Chlorine	Lognormal[a]	days/kg	4.6E−02	2.0	7.7E−03	2.7E−01	MO0406SPAETPBM.002 [DIRS 170150]
	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[a]	days/L	1.8E−02	2.0	2.9E−03	1.0E−01	MO0406SPAETPBM.002 [DIRS 170150]
	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	Minimum or Value for CD	Maximum or Percentile for CD	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[a]	days/kg	3.0E−02	2.0	5.0E−03	1.8E−01	MO0406SPAETPBM.002 [DIRS 170150]
	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[a]	days/kg	4.4E−02	10.0	1.2E−04	1.7E+01	MO0406SPAETPBM.002 [DIRS 170150]
	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			3.5E−01	5.8	3.7E−03	3.3E+01	
	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	Minimum or Value for CD	Maximum or Percentile for CD	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	Beef cattle	Uniform	kg/day	–	–	29	68	MO0406SPAETPBM.002 [DIRS 170150]
	Dairy cow			–	–	50	73	
	Poultry			–	–	0.12	0.40	
	Laying hen			–	–	0.12	0.40	
Animal consumption rate of water	Beef cattle	Fixed	L/day	60	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
	Dairy cow	Uniform		–	–	60	100	
	Poultry	Fixed		0.5	–	–	–	
	Laying hen	Fixed		0.5	–	–	–	
Animal consumption rate of soil	Beef cattle	Uniform	kg/day	–	–	0.4	1.0	MO0406SPAETPBM.002 [DIRS 170150]
	Dairy cow			–	–	0.8	1.1	
	Poultry			–	–	0.01	0.03	
	Laying hen			–	–	0.01	0.03	
FISH SUBMODEL								
Bioaccumulation factor	Carbon	Lognormal[a]	L/kg	4.6E+03	3.2	2.3E+02	9.2E+04	MO0406SPAETPBM.002 [DIRS 170150]
	Chlorine			2.2E+02	5.6	2.6E+00	1.9E+04	
	Selenium			2.3E+02	2.0	3.9E+01	1.4E+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**	**Minimum or Value for CD**	**Maximum or Percentile for CD**	**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, present-day climate	Carbon	Fixed	–	1.0	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
	Other elements	Uniform	–	–	–	2.2	6.1	
Water concentration modifying factor, future climate	Carbon	Fixed	–	1.0	–	–	–	
	Other elements	Uniform	–	–	–	1.5	3.3	
SPECIAL CARBON–14 MODEL								
C-14 emission rate		Fixed	1/yr	22	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Annual water demand		Fixed	m^3/yr	3,714,450	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Annual average wind speed	Inhalation	Uniform	m/s	–	–	2.1	2.8	MO0406SPAETPBM.002 [DIRS 170150]
	Crops			–	–	1.5	2.3	
C-14 mixing height	Inhalation	Fixed	m	2	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
	Crops			1	–	–	–	
Fraction of air-derived carbon in plants		Fixed	–	0.98	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Fraction of soil-derived carbon in plants		Fixed	–	0.02	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Fraction of stable carbon in plants	Leafy vegetables	Fixed	–	0.09	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
	Other vegetables			0.09	–	–	–	
	Fruit			0.09	–	–	–	
	Grain			0.40	–	–	–	
	Forage			0.09	–	–	–	
Fraction of stable carbon in soil		Fixed	–	0.03	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]

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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
Concentration of stable carbon in air		Fixed	kg/m^3	1.8E−04	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Concentration of stable carbon in water		Fixed	kg/L	2.0E−05	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
Fraction of stable carbon in animal products	Meat	Fixed	–	0.24	–	–	–	MO0406SPAETPBM.002 [DIRS 170150]
	Milk			0.07	–	–	–	
	Poultry			0.2	–	–	–	
	Eggs			0.15	–	–	–	
EXTERNAL EXPOSURE SUBMODEL								
Population proportion	Outdoor workers	Uniform	%	–	–	2.9	8.1	MO0407SPACRBSM.002 [DIRS 170677]
	Indoor workers			–	–	Calculated	Calculated	
	Commuters			–	–	33.9	44.5	
	Nonworkers			–	–	34.4	44.0	
Time spent by outdoor workers	Active outdoors	Lognormal[b]	hr/day	3.1	0.2	2.6	3.7	MO0407SPACRBSM.002 [DIRS 170677]
	Inactive outdoors			4.0	0.3	3.3	4.8	
	Active indoors			6.6	Calculated	–	–	
	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[b]	hr/day	0.3	0.1	0.1	0.7	
	Inactive outdoors			1.3	0.2	0.9	1.9	
	Active indoors			12.1	Calculated	–	–	
	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[b]	hr/day	0.3	0.1	0.1	0.7	
	Inactive outdoors			1.4	0.2	1.0	2.0	
	Active indoors			6.0	Calculated	–	–	
	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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
Time spent by non workers	Active outdoors	Lognormal[b]	hr/day	0.3	0.1	0.1	0.7	
	Inactive outdoors			1.2	0.2	0.8	1.8	
	Active indoors			12.2	Calculated	–	–	
	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	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
	Cl-36			0.4	–	–	–	
	Se-79			0.1	–	–	–	
	Sr-90			0.4	–	–	–	
	Tc-99			0.2	–	–	–	
	Sn-126			0.4	–	–	–	
	I-129			0.1	–	–	–	
	Cs-135			0.1	–	–	–	
	Cs-137			0.4	–	–	–	
	Pu-242			0.1	–	–	–	
	U-238			0.4	–	–	–	
	Pu-238			0.1	–	–	–	
	U-234			0.2	–	–	–	
	Th-230			0.3	–	–	–	
	Ra-226			0.4	–	–	–	
	Pb-210			0.4	–	–	–	
	Pu-240			0.1	–	–	–	
	U-236			0.1	–	–	–	
	Th-232			0.2	–	–	–	
	Ra-228			0.4	–	–	–	
	U-232			0.3	–	–	–	
	Th-228			0.4	–	–	–	
	Am-243			0.4	–	–	–	
	Pu-239			0.3	–	–	–	
	U-235			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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
	Ac-227			0.4	–	–	–	
	Am-241			0.2	–	–	–	
	Np-237			0.4	–	–	–	
	U-233			0.4	–	–	–	
	Th-229			0.4	–	–	–	
Dose coefficient for exposure to contaminated soil (infinite depth)		Fixed	(Sv/yr)/(Bq/m^3)	See Table 4.1-4	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
INHALATION SUBMODEL								
Breathing rate	Active outdoors	Fixed	m^3/hr	1.57	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
	Inactive outdoors			1.08	–	–	–	
	Active indoors			1.08	–	–	–	
	Asleep indoors			0.39	–	–	–	
	Away			1.08 [c]	–	–	–	
Dose conversion factor for inhalation		Fixed	Sv/Bq	See Table 4.1-3	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
Fraction of houses with evaporative coolers		Binomial	–	0.738	Batch size = 187	–	–	MO0407SPACRBSM.002 [DIRS 170677]
Evaporative cooler use factor	Present-day climate	Uniform	–	–	–	0.32	0.46	MO0407SPACRBSM.002 [DIRS 170677]
	Future climate	Uniform	–	–	–	0.03	0.14	
Equilibrium factor for ^{222}Rn decay products	Outdoors	Uniform	–	–	–	0.5	0.7	MO0406SPAETPBM.002 [DIRS 170150]
	Indoors	Uniform	–	–	–	0.3	0.5	
Dose conversion factor for inhalation of ^{222}Rn decay products		Fixed	Sv/Bq	1.33E−8	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]

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	Minimum or Value for CD	Maximum or Percentile for CD	DTN/Reference
INGESTION SUBMODEL								
Consumption rate of water		Fixed	L/day	2.0	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]
Consumption rate of locally produced food	Leafy vegetables	Lognormal[b]	kg/yr	3.78	0.88	–	–	MO0407SPACRBSM.002 [DIRS 170677]
	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/day	–	–	50 100 200	0% 50% 100%	MO0407SPACRBSM.002 [DIRS 170677]
Dose conversion factor for ingestion		Fixed	Sv/Bq	See Table 4.1-3	–	–	–	MO0407SPACRBSM.002 [DIRS 170677]

SD = standard deviation; SE = standard error; CD = cumulative distribution

[a] Lognormal distribution defined using geometric mean and geometric standard deviation
[b] Lognormal distributions defined using arithmetic mean and arithmetic standard deviation
[c] 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	5.730E+03 years
Chlorine-36 (^{36}Cl)		100	3.01E+05 years
Selenium-79 (^{79}Se)		100	6.50E+04 years
Strontium-90 (^{90}Sr)		100	2.912E+01 years
	Yttrium-90 (^{90}Y)	100	6.40E+01 hours
Technetium-99 (^{99}Tc)		100	2.13E+05 years
Tin-126 (^{126}Sn)		100	1.0E+05 years
	Antimony-126m (^{126m}Sb)	100	1.90E+01 minutes
	Antimony-126 (^{126}Sb)	14	1.24E+01 days
Iodine-129 (^{129}I)		100	1.57E+07 years
Cesium-135 (^{135}Cs)		100	2.3E+06 years
Cesium-137 (^{137}Cs)		100	3.00E+01 years
	Barium-137m (^{137m}Ba)	94.60	2.552E+00 minutes
Thorium Series (4n)			
Plutonium-240 (^{240}Pu)		100	6.537E+03 years
Uranium-236 (^{236}U)		100	2.3415E+07 years
Thorium-232 (^{232}Th)		100	1.405E+10 years
Radium-228 (^{228}Ra)		100	5.75E+00 years
	Actinium-228 (^{228}Ac)	100	6.13E+00 hours
Uranium-232 (^{232}U)		100	7.2E+01 years
Thorium-228 (^{228}Th)		100	1.9131E+00 years
	Radium-224 (^{224}Ra)	100	3.66E+00 days
	Radon-220 (^{220}Rn)	100	5.56E+01 seconds
	Polonium-216 (^{216}Po)	100	1.5 E−01 seconds
	Lead-212 (^{212}Pb)	100	1.064E+01 hours
	Bismuth-212 (^{212}Bi)	100	6.055 E+01 minutes
	Polonium-212 (^{212}Po)	64.07	3.05 E−07 seconds
	Thallium-208 (^{208}Tl)	35.93	3.07E+00 minutes
Neptunium Series (4n+1)			
Americium-241 (^{241}Am)		100	4.322E+02 years
Neptunium-237 (^{237}Np)		100	2.14E+06 years
	Protactinium-233 (^{233}Pa)	100	2.70 E+01 days
Uranium-233 (^{233}U)		100	1.585E+05 years
Thorium-229 (^{229}Th)		100	7.340E+03 years
	Radium-225 (^{225}Ra)	100	1.48E+01 days
	Actinium-225 (^{225}Ac)	100	1.00E+01 days
	Francium-221 (^{221}Fr)	100	4.8E+00 minutes
	Astatine-217 (^{217}At)	100	3.23E−02 seconds
	Bismuth-213 (^{213}Bi)	100	4.565E+01 minutes
	Polonium-213 (^{213}Po)	97.84	4.2E−06 seconds
	Thallium-209 (^{209}Tl)	2.16	2.20 E+00 minutes
	Lead-209 (^{209}Pb)	100	3.253E+00 hours

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 years
Uranium-238 (^{238}U)		100	4.468E+09 years
	Thorium-234 (^{234}Th)	100	2.410E+01 days
	Protactinium-234m (^{234m}Pa)	99.80	1.17E+00 minutes
	Protactinium-234 (^{234}Pa)	0.33	6.70E+00 hours
Plutonium-238 (^{238}Pu)		100	8.774E+01 years
Uranium-234 (^{234}U)		100	2.445E+05 years
Thorium-230 (^{230}Th)		100	7.7E+04 years
Radium-226 (^{226}Ra)		100	1.600E+03 years
	Radon-222 (^{222}Rn)	100	3.8235E+00 days
	Polonium-218 (^{218}Po)	100	3.05E+00 minutes
	Lead-214 (^{214}Pb)	99.98	2.68 E+01 minutes
	Astatine-218 (^{218}At)	0.02	2.E+00 seconds
	Bismuth-214 (^{214}Bi)	100	1.99E+01 minutes
	Polonium-214 (^{214}Po)	99.98	1.643E−04 seconds
	Thallium-210 (^{210}Tl)	0.02	1.3E+00 minutes
Lead-210 (^{210}Pb)		100	2.23 E+01 years
	Bismuth-210 (^{210}Bi)	100	5.012E+00 days
	Polonium-210 (^{210}Po)	100	1.3838 E+02 days
Actinium Series (4n + 3)			
Americium-243 (^{243}Am)		100	7.380E+03 years
	Neptunium-239 (^{239}Np)	100	2.355E+00 days
Plutonium-239 (^{239}Pu)		100	2.4065E+04 years
Uranium-235 (^{235}U)		100	7.038E+08 years
	Thorium-231 (^{231}Th)	100	2.552E+01 hours
Protactinium-231 (^{231}Pa)		100	3.276E+04 years
Actinium-227 (^{227}Ac)		100	2.1773E+01 years
	Thorium-227 (^{227}Th)	98.62	1.8718E+01 days
	Francium-223 (^{223}Fr)	1.38	2.18E+01 minutes
	Radium-223 (^{223}Ra)	100	1.1434E+01 days
	Radon-219 (^{219}Rn)	100	3.96 E+00 seconds
	Polonium-215 (^{215}Po)	100	1.78 E−03 seconds
	Lead-211 (^{211}Pb)	100	3.61 E+01 minutes
	Bismuth-211 (^{211}Bi)	100	2.14 E+00 minutes
	Thallium-207 (^{207}Tl)	99.72	4.77 E+00 minutes
	Polonium-211 (^{211}Po)	0.28	5.16E−01 seconds

Source: DTN: MO0407SPACRBSM.002 [DIRS 170677].
NOTE: Short-lived decay products of primary radionuclides are modeled 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)	
		Inhalation	Ingestion
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: MO0407SPACRBSM.002 [DIRS 170677].
NOTES: 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 for Infinite Depth (Sv/s per Bq/m^3)
Carbon-14 (^{14}C)		7.20E−23
Chlorine-36 (^{36}Cl)		1.28E−20
Selenium-79 (^{79}Se)		9.96E−23
Strontium-90 (^{90}Sr)		3.77E−21
	Yttrium-90 (^{90}Y)	1.28E−19
Technetium-99 (^{99}Tc)		6.72E−22
Tin-126 (^{126}Sn)		7.89E−19
	Antimony-126m (^{126m}Sb)	4.98E−17
	Antimony-126 (^{126}Sb)	9.16E−17
Iodine-129 (^{129}I)		6.93E−20
Cesium-135 (^{135}Cs)		2.05E−22
Cesium-137 (^{137}Cs)		4.02E−21
	Barium-137m (^{137m}Ba)	1.93E−17
Thorium Series (4n)		
Plutonium-240 (^{240}Pu)		7.85E−22
Uranium-236 (^{236}U)		1.15E−21
Thorium-232 (^{232}Th)		2.79E−21
Radium-228 (^{228}Ra)		0.00E+00
	Actinium-228 (^{228}Ac)	3.20E−17
Uranium-232 (^{232}U)		4.83E−21
Thorium-228 (^{228}Th)		4.25E−20
	Radium-224 (^{224}Ra)	2.74E−19
	Radon-220 (^{220}Rn)	1.23E−20
	Polonium-216 (^{216}Po)	5.58E−22
	Lead-212 (^{212}Pb)	3.77E−18
	Bismuth-212 (^{212}Bi)	6.27E−18
	Polonium-212 (^{212}Po)	0.00E+00
	Thallium-208 (^{208}Tl)	1.23E−16
Neptunium Series (4n+1)		
Americium-241 (^{241}Am)		2.34E−19
Neptunium-237 (^{237}Np)		4.17E−19
	Protactinium-233 (^{233}Pa)	5.46E−18
Uranium-233 (^{233}U)		7.48E−21
Thorium-229 (^{229}Th)		1.72E−18
	Radium-225 (^{225}Ra)	5.90E−20
	Actinium-225 (^{225}Ac)	3.41E−19
	Francium-221 (^{221}Fr)	8.22E−19
	Astatine-217 (^{217}At)	9.49E−21
	Bismuth-213 (^{213}Bi)	4.10E−18
	Polonium-213 (^{213}Po)	0.00E+00
	Thallium-209 (^{209}Tl)	6.92E−17
	Lead-209 (^{209}Pb)	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 for Infinite Depth (Sv/s per Bq/m^3)
Uranium Series (4n + 2)		
Plutonium-242 (^{242}Pu)		6.85E−22
Uranium-238 (^{238}U)		5.52E−22
	Thorium-234 (^{234}Th)	1.29E−19
	Protactinium-234m (^{234m}Pa)	4.80E−19
	Protactinium-234 (^{234}Pa)	6.18E−17
Plutonium-238 (^{238}Pu)		8.10E−22
Uranium-234 (^{234}U)		2.15E−21
Thorium-230 (^{230}Th)		6.47E−21
Radium-226 (^{226}Ra)		1.70E−19
	Radon-222 (^{222}Rn)	1.26E−20
	Polonium-218 (^{218}Po)	3.02E−22
	Lead-214 (^{214}Pb)	7.18E−18
	Astatine-218 (^{218}At)	3.13E−20
	Bismuth-214 (^{214}Bi)	5.25E−17
	Polonium-214 (^{214}Po)	2.75E−21
	Thallium-210 (^{210}Tl)	–
Lead-210 (^{210}Pb)		1.31E−20
	Bismuth-210 (^{210}Bi)	1.93E−20
	Polonium-210 (^{210}Po)	2.80E−22
Actinium Series (4n + 3)		
Americium-243 (^{243}Am)		7.60E−19
	Neptunium-239 (^{239}Np)	4.03E−18
Plutonium-239 (^{239}Pu)		1.58E−21
Uranium-235 (^{235}U)		3.86E−18
	Thorium-231 (^{231}Th)	1.95E−19
Protactinium-231 (^{231}Pa)		1.02E−18
Actinium-227 (^{227}Ac)		2.65E−21
	Thorium-227 (^{227}Th)	2.79E−18
	Francium-223 (^{223}Fr)	1.06E−18
	Radium-223 (^{223}Ra)	3.23E−18
	Radon-219 (^{219}Rn)	1.65E−18
	Polonium-215 (^{215}Po)	5.44E−21
	Lead-211 (^{211}Pb)	1.64E−18
	Bismuth-211 (^{211}Bi)	1.37E−18
	Thallium-207 (^{207}Tl)	1.06E−19
	Polonium-211 (^{211}Po)	2.55E−19

Source: MO0407SPACRBSM.002 [DIRS 170677].

Table 4.1-5. Comparison of Input Parameters for This and Previous Revision of the Analysis

Parameter Name	Previous Revision: DTN	Previous Revision: Parameter Value and Percentile for Cumulative Distribution		Current Revision: DTN	Current Revision: Parameter Value and Percentile for Cumulative Distribution	
Agricultural and Environmental Input Parameters						
Average annual irrigation rate, present-day climate, normal distribution (m/yr)	MO0306SPAAEIBM.001 [DIRS 163812]	Normal distribution Mean = 0.94 Standard Error = 0.08 Minimum = 0.73 Maximum = 1.15		MO0403SPAAEIBM.002 [DIRS 169392]	Normal distribution Mean = 0.95 Standard Error = 0.08 Minimum = 0.74 Maximum = 1.16	
Irrigation application, present-day climate, leafy vegetables (mm)	MO0306SPAAEIBM.001 [DIRS 163812]	6.0	0%	MO0403SPAAEIBM.002 [DIRS 169392]	6.0	0%
		7.4	5%		7.5	5%
		8.4	20%		8.4	20%
		10.0	35%		10.0	35%
		10.9	50%		10.9	50%
		20.8	65%		20.8	65%
		22.0	80%		22.0	80%
		23.6	95%		23.5	95%
		27.8	100%		27.7	100%
Irrigation application, present-day climate, other vegetables (mm)	MO0306SPAAEIBM.001 [DIRS 163812]	8.0	0%	MO0403SPAAEIBM.002 [DIRS 169392]	8.0	0%
		9.0	5%		9.1	5%
		18.7	20%		18.9	20%
		19.7	35%		19.8	35%
		21.2	50%		21.2	50%
		32.9	65%		33.3	65%
		34.9	80%		34.8	80%
		41.2	95%		44.7	95%
		48.6	100%		52.7	100%
Irrigation application, present-day climate, fruits (mm)	MO0306SPAAEIBM.001 [DIRS 163812]	5.0	0%	MO0403SPAAEIBM.002 [DIRS 169392]	5.0	0%
		6.0	5%		6.0	5%
		30.2	28%		30.3	28%
		35.5	51%		35.4	51%
		48.4	72%		48.4	72%
		49.2	95%		49.4	95%
		58.1	100%		58.3	100%

Table 4.1-5. Comparison of Input Parameters for This and Previous Revision of the Analysis (Continued)

Parameter Name	Previous Revision			Current Revision		
	DTN	Parameter Value and Percentile for Cumulative Distribution		DTN	Parameter Value and Percentile for Cumulative Distribution	
Irrigation application, present-day climate, grains (mm)	MO0306SPAAEIBM.001 [DIRS 163812]	43.0 48.7 50.1 50.3 77.9 91.9	0% 5% 35% 65% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]	43.0 48.6 50.1 50.4 77.9 91.9	0% 5% 35% 65% 95% 100%
Irrigation application, present-day climate, cattle forage (mm)	MO0306SPAAEIBM.001 [DIRS 163812]	50.0 56.5 57.5 60.2 71.0	0% 5% 72% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]	50.0 56.3 57.6 60.0 71.0	0% 5% 72% 95% 100%
Daily average irrigation rate, present-day climate, leafy vegetables (mm/day)	MO0306SPAAEIBM.001 [DIRS 163812]	4.00 5.11 5.19 5.21 5.38 5.46 5.98 7.06	0% 5% 20% 35% 50% 80% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]	4.00 5.11 5.19 5.21 5.38 5.48 6.00 7.08	0% 5% 20% 35% 50% 80% 95% 100%
Daily average irrigation rate, present-day climate, other vegetables (mm/day)	MO0306SPAAEIBM.001 [DIRS 163812]	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%	MO0403SPAAEIBM.002 [DIRS 169392]	5.00 6.07 6.65 6.93 7.67 8.36 9.03 9.26 10.93	0% 5% 20% 35% 50% 65% 80% 95% 100%

Table 4.1-5. Comparison of Input Parameters for This and Previous Revision of the Analysis (Continued)

Parameter Name	Previous Revision: DTN	Previous Revision: Parameter Value and Percentile for Cumulative Distribution		Current Revision: DTN	Current Revision: Parameter Value and Percentile for Cumulative Distribution	
Daily average irrigation rate, present-day climate, fruits (mm/day)	MO0306SPAAEIBM.001 [DIRS 163812]	4.00 5.38 7.00 7.56 8.35 8.60 10.15	0% 5% 28% 51% 72% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]	4.00 5.40 7.02 7.59 8.38 8.67 10.23	0% 5% 28% 51% 72% 95% 100%
Daily average irrigation rate, present-day climate, grains (mm/day)	MO0306SPAAEIBM.001 [DIRS 163812]	3.00 3.44 3.58 3.86 7.67 9.05	0% 5% 35% 65% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]	3.00 3.44 3.58 3.87 7.69 9.07	0% 5% 35% 65% 95% 100%
Daily average irrigation rate, present-day climate, cattle forage (mm/day)	MO0306SPAAEIBM.001 [DIRS 163812]	5.00 5.84 6.18 9.00 10.62	0% 5% 73% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]	5.00 5.85 6.18 9.02 10.64	0% 5% 73% 95% 100%
Overwatering rate, present-day climate (m/yr)	MO0306SPAAEIBM.001 [DIRS 163812]	0.009 0.030 0.045 0.076 0.128 0.233 0.275	0% 19% 38% 57% 76% 95% 100%	MO0403SPAAEIBM.002 [DIRS 169392]	0.009 0.030 0.045 0.077 0.129 0.233 0.275	0% 19% 38% 57% 76% 95% 100%
Environmental Transport Input Parameters						
Cesium transfer factor for leafy vegetables (both climates)	MO0306SPAETPBM.001 [DIRS 163814]	Lognormal distribution [a] GM = 1.2E−01 GSD = 2.5 Minimum = 1.2E−02 Maximum = 1.2E+00		MO0406SPAETPBM.002 [DIRS 170150]	Lognormal distribution [a] GM = 8.5E−02 GSD = 2.5 Minimum = 7.7E−03 Maximum = 9.4E−01	

Table 4.1-5. Comparison of Input Parameters for This and Previous Revision of the Analysis (Continued)

Parameter Name	Previous Revision		Current Revision	
	DTN	**Parameter Value and Percentile for Cumulative Distribution**	**DTN**	**Parameter Value and Percentile for Cumulative Distribution**
Cesium transfer coefficient for eggs	MO0306SPAETPBM.001 [DIRS 163814]	Lognormal distribution [a] GM = 5.9E−01 GSD = 2.3 Minimum = 7.2E−02 Maximum = 4.8E+00	MO0406SPAETPBM.002 [DIRS 170150]	Lognormal distribution [a] GM = 3.5E−01 GSD = 5.8 Minimum = 3.7E−03 Maximum = 3.3E+01
Selenium bioaccumulation factor	MO0306SPAETPBM.001 [DIRS 163814]	Upper truncation limit for the lognormal distribution Max = 1.2E+03	MO0406SPAETPBM.002 [DIRS 170150]	Upper truncation limit for the lognormal distribution Max = 1.4E+03
Characteristics of the Receptor				
Half-life of Pu-238	MO0306SPACRBSM.001 [DIRS 163813]	87.74E+01 years [b]	MO0407SPACRBSM.002 [DIRS 170677]	8.774E+01 years
Inhalation Exposure Input Parameters				
Parameter whose value changed is not used in the groundwater exposure scenario	MO0305SPAINEXI.001 [DIRS 163808]	N/A	MO0407SPAINEXI.002 [DIRS 170597]	N/A
Soil-related Input Parameters				
The DTN change concerns description of the parameter applicability for different climate states; parameter values remained the same	MO0305SPASRPBM.001 [DIRS 163815]	N/A	MO0407SPASRPBM.002 [DIRS 170755]	N/A

GM = geometric mean; GSD = geometric standard deviation

[a] Lognormal distribution defined using geometric mean and geometric standard deviation
[b] Typographical error in the DTN; the correct value was used in the model.

4.1.2 Calculation of Conversion Factors for Groundwater Protection Standard

Conversion factors for beta- and photon- emitting radionuclides were calculated using the data from Federal Guidance Report No. 11 (FGR 11) (DOE 2004 [DIRS 169713]). The values included in FGR 11 are considered established fact.

Data from FGR 12 (Eckerman and Ryman 1993 [DIRS 107684]) and the CRC Handbook of Chemistry and Physics (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) were also used. These data are considered established fact.

The data described above are listed and used in Section 6.3.

4.2 CRITERIA

Three requirements from the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], 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 166275], Table 2-3.

In addition to the requirements listed in Table 4.2-1, definition of terms in 10 CFR 63.2 and description of concepts in 10 CFR 63.102 [DIRS 156605] that are relevant to biosphere modeling are also applicable to this analysis.

Listed below are NRC (U.S. Nuclear Regulatory Commission) acceptance criteria (AC) from Sections 2.2.1.2.13 (Redistribution of Radionuclides in Soil) and 2.2.1.3.14 (Biosphere Characteristics) of the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) (YMRP), based on the requirements of 10 CFR 63.114, 63.305, and 63.312 [DIRS 156605], that were considered when modeling biosphere characteristics.

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

Acceptance Criterion 1, *System Description and Model Integration Are Adequate.*

(1) Total system performance assessment adequately incorporates important features, physical phenomena and couplings between different models, and uses consistent and appropriate assumptions throughout the abstraction of redistribution of radionuclides in the soil abstraction process;

(2) The total system performance assessment model abstraction identifies and describes aspects of redistribution of radionuclides in soil that are important to repository

performance, including the technical bases for these descriptions. For example, the abstraction should include modeling of the deposition of contaminated material in the soil and determination of the depth distribution of the deposited radionuclides;

(3) Relevant site features, events, and processes have been appropriately modeled in the abstraction of redistribution of radionuclides, from surface processes, and sufficient technical bases are provided; and

(4) Guidance in NUREG–1297 and NUREG–1298, or other acceptable approaches for peer reviews, is followed.

Acceptance Criterion 2, ***Data Are Sufficient for Model Justification.***

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

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

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

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

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

(3) Uncertainty is adequately represented in parameters for conceptual models, process models, and alternative conceptual models considered in developing the total system performance assessment abstraction of redistribution of radionuclides in soil, either through sensitivity analyses, conservative limits, or bounding values supported by

data, as necessary. Correlations between input values are appropriately established in the total system performance assessment.

Acceptance Criteria from Section 2.2.1.3.14, Biosphere Characteristics

Acceptance Criterion 1, *System Description and Model Integration Are Adequate.*

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

(4) Guidance in NUREG–1297 and NUREG–1298 or in other acceptable approaches for peer reviews, is followed.

Acceptance Criterion 2, *Data Are Sufficient for Model Justification.*

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

(2) Data are sufficient to assess the degree to which features, events, and processes related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63, the U.S. Department of Energyshould 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.

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

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

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

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

Despite the title of YMRP Section 2.2.1.3.12, *Concentrations of Radionuclides in Groundwater*, the ACs in that section do not apply to this report on BDCFs for the groundwater exposure scenario and conversion factors for evaluating compliance with the groundwater protection standard because these ACs address only the evaluation of the concentration of radionuclides in the groundwater and not the dose which would result from drinking or being exposed to that water.

Also, despite the title of YMRP Section 2.2.1.4.3, *Analysis of Performance that Demonstrates Compliance with the Separate Ground-Water Protection Standards*, and some references to dose, the ACs in that section do not apply to this report because they address only the evaluation of radionuclide concentrations and locations. Nevertheless, to the extent that these ACs are intended to address compliance with the separate groundwater protection standard, the conversion factors developed in this report are a necessary and accurate component of such a compliance demonstration, as discussed in Sections 4.1.2 and 6.3.

4.3 CODES, STANDARDS, AND REGULATIONS

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

5. ASSUMPTIONS

No assumptions were used in this analysis.

INTENTIONALLY LEFT BLANK

6. SCIENTIFIC ANALYSIS DISCUSSION

The objectives of this analysis were to calculate:

1. BDCFs for the groundwater exposure scenario—these BDCFs are used as input to the TSPA-LA model and allow calculating the annual dose to the reasonably maximally exposed individual (RMEI) from a given concentration of radionuclides in groundwater. The dose to the RMEI is used to evaluate compliance with the individual protection standard (10 CFR 63.311 [DIRS 156605]).

2. Conversion factors that are 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 are used in the TSPA-LA for evaluating compliance with the radionuclide concentration and dose limits of 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 (RMEI) 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 2003 [DIRS 166296], pp. 51 to 52). 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

The radionuclides of interest for the biosphere model depend on the exposure scenario, as discussed in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.1.3). The following twenty-eight radionuclides were identified as important for the TSPA-LA for scenario classes involving radionuclide releases to groundwater: 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 2004 [DIRS 169460], Section 6.1.3). 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 2003 [DIRS 166296], Section 1.3).

The biosphere model accounts for the decay products of the primary radionuclides. The short-lived decay products (half-lives 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 as a primary radionuclide or its long-lived decay product) (BSC 2004 [DIRS 169460], Section 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 2004 [DIRS 169460], 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, is presented in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], 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, crop irrigation, animal consumption, and fish farming.

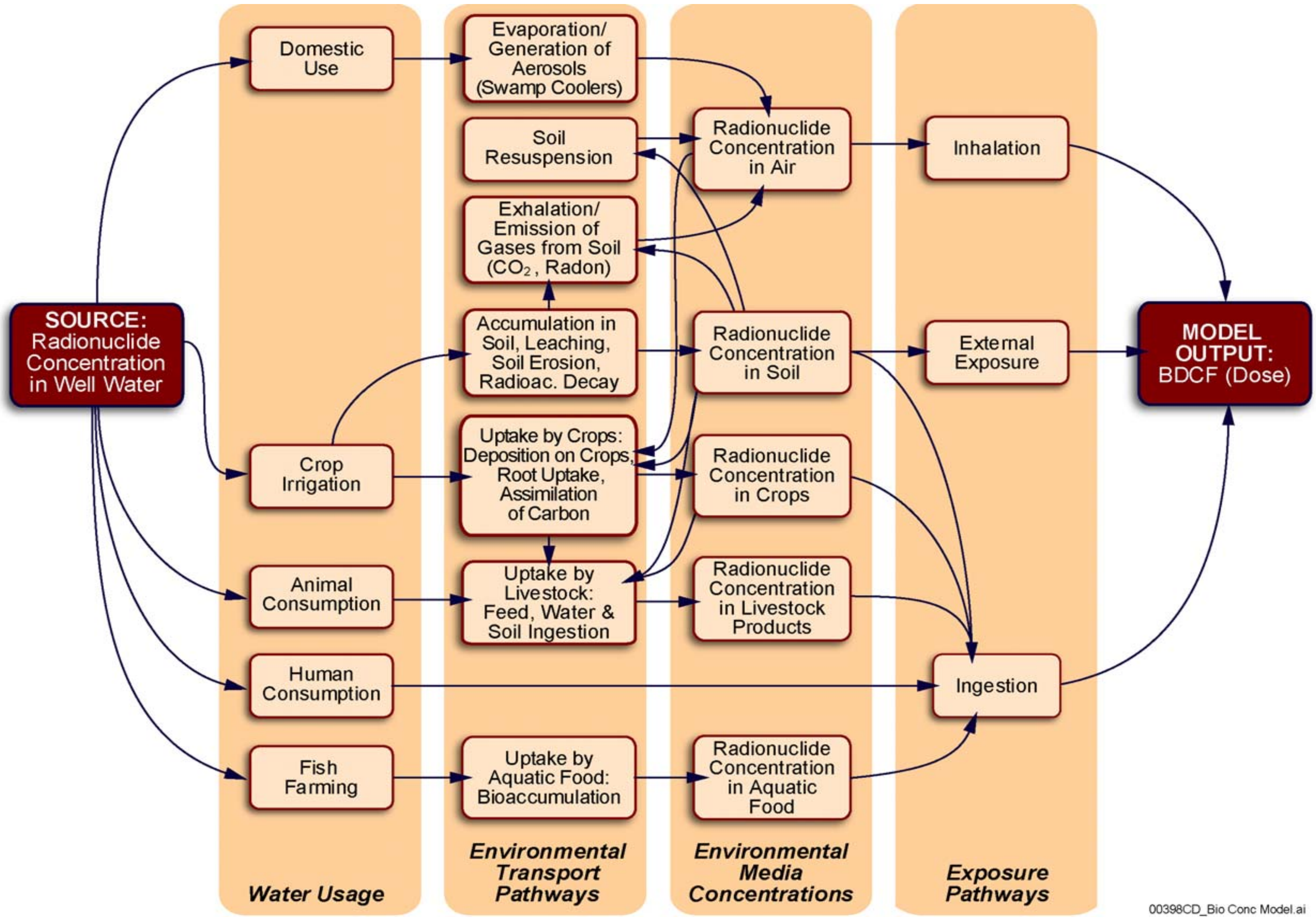


Figure 6.1-1. Conceptual Representation of the Biosphere Model for the Groundwater Exposure Scenario

6-3

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 on crop surfaces)
- Radionuclide deposition on crop surfaces by wet processes resulting from using contaminated irrigation water
- Translocation of contaminants from the deposition site to the edible tissues of vegetation
- Post–deposition retention by crops (including weathering processes)
- Radionuclide uptake by crops 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 direct (inhalation and ingestion) or indirect (external exposure) 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. Other activities and the associated exposures were evaluated for inclusion in the biosphere model (BSC 2004 [DIRS 169460]) but were not included because of low consequences. Such an approach did not underestimate the risk to the RMEI.

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 water and water-based beverages and water used in food preparation.
Soil	Ingestion	Inadvertent soil ingestion.	Recreational activities, occupational activities, gardening, and consumption of fresh fruit and vegetables.
	External	External radiation exposure.	Activities on or near contaminated soils.
Air	Inhalation	Breathing resuspended particles, gases (^{222}Rn and progeny, plus $^{14}CO_2$), and aerosols from evaporative coolers.	Any outdoor activities, including soil-disturbing activities related to work and recreation. Domestic activities, including sleeping.
Plants	Ingestion	Consumption of locally produced crops: leafy vegetables, other vegetables, fruit, and grain.	Eating contaminated crop foodstuffs.
Animals	Ingestion	Consumption of locally produced animal products: meat, poultry, milk, and eggs.	Eating contaminated animal product foodstuffs.
Fish	Ingestion	Consumption of locally produced freshwater fish.	Eating fish.

Source: BSC 2004 [DIRS 169460], 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.

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 forecasted based on the study of past climates (BSC 2004 [DIRS 170002], Section 1). Temperature and precipitation records from present-day meteorological stations at colder and wetter sites were selected to represent future climate states (BSC 2004 [DIRS 170002], Section 6.6.1). The forecasted future climate states, durations, and future climate analogue locations are summarized in Table 6.1-2.

Table 6.1-2. Predicted Future Climates and the Future Climate Analogue Locations

Climate State	Duration	Representative Meteorological Stations
Present-day 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: BSC 2004 [DIRS 170002], Table 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 present-day climate), and glacial transition climate (colder than monsoon but similar precipitation) (BSC 2003 [DIRS 166296], p. 79). Within the TSPA-LA 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 6.2.2).

A proportionality function was developed based on BDCFs for the present-day (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, forecasted 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 present-day 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). The BDCFs for a given radionuclide appear to be 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 present-day climate and the upper bound of the glacial transition climate (Section 6.2.2).

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 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 that (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 metabolically and 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 2004 [DIRS 169671]).

6.1.5 Biosphere Model

This analysis was performed using a verified and validated model, ERMYN, which is described in the *Biosphere Model Report* (BSC 2004 [DIRS 169460]). The model files were obtained from the Model Warehouse (DTN: MO0306MWDBGSMF.001 [DIRS 163816]). Additional verification of the model files for GoldSim version 8.01 SP4 is presented in Appendix E.

The ERMYN model (BSC 2004 [DIRS 169460]), 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 2004 [DIRS 169460]), which describes the ERMYN model:

1. Describes the biosphere model objectives, reference biosphere, human receptor, exposure scenarios, environmental transport pathways, and human exposure pathways (BSC 2004 [DIRS 169460], Section 6.1).

2. Develops the conceptual model based on site-specific FEPs, the reference biosphere and human receptor, and a number of other approximations (BSC 2004 [DIRS 169460], Sections 6.2 and 6.3).

3. Describes the mathematical model and submodels based on the conceptual model and other published biosphere models (BSC 2004 [DIRS 169460], Sections 6.4 and 6.5).

4. Summarizes model input parameters and uncertainty distributions (BSC 2004 [DIRS 169460], Section 6.6).

5. Identifies model improvements compared with the previous biosphere model (BSC 2004 [DIRS 169460], Section 6.7).

6. Constructs the ERMYN implementation tool based on the mathematical model using GoldSim stochastic simulation software (BSC 2004 [DIRS 169460], Sections 6.8 and 6.9).

7. Verifies the ERMYN implementation tool in GoldSim (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169460], 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:

- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673]).

- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671]).

- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672]).

- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458]).

- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459]).

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.

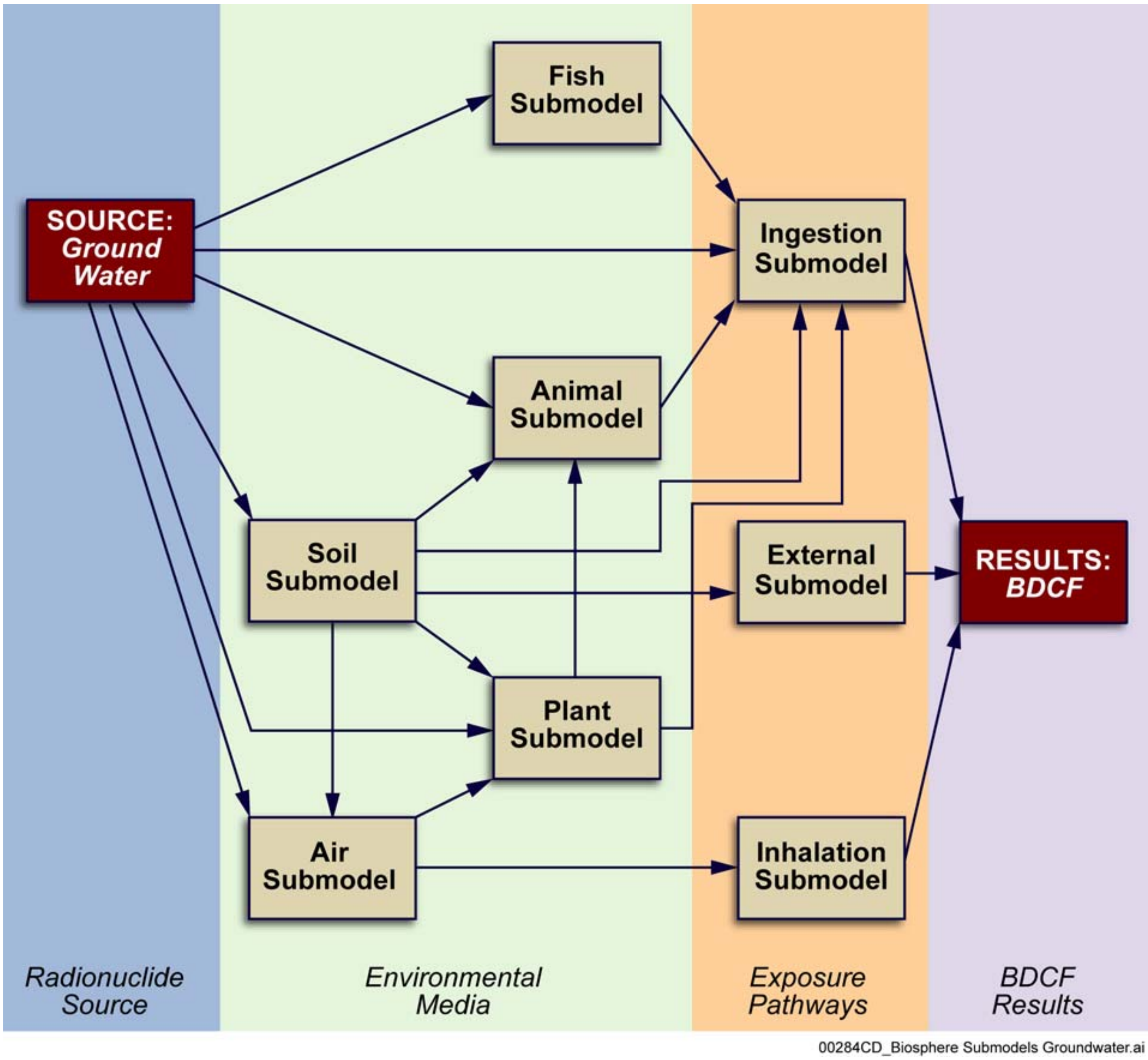


Figure 6.1-2. Relationships Among Submodels for the Groundwater Exposure Scenario

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

The BDCFs for the 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. A 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 groundwater exposure 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 method for consistency with the sampling technique to be used in TSPA (BSC 2003 [DIRS 166296], 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 present-day (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 present-day 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 present-day climate and the upper bound of the glacial transition climate, which is forecasted to start in about 2,000 years and last through the compliance period (BSC 2004 [DIRS 170002]). For the upper bound of the glacial transition climate, climate-dependent model input parameters were based on future climate analogue 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 first calculated for two climates (the present-day climate and one future climate state, represented by 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. In the next step, the BDCFs for the monsoon and the glacial transition climates were calculated as described in this section.

Table 6.2-1. Mean Biosphere Dose Conversion Factors for Climate Extremes and Their Ratios

Radionuclide	Mean BDCF, rem/yr per pCi/L		BDCF Ratio (Glacial Transition to Present-Day Climate)
	Present-Day Climate	Glacial Transition Climate- Upper Bound	
C-14	9.10E−06	8.52E−06	0.94
Cl-36	2.07E−05	1.55E−05	0.75
Se-79	6.19E−05	3.97E−05	0.64
Sr-90	1.64E−04	1.43E−04	0.87
Tc-99	2.26E−06	1.93E−06	0.85
Sn-126	6.33E−03	3.51E−03	0.55
I-129	3.36E−04	2.91E−04	0.86
Cs-135	5.57E−05	3.39E−05	0.61
Cs-137	4.82E−04	2.85E−04	0.59
Pb-210	9.04E−03	7.48E−03	0.83
Ra-226	9.69E−02	5.71E−02	0.59
Ac-227	3.11E−02	1.75E−02	0.56
Th-229	3.41E−02	1.84E−02	0.54
Th-230	2.93E−02	1.72E−02	0.59
Th-232	4.45E−02	2.44E−02	0.55
Pa-231	1.01E−01	5.76E−02	0.57
U-232	5.82E−03	3.26E−03	0.56
U-233	1.86E−03	1.06E−03	0.57
U-234	1.28E−03	7.27E−04	0.57
U-236	1.14E−03	6.43E−04	0.57
U-238	1.13E−03	6.44E−04	0.57
Np-237	6.98E−03	5.13E−03	0.73
Pu-238	4.69E−03	3.38E−03	0.72
Pu-239	9.25E−03	5.96E−03	0.64
Pu-240	9.01E−03	5.83E−03	0.65
Pu-242	8.91E−03	5.73E−03	0.64
Am-241	6.83E−03	4.65E−03	0.68
Am-243	9.57E−03	6.14E−03	0.64

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150]; MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: The mean BDCF values and their ratios were calculated using Excel (*GW BDCF Realizations_MC and FC_Rev 3.xls*; Appendix B).

The BDCF values for the upper bound of the glacial transition climate are consistently lower than the corresponding values for the present-day climate. The differences between the BDCFs are about a factor of less than two. For example, the ratios of the BDCFs for the glacial transition and the present-day climates for four radionuclides identified as important in the previous TSPA effort (BSC 2001 [DIRS 154659], Figures 4.1-8a and 4.1-8b) were 0.94 for ^{14}C, 0.85 for ^{99}Tc, 0.86 for ^{129}I, and 0.73 for ^{237}Np. Inspection of the BDCF distributions for the present-day climate (see 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, 3.4 for ^{99}Tc, 2.1 for ^{129}I, and 2.7 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 present-day 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 Their Average Values for the Present-Day Climate and the Upper Bound of the Glacial Transition Climate

Parameter	Present-Day Climate	Glacial Transition Climate (Upper Bound)
Growing time, other vegetables	80 days	100 days
Growing time, fruits	160 days	105 days
Growing time, grains	200 days	185 days
Growing time, cattle forage	75 days	90 days
Irrigation application, leafy vegetables	14.7 mm	14.6 mm
Irrigation application, other vegetables	26.0 mm	25.0 mm
Irrigation application, fruits	33.9 mm	34.2 mm
Irrigation application, grains	56.7 mm	51.3 mm
Irrigation application, cattle forage	57.8 mm	53.5 mm
Average annual irrigation rate	0.95 m/yr	0.50 m/yr
Daily average irrigation rate, leafy vegetables	5.41 mm/day	3.81 mm/day
Daily average irrigation rate, other vegetables	7.71 mm/day	3.84 mm/day
Daily average irrigation rate, fruits	7.41 mm/day	3.90 mm/day
Daily average irrigation rate, grains	4.64 mm/day	3.36 mm/day
Daily average irrigation rate, cattle forage	6.55 mm/day	4.14 mm/day
Overwatering rate	0.079 m/yr	0.067 m/yr
Water concentration modifying factor (for fisheries)	4.15 [a]	2.4 [a]
Evaporative cooler use factor	0.39	0.085

Source: MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150].

[a] All radionuclides except C-14, for which 1 was used.

The model was then 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).

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
C-14	−0.0186	−0.0041	0.0004	−0.0266	0.0369	0.0170	−0.0177	−0.0331	0.0106
Cl-36	−0.0103	0.0040	0.0290	0.0100	0.0007	−0.0305	0.0140	0.0294	−0.0230
Se-79	0.0031	0.0324	−0.0234	0.0102	−0.0195	0.0155	0.0341	−0.0419	0.0020
Sr-90	0.0019	0.0325	0.0189	−0.0076	0.0746	0.0082	0.0669	0.0057	−0.0422
Tc-99	0.0507	0.0947	0.0235	0.0422	0.0209	0.0135	0.0194	0.0485	−0.1193
Sn-126	0.0189	0.0391	0.0490	0.0141	0.0477	−0.0167	−0.0193	−0.0397	0.0210
I-129	0.0203	0.0245	−0.0308	0.0312	−0.0171	0.0417	0.0334	0.0134	−0.0539
Cs-135	0.0223	0.0464	0.0163	−0.0126	−0.0162	0.0654	0.0064	0.0192	−0.0236
Cs-137	0.0394	−0.0030	0.0441	−0.0017	0.0294	−0.0016	0.0215	0.0082	−0.0517
Pb-210	0.0203	0.0138	0.0056	−0.0145	0.0272	0.0296	0.0173	−0.0426	−0.0099
Ra-226	−0.0057	0.0480	0.0178	0.0011	0.0267	0.0078	0.0341	−0.0375	0.0296
Ac-227	−0.0033	−0.0213	0.0299	−0.0192	0.0253	−0.0198	−0.0347	−0.0121	−0.0133
Th-229	0.0160	0.0402	0.0348	−0.0214	−0.0079	−0.0356	0.0081	−0.0047	−0.0111
Th-230	0.0054	0.0604	0.0151	−0.0098	−0.0012	0.0055	0.0182	−0.0097	0.0458
Th-232	0.0199	0.0491	0.0273	−0.0299	−0.0016	−0.0379	0.0127	−0.0102	−0.0067
Pa-231	0.0353	0.0638	0.0347	0.0134	−0.0152	−0.0218	0.0271	−0.0286	−0.0012
U-232	−0.0477	−0.0149	−0.0091	−0.0493	−0.0075	0.0190	−0.0111	−0.0078	−0.0109
U-233	−0.0375	−0.0010	−0.0313	−0.0361	−0.0415	0.0294	−0.0078	−0.0077	−0.0032
U-234	−0.0421	−0.0055	−0.0296	−0.0364	−0.0339	0.0320	−0.0036	−0.0065	−0.0088
U-236	−0.0453	−0.0087	−0.0301	−0.0400	−0.0316	0.0343	−0.0042	−0.0069	−0.0104
U-238	−0.0443	−0.0085	−0.0314	−0.0411	−0.0321	0.0344	−0.0036	−0.0076	−0.0104
Np-237	−0.0019	0.0577	0.0147	−0.0197	0.0233	0.0008	−0.0266	0.0137	−0.0052
Pu-238	0.0134	0.0162	0.0188	−0.0182	0.0162	−0.0025	−0.0059	0.0195	−0.0229
Pu-239	0.0508	0.0459	0.0176	−0.0033	0.0136	−0.0138	0.0165	−0.0139	−0.0141
Pu-240	0.0486	0.0448	0.0174	−0.0026	0.0143	−0.0137	0.0163	−0.0130	−0.0153
Pu-242	0.0517	0.0467	0.0177	−0.0032	0.0131	−0.0140	0.0165	−0.0142	−0.0140
Am-241	0.0193	0.0210	0.0417	−0.0098	0.0111	−0.0294	0.0318	−0.0125	−0.0152
Am-243	0.0278	0.0446	0.0285	−0.0103	−0.0053	−0.0190	0.0446	−0.0335	−0.0005

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 concen-tration modifying factor	Evaporative Cooler Use Factor
		Leafy Vegeta-bles	Other Vege-tables	Fruits	Grains	Cattle Forage			
C-14	−0.0900	0.0121	0.1062	0.0619	0.0020	0.0675	−0.0011	0.0000	0.0073
Cl-36	0.2499	−0.0313	0.0439	0.0063	−0.0136	0.0187	−0.0284	0.0462	−0.0091
Se-79	0.1326	0.0482	0.0268	0.0015	−0.0189	0.0140	0.0339	0.0105	−0.0027
Sr-90	0.2336	0.0344	0.0094	0.0619	−0.0230	0.0564	−0.0233	0.0581	0.0302
Tc-99	0.1896	0.0688	0.0264	0.0024	−0.0357	0.0055	−0.0453	0.0124	0.0405
Sn-126	0.2343	−0.0116	0.0265	0.0055	0.0196	−0.0208	−0.0059	−0.0097	0.0207
I-129	0.0799	0.0429	0.0132	0.0124	0.0111	0.0534	0.0222	0.0019	−0.0053
Cs-135	0.0881	0.0273	−0.0124	0.0163	−0.0313	−0.0216	−0.0054	0.1291	0.0068
Cs-137	0.2018	0.0053	−0.0199	0.0436	−0.0202	−0.0579	−0.0155	0.1207	0.0317
Pb-210	0.0730	0.0308	0.0480	−0.0204	−0.0005	−0.0104	0.0694	0.1329	0.0198
Ra-226	0.3578	−0.0125	0.0528	−0.0050	−0.0099	0.0072	−0.0266	0.0058	−0.0955
Ac-227	0.1138	0.0451	0.0956	0.0172	0.0008	−0.0055	−0.0180	0.0367	0.3832
Th-229	0.2144	0.0037	0.0694	0.0077	0.0313	0.0217	0.0077	−0.0177	0.0366
Th-230	0.1972	0.0139	0.0328	−0.0116	0.0145	0.0136	−0.0147	−0.0327	−0.0715
Th-232	0.2522	0.0025	0.0571	0.0044	0.0353	0.0198	0.0055	−0.0235	0.0106
Pa-231	0.2171	0.0066	0.0758	0.0059	0.0326	−0.0111	−0.0082	−0.0224	−0.0290
U-232	0.1043	0.0069	0.0551	−0.0310	−0.0396	0.0310	−0.0367	0.0573	0.2617
U-233	0.0379	−0.0111	0.0165	−0.0317	−0.0454	0.0496	−0.0420	0.0279	0.0930
U-234	0.0417	−0.0095	0.0198	−0.0302	−0.0504	0.0484	−0.0388	0.0329	0.1256
U-236	0.0384	−0.0085	0.0227	−0.0301	−0.0514	0.0476	−0.0352	0.0359	0.1341
U-238	0.0394	−0.0097	0.0202	−0.0298	−0.0516	0.0477	−0.0355	0.0359	0.1279
Np-237	0.1605	0.0288	0.0813	0.0171	−0.0276	0.0190	−0.0275	0.0117	0.1824
Pu-238	0.1578	0.0098	0.1095	0.0337	0.0007	−0.0008	0.0293	0.0412	0.2320
Pu-239	0.2064	0.0144	0.0998	0.0186	0.0136	−0.0121	0.0138	−0.0074	0.0501
Pu-240	0.2100	0.0132	0.1023	0.0195	0.0132	−0.0114	0.0134	−0.0053	0.0541
Pu-242	0.2050	0.0147	0.0991	0.0181	0.0135	−0.0129	0.0139	−0.0081	0.0486
Am-241	0.2218	0.0460	0.1010	0.0266	−0.0243	−0.0070	−0.0198	0.0374	0.1258
Am-243	0.1998	0.0464	0.0882	0.0135	0.0013	−0.0151	−0.0245	0.0094	0.0412

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150]; MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: Values were calculated using Excel (*Correlations for climate dependent parameters_Rev 3.xls*; Appendix B). Correlation coefficients in shaded cells differ significantly from zero at the 99% confidence level.

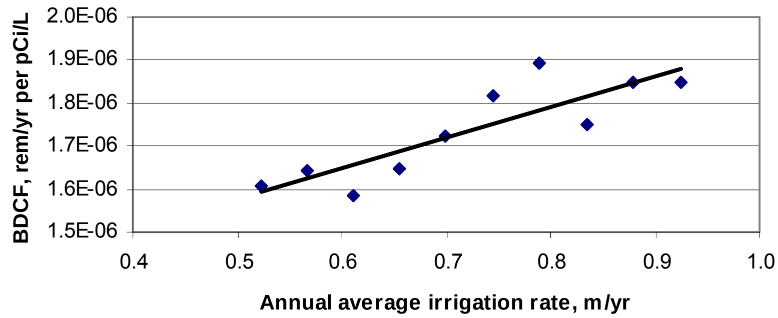
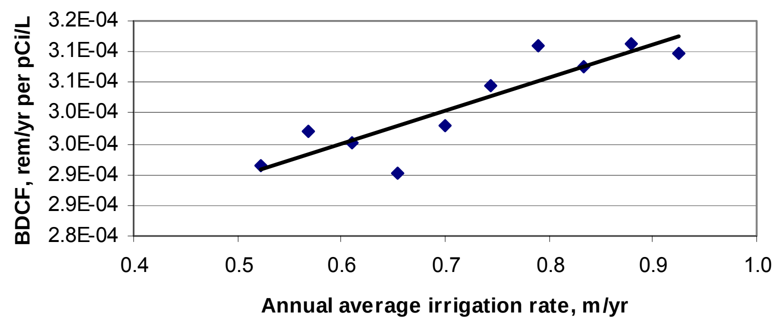
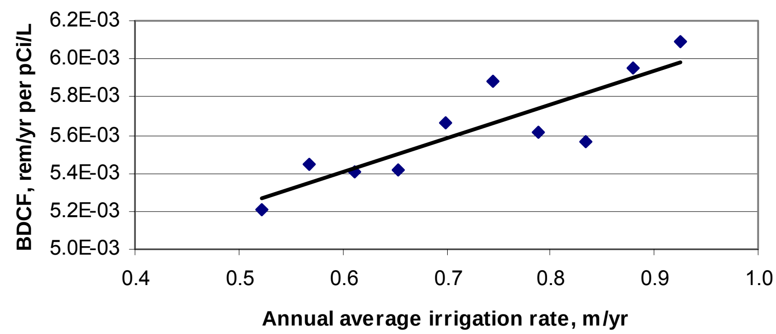
The shaded cells contain correlation coefficients with values that differ from zero at the 99 percent confidence level (see Section 6.2.3 for discussion of the statistical test to determine values of correlation coefficients that represent true correlation at a given confidence level). The calculations were carried out using Excel (*Correlations for climate dependent parameters_Rev 3.xls*; Appendix B).

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_Rev 3.xls*; Appendix B).

BDCFs for 9 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 fishpond water concentration modifying factor because all these parameters have higher values in hotter climates. 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 average annual 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 mean BDCF for ^{14}C for the upper bound of the glacial transition climate is less than the mean BDCF for the present-day climate (Table 6.2-1) 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 6.2-4. 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	1.61E−06	
101-200	5.67E−01	1.64E−06	
201-300	6.11E−01	1.58E−06	
301-400	6.54E−01	1.65E−06	
401-500	6.99E−01	1.72E−06	
501-600	7.44E−01	1.82E−06	
601-700	7.89E−01	1.89E−06	
701-800	8.34E−01	1.75E−06	
801-900	8.79E−01	1.85E−06	
901-1000	9.24E−01	1.85E−06	
Iodine-129			
1-100	5.22E−01	2.92E−04	
101-200	5.67E−01	2.97E−04	
201-300	6.11E−01	2.95E−04	
301-400	6.54E−01	2.90E−04	
401-500	6.99E−01	2.98E−04	
501-600	7.44E−01	3.05E−04	
601-700	7.89E−01	3.11E−04	
701-800	8.34E−01	3.08E−04	
801-900	8.79E−01	3.11E−04	
901-1000	9.24E−01	3.10E−04	
Neptunium-237			
1-100	5.22E−01	5.21E−03	
101-200	5.67E−01	5.45E−03	
201-300	6.11E−01	5.41E−03	
301-400	6.54E−01	5.42E−03	
401-500	6.99E−01	5.66E−03	
501-600	7.44E−01	5.88E−03	
601-700	7.89E−01	5.61E−03	
701-800	8.34E−01	5.57E−03	
801-900	8.79E−01	5.95E−03	
901-1000	9.24E−01	6.09E−03	

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0306MWDBGSMF.001 [DIRS 163816]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150].

NOTE: Values were calculated using Excel (*Dependence of BDCFs on Irrigation Rate_Rev 3.xls*; Appendix B).

[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 annual average irrigation rate (Table 6.2-4), 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 present-day and the upper bound of the glacial transition climates. The strength of the observed dependencies shows that BDCFs can be scaled with the average annual irrigation rate. Based on the future climate analogue sites (DTN: MO0403SPAAEIBM.002 [DIRS 169392]), values of the average annual irrigation rates are:

- 0.95 m/yr for the present-day 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.

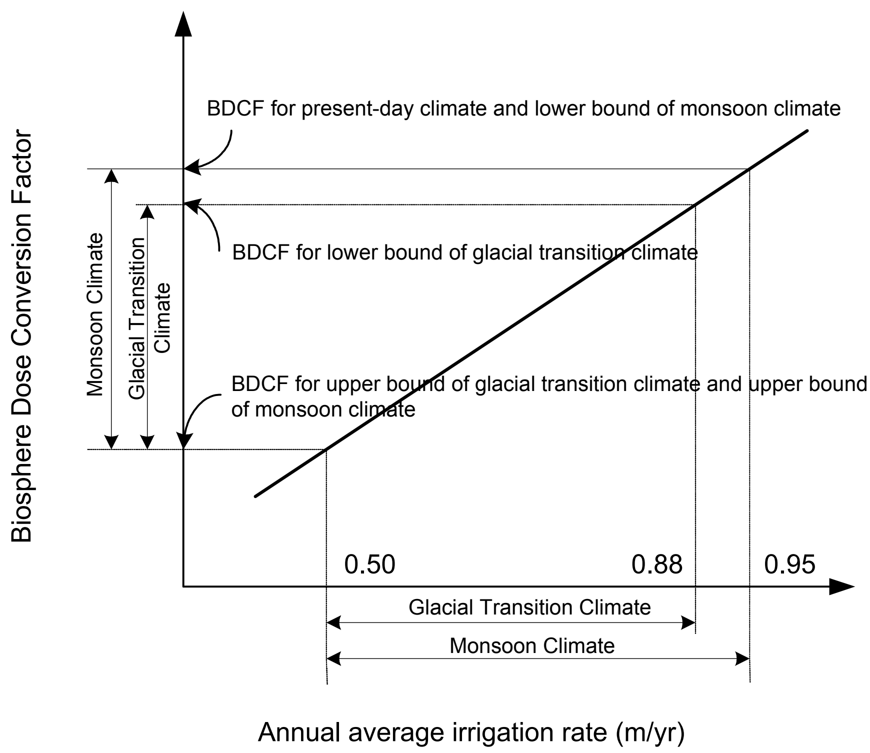


Figure 6.2-1. Scaling of the Biosphere Dose Conversion Factors

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

$$BDCF_{LBGT} = BDCF_{UBGT} + \frac{0.88 - 0.50}{0.95 - 0.50}(BDCF_{IC} - BDCF_{UBGT}) \qquad \text{(Eq. 6.2-1)}$$

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 present-day climate (interglacial)
$\frac{0.88 - 0.50}{0.95 - 0.50}$	=	Scaling factor equal to the difference in average annual irrigation rates between the lower and upper bounds of the glacial transition climate divided by the difference in average annual irrigation rates between the present-day 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 present-day 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

$$BDCF_{GTC} = BDCF_{UBGT} + \frac{0.88 - 0.50}{0.95 - 0.50}(BDCF_{IC} - BDCF_{UBGT})\ RAND \qquad \text{(Eq. 6.2-3)}$$

where

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

These calculations were performed using Excel (*GW BDCF Realizations_MC and FC_Rev 3.xls*; Appendix B).

6.2.3 Modeling Results: Biosphere Dose Conversion Factors

BDCFs for the present-day 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 *GW BDCF Realizations_MC and FC_Rev 3.xls*

(Appendix B). Summary statistics for the BDCFs are presented in Tables 6.2-5 to 6.2-7 for the present-day 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 percent.

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. In addition, the combined value of BDCF for ^{226}Ra and ^{210}Pb is provided, in case the concentration of ^{210}Pb in groundwater is not calculated in the TSPA-LA model. The combined ^{226}Ra – ^{210}Pb value was calculated for the activity concentration of ^{210}Pb in groundwater equal to that of ^{226}Ra, i.e., for the condition of radioactive equilibrium between these two radionuclides.

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

	C-14	**Cl-36**	**Se-79**	**Sr-90**	**Tc-99**	**Sn-126**	**I-129**	**Cs-135**	**Cs-137**	**Pb-210**	**Ra-226**
Mean	9.10E−06	2.07E−05	6.19E−05	1.64E−04	2.26E−06	6.33E−03	3.36E−04	5.57E−05	4.82E−04	9.04E−03	9.69E−02
STD	6.67E−06	4.23E−05	1.05E−04	2.57E−05	2.38E−06	3.94E−03	1.14E−04	4.01E−05	2.28E−04	3.54E−03	4.77E−02
Minimum	4.15E−06	3.43E−06	9.71E−06	1.23E−04	1.18E−06	2.03E−04	2.21E−04	1.15E−05	1.52E−04	5.80E−03	2.48E−03
5%	4.92E−06	5.21E−06	1.50E−05	1.35E−04	1.31E−06	1.12E−03	2.43E−04	1.90E−05	2.33E−04	6.26E−03	3.89E−02
10%	5.20E−06	5.78E−06	1.77E−05	1.39E−04	1.36E−06	1.85E−03	2.51E−04	2.22E−05	2.59E−04	6.45E−03	4.69E−02
15%	5.47E−06	6.52E−06	1.98E−05	1.43E−04	1.42E−06	2.57E−03	2.58E−04	2.53E−05	2.84E−04	6.61E−03	5.26E−02
20%	5.66E−06	7.07E−06	2.18E−05	1.45E−04	1.46E−06	3.15E−03	2.64E−04	2.82E−05	3.01E−04	6.76E−03	5.79E−02
25%	5.90E−06	7.73E−06	2.40E−05	1.48E−04	1.51E−06	3.60E−03	2.70E−04	3.10E−05	3.26E−04	6.94E−03	6.25E−02
30%	6.09E−06	8.65E−06	2.65E−05	1.50E−04	1.55E−06	3.97E−03	2.78E−04	3.35E−05	3.47E−04	7.11E−03	6.75E−02
35%	6.34E−06	9.51E−06	2.82E−05	1.52E−04	1.61E−06	4.25E−03	2.84E−04	3.62E−05	3.64E−04	7.25E−03	7.20E−02
40%	6.54E−06	1.05E−05	3.05E−05	1.54E−04	1.67E−06	4.56E−03	2.91E−04	3.91E−05	3.85E−04	7.46E−03	7.73E−02
45%	6.83E−06	1.16E−05	3.29E−05	1.56E−04	1.72E−06	5.08E−03	2.99E−04	4.17E−05	4.03E−04	7.69E−03	8.20E−02
50%	7.04E−06	1.28E−05	3.57E−05	1.59E−04	1.78E−06	5.54E−03	3.09E−04	4.53E−05	4.27E−04	7.94E−03	8.81E−02
55%	7.36E−06	1.42E−05	3.84E−05	1.62E−04	1.85E−06	5.98E−03	3.16E−04	4.85E−05	4.51E−04	8.20E−03	9.33E−02
60%	7.78E−06	1.56E−05	4.25E−05	1.64E−04	1.93E−06	6.47E−03	3.29E−04	5.17E−05	4.74E−04	8.47E−03	9.93E−02
65%	8.35E−06	1.76E−05	4.75E−05	1.66E−04	2.03E−06	6.96E−03	3.39E−04	5.57E−05	5.09E−04	8.83E−03	1.06E−01
70%	8.84E−06	1.93E−05	5.33E−05	1.71E−04	2.14E−06	7.75E−03	3.50E−04	6.09E−05	5.38E−04	9.19E−03	1.14E−01
75%	9.55E−06	2.22E−05	6.15E−05	1.75E−04	2.30E−06	8.53E−03	3.64E−04	6.60E−05	5.73E−04	9.66E−03	1.21E−01
80%	1.06E−05	2.53E−05	7.22E−05	1.79E−04	2.49E−06	9.35E−03	3.83E−04	7.35E−05	6.21E−04	1.04E−02	1.32E−01
85%	1.19E−05	2.91E−05	9.01E−05	1.86E−04	2.85E−06	1.03E−02	4.07E−04	8.74E−05	6.76E−04	1.12E−02	1.44E−01
90%	1.40E−05	3.71E−05	1.19E−04	1.95E−04	3.46E−06	1.16E−02	4.50E−04	1.04E−04	7.51E−04	1.26E−02	1.63E−01
95%	2.05E−05	5.33E−05	1.67E−04	2.13E−04	4.41E−06	1.42E−02	5.18E−04	1.32E−04	9.28E−04	1.60E−02	1.84E−01
Maximum	9.35E−05	8.85E−04	1.89E−03	3.78E−04	6.19E−05	2.03E−02	1.98E−03	4.77E−04	1.69E−03	3.66E−02	4.27E−01

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

	Ra-226 +Pb-210	**Ac-227**	**Th-229**	**Th-230**	**Th-232**	**Pa-231**	**U-232**	**U-233**	**U-234**	**U-236**	**U-238**
Mean	1.06E−01	3.11E−02	3.41E−02	2.93E−02	4.45E−02	1.01E−01	5.82E−03	1.86E−03	1.28E−03	1.14E−03	1.13E−03
STD	4.81E−02	1.08E−02	1.86E−02	2.58E−02	2.28E−02	6.66E−02	2.33E−03	2.20E−03	1.13E−03	9.64E−04	9.56E−04
Minimum	1.18E−02	1.36E−02	4.80E−03	1.04E−03	6.60E−03	1.01E−02	1.83E−03	2.36E−04	2.29E−04	2.17E−04	2.17E−04
5%	4.67E−02	1.76E−02	1.28E−02	5.82E−03	1.81E−02	3.13E−02	2.73E−03	3.46E−04	3.29E−04	3.10E−04	3.07E−04
10%	5.54E−02	1.94E−02	1.54E−02	7.26E−03	2.10E−02	3.71E−02	3.22E−03	4.18E−04	3.98E−04	3.73E−04	3.69E−04
15%	6.13E−02	2.05E−02	1.75E−02	8.88E−03	2.39E−02	4.42E−02	3.55E−03	5.00E−04	4.57E−04	4.25E−04	4.19E−04
20%	6.70E−02	2.19E−02	1.96E−02	1.01E−02	2.65E−02	4.96E−02	3.91E−03	5.61E−04	5.10E−04	4.76E−04	4.70E−04
25%	7.15E−02	2.32E−02	2.11E−02	1.13E−02	2.87E−02	5.49E−02	4.16E−03	6.06E−04	5.62E−04	5.26E−04	5.17E−04
30%	7.62E−02	2.42E−02	2.29E−02	1.29E−02	3.07E−02	6.12E−02	4.46E−03	6.67E−04	6.06E−04	5.64E−04	5.56E−04
35%	8.14E−02	2.53E−02	2.46E−02	1.44E−02	3.21E−02	6.57E−02	4.72E−03	7.45E−04	6.57E−04	6.12E−04	5.97E−04
40%	8.56E−02	2.66E−02	2.65E−02	1.61E−02	3.50E−02	7.11E−02	4.91E−03	8.22E−04	7.27E−04	6.71E−04	6.58E−04
45%	9.06E−02	2.80E−02	2.85E−02	1.83E−02	3.71E−02	7.61E−02	5.18E−03	9.13E−04	7.90E−04	7.31E−04	7.25E−04
50%	9.67E−02	2.94E−02	3.00E−02	2.08E−02	4.00E−02	8.28E−02	5.45E−03	1.05E−03	8.57E−04	7.87E−04	7.84E−04
55%	1.03E−01	3.09E−02	3.19E−02	2.32E−02	4.24E−02	8.85E−02	5.69E−03	1.16E−03	9.85E−04	9.04E−04	8.99E−04
60%	1.09E−01	3.23E−02	3.36E−02	2.62E−02	4.45E−02	9.76E−02	5.99E−03	1.35E−03	1.08E−03	9.95E−04	9.90E−04
65%	1.15E−01	3.37E−02	3.62E−02	2.87E−02	4.71E−02	1.06E−01	6.34E−03	1.56E−03	1.22E−03	1.11E−03	1.10E−03
70%	1.24E−01	3.51E−02	3.88E−02	3.40E−02	5.02E−02	1.16E−01	6.68E−03	1.83E−03	1.36E−03	1.24E−03	1.23E−03
75%	1.32E−01	3.69E−02	4.19E−02	3.84E−02	5.45E−02	1.25E−01	7.12E−03	2.15E−03	1.54E−03	1.39E−03	1.40E−03
80%	1.41E−01	3.90E−02	4.56E−02	4.47E−02	5.95E−02	1.43E−01	7.50E−03	2.61E−03	1.82E−03	1.60E−03	1.62E−03
85%	1.54E−01	4.12E−02	5.05E−02	5.23E−02	6.64E−02	1.61E−01	7.96E−03	3.20E−03	2.11E−03	1.88E−03	1.89E−03
90%	1.70E−01	4.49E−02	5.82E−02	6.30E−02	7.48E−02	1.95E−01	8.76E−03	4.36E−03	2.73E−03	2.40E−03	2.35E−03
95%	1.94E−01	5.03E−02	7.11E−02	8.67E−02	8.82E−02	2.34E−01	9.98E−03	6.49E−03	3.63E−03	3.06E−03	3.07E−03
Maximum	4.37E−01	1.09E−01	1.20E−01	1.63E−01	1.46E−01	5.68E−01	1.68E−02	1.55E−02	7.76E−03	6.87E−03	6.68E−03

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

	Np-237	Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Am-243
Mean	6.98E−03	4.69E−03	9.25E−03	9.01E−03	8.91E−03	6.83E−03	9.57E−03
STD	2.50E−03	1.14E−03	3.75E−03	3.52E−03	3.67E−03	2.06E−03	4.23E−03
Minimum	3.85E−03	2.90E−03	3.73E−03	3.73E−03	3.56E−03	2.97E−03	2.96E−03
5%	4.45E−03	3.37E−03	5.09E−03	5.04E−03	4.86E−03	4.29E−03	4.75E−03
10%	4.77E−03	3.57E−03	5.54E−03	5.47E−03	5.30E−03	4.71E−03	5.35E−03
15%	4.99E−03	3.68E−03	5.96E−03	5.87E−03	5.70E−03	5.02E−03	5.81E−03
20%	5.19E−03	3.81E−03	6.28E−03	6.21E−03	6.01E−03	5.21E−03	6.25E−03
25%	5.37E−03	3.91E−03	6.60E−03	6.53E−03	6.32E−03	5.40E−03	6.71E−03
30%	5.56E−03	4.04E−03	6.85E−03	6.77E−03	6.55E−03	5.58E−03	7.02E−03
35%	5.75E−03	4.13E−03	7.18E−03	7.08E−03	6.87E−03	5.86E−03	7.35E−03
40%	5.91E−03	4.26E−03	7.60E−03	7.51E−03	7.28E−03	6.05E−03	7.71E−03
45%	6.10E−03	4.35E−03	7.96E−03	7.79E−03	7.64E−03	6.26E−03	8.17E−03
50%	6.37E−03	4.45E−03	8.35E−03	8.20E−03	8.02E−03	6.45E−03	8.62E−03
55%	6.57E−03	4.56E−03	8.72E−03	8.57E−03	8.41E−03	6.62E−03	9.11E−03
60%	6.82E−03	4.70E−03	9.14E−03	8.94E−03	8.77E−03	6.87E−03	9.48E−03
65%	7.06E−03	4.82E−03	9.64E−03	9.37E−03	9.28E−03	7.09E−03	1.01E−02
70%	7.44E−03	4.99E−03	1.02E−02	9.99E−03	9.84E−03	7.42E−03	1.07E−02
75%	7.89E−03	5.19E−03	1.09E−02	1.06E−02	1.05E−02	7.75E−03	1.14E−02
80%	8.30E−03	5.42E−03	1.16E−02	1.13E−02	1.13E−02	8.14E−03	1.24E−02
85%	8.82E−03	5.68E−03	1.28E−02	1.23E−02	1.23E−02	8.68E−03	1.36E−02
90%	9.89E−03	6.12E−03	1.42E−02	1.38E−02	1.38E−02	9.38E−03	1.49E−02
95%	1.19E−02	6.82E−03	1.68E−02	1.62E−02	1.62E−02	1.08E−02	1.77E−02
Maximum	2.49E−02	1.41E−02	2.76E−02	2.66E−02	2.67E−02	1.71E−02	3.68E−02

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0306MWDBGSMF.001 [DIRS 163816]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677];, MO0406SPAETPBM.002 [DIRS 170150].

NOTE: See Excel file *GW BDCF Realizations_MC and FC_Rev 3.xls* in Appendix B for details of calculations.

STD = standard deviation.

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

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226
Mean	8.80E−06	1.83E−05	5.07E−05	1.53E−04	2.10E−06	4.96E−03	3.13E−04	4.44E−05	3.83E−04	8.26E−03	7.65E−02
STD	6.67E−06	4.04E−05	7.82E−05	2.22E−05	2.14E−06	3.23E−03	9.42E−05	3.16E−05	1.87E−04	2.82E−03	3.99E−02
Minimum	3.79E−06	3.13E−06	8.91E−06	1.21E−04	1.15E−06	1.54E−04	2.19E−04	9.72E−06	1.16E−04	5.60E−03	2.23E−03
5%	4.65E−06	4.64E−06	1.35E−05	1.30E−04	1.27E−06	8.91E−04	2.35E−04	1.55E−05	1.81E−04	6.03E−03	2.83E−02
10%	4.88E−06	5.18E−06	1.50E−05	1.33E−04	1.30E−06	1.40E−03	2.42E−04	1.78E−05	2.02E−04	6.22E−03	3.52E−02
15%	5.18E−06	5.60E−06	1.71E−05	1.35E−04	1.34E−06	1.99E−03	2.48E−04	2.03E−05	2.22E−04	6.32E−03	3.98E−02
20%	5.37E−06	6.19E−06	1.85E−05	1.37E−04	1.38E−06	2.42E−03	2.53E−04	2.23E−05	2.36E−04	6.46E−03	4.50E−02
25%	5.59E−06	6.62E−06	2.01E−05	1.39E−04	1.42E−06	2.66E−03	2.58E−04	2.48E−05	2.53E−04	6.57E−03	4.84E−02
30%	5.81E−06	7.21E−06	2.19E−05	1.41E−04	1.46E−06	2.98E−03	2.63E−04	2.74E−05	2.71E−04	6.68E−03	5.22E−02
35%	6.01E−06	8.12E−06	2.36E−05	1.43E−04	1.50E−06	3.26E−03	2.70E−04	2.95E−05	2.87E−04	6.85E−03	5.68E−02
40%	6.28E−06	8.92E−06	2.53E−05	1.45E−04	1.54E−06	3.55E−03	2.76E−04	3.18E−05	3.04E−04	7.03E−03	6.08E−02
45%	6.53E−06	9.76E−06	2.70E−05	1.47E−04	1.60E−06	3.91E−03	2.82E−04	3.38E−05	3.21E−04	7.18E−03	6.43E−02
50%	6.77E−06	1.06E−05	2.90E−05	1.49E−04	1.65E−06	4.22E−03	2.90E−04	3.64E−05	3.40E−04	7.34E−03	6.92E−02
55%	7.03E−06	1.16E−05	3.15E−05	1.50E−04	1.71E−06	4.69E−03	2.95E−04	3.87E−05	3.59E−04	7.54E−03	7.27E−02
60%	7.51E−06	1.30E−05	3.47E−05	1.53E−04	1.78E−06	4.99E−03	3.04E−04	4.14E−05	3.81E−04	7.79E−03	7.82E−02
65%	8.03E−06	1.47E−05	3.92E−05	1.55E−04	1.86E−06	5.44E−03	3.14E−04	4.46E−05	4.06E−04	8.08E−03	8.27E−02
70%	8.56E−06	1.66E−05	4.45E−05	1.58E−04	1.99E−06	6.03E−03	3.23E−04	4.94E−05	4.25E−04	8.43E−03	9.00E−02
75%	9.26E−06	1.87E−05	5.08E−05	1.61E−04	2.11E−06	6.64E−03	3.38E−04	5.32E−05	4.57E−04	8.78E−03	9.65E−02
80%	1.04E−05	2.21E−05	6.04E−05	1.65E−04	2.30E−06	7.47E−03	3.53E−04	5.80E−05	4.97E−04	9.25E−03	1.07E−01
85%	1.16E−05	2.59E−05	7.48E−05	1.70E−04	2.56E−06	8.18E−03	3.74E−04	6.65E−05	5.43E−04	1.01E−02	1.14E−01
90%	1.37E−05	3.32E−05	9.45E−05	1.78E−04	3.17E−06	9.06E−03	4.05E−04	8.14E−05	6.18E−04	1.12E−02	1.27E−01
95%	2.03E−05	4.94E−05	1.33E−04	1.93E−04	4.08E−06	1.11E−02	4.68E−04	1.00E−04	7.13E−04	1.41E−02	1.51E−01
Maximum	9.33E−05	8.37E−04	1.05E−03	3.74E−04	5.40E−05	2.00E−02	1.58E−03	4.21E−04	1.62E−03	2.84E−02	3.96E−01

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

	Ra-226 +Pb-210	Ac-227	Th-229	Th-230	Th-232	Pa-231	U-232	U-233	U-234	U-236	U-238
Mean	8.48E−02	2.45E−02	2.64E−02	2.32E−02	3.45E−02	7.95E−02	4.60E−03	1.46E−03	9.93E−04	8.79E−04	8.80E−04
STD	4.01E−02	8.34E−03	1.50E−02	2.08E−02	1.88E−02	5.35E−02	1.82E−03	1.75E−03	8.80E−04	7.45E−04	7.36E−04
Minimum	1.01E−02	1.27E−02	4.48E−03	7.47E−04	6.02E−03	9.79E−03	1.80E−03	2.34E−04	2.25E−04	2.11E−04	2.11E−04
5%	3.58E−02	1.50E−02	9.40E−03	4.39E−03	1.30E−02	2.50E−02	2.34E−03	2.98E−04	2.89E−04	2.67E−04	2.64E−04
10%	4.30E−02	1.59E−02	1.15E−02	5.65E−03	1.58E−02	2.97E−02	2.59E−03	3.48E−04	3.17E−04	3.01E−04	3.03E−04
15%	4.77E−02	1.69E−02	1.34E−02	6.76E−03	1.80E−02	3.39E−02	2.82E−03	3.86E−04	3.57E−04	3.37E−04	3.36E−04
20%	5.32E−02	1.75E−02	1.46E−02	7.93E−03	1.97E−02	3.79E−02	3.06E−03	4.32E−04	3.91E−04	3.66E−04	3.61E−04
25%	5.64E−02	1.83E−02	1.61E−02	9.09E−03	2.17E−02	4.23E−02	3.29E−03	4.79E−04	4.32E−04	4.01E−04	3.94E−04
30%	6.04E−02	1.92E−02	1.73E−02	1.03E−02	2.33E−02	4.65E−02	3.48E−03	5.15E−04	4.75E−04	4.37E−04	4.36E−04
35%	6.46E−02	2.00E−02	1.85E−02	1.13E−02	2.50E−02	5.12E−02	3.70E−03	5.66E−04	5.16E−04	4.79E−04	4.79E−04
40%	6.92E−02	2.07E−02	2.00E−02	1.30E−02	2.64E−02	5.58E−02	3.89E−03	6.31E−04	5.71E−04	5.25E−04	5.13E−04
45%	7.23E−02	2.17E−02	2.12E−02	1.44E−02	2.80E−02	5.95E−02	4.07E−03	7.05E−04	6.09E−04	5.61E−04	5.69E−04
50%	7.71E−02	2.26E−02	2.30E−02	1.63E−02	2.96E−02	6.39E−02	4.27E−03	7.96E−04	6.83E−04	6.20E−04	6.21E−04
55%	8.11E−02	2.37E−02	2.46E−02	1.87E−02	3.15E−02	7.02E−02	4.48E−03	9.14E−04	7.51E−04	6.88E−04	6.82E−04
60%	8.65E−02	2.48E−02	2.63E−02	2.03E−02	3.46E−02	7.56E−02	4.71E−03	1.05E−03	8.14E−04	7.65E−04	7.57E−04
65%	9.18E−02	2.58E−02	2.84E−02	2.33E−02	3.74E−02	8.16E−02	4.94E−03	1.23E−03	9.43E−04	8.59E−04	8.49E−04
70%	9.80E−02	2.70E−02	3.05E−02	2.69E−02	4.01E−02	9.23E−02	5.18E−03	1.40E−03	1.07E−03	9.62E−04	9.35E−04
75%	1.06E−01	2.90E−02	3.26E−02	3.03E−02	4.29E−02	1.02E−01	5.46E−03	1.68E−03	1.23E−03	1.10E−03	1.04E−03
80%	1.15E−01	3.06E−02	3.56E−02	3.52E−02	4.69E−02	1.13E−01	5.85E−03	1.97E−03	1.41E−03	1.24E−03	1.24E−03
85%	1.23E−01	3.27E−02	3.88E−02	4.15E−02	5.23E−02	1.26E−01	6.44E−03	2.45E−03	1.71E−03	1.45E−03	1.46E−03
90%	1.37E−01	3.50E−02	4.40E−02	4.88E−02	5.77E−02	1.48E−01	6.99E−03	3.27E−03	2.09E−03	1.74E−03	1.83E−03
95%	1.59E−01	3.93E−02	5.69E−02	6.56E−02	6.95E−02	1.88E−01	7.99E−03	4.93E−03	2.87E−03	2.43E−03	2.40E−03
Maximum	4.06E−01	9.57E−02	9.68E−02	1.41E−01	1.28E−01	5.05E−01	1.44E−02	1.33E−02	7.41E−03	6.27E−03	4.74E−03

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

	Np-237	Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Am-243
Mean	6.05E−03	4.07E−03	7.57E−03	7.41E−03	7.31E−03	5.74E−03	7.88E−03
STD	2.02E−03	9.48E−04	3.00E−03	2.89E−03	3.03E−03	1.69E−03	3.41E−03
Minimum	3.57E−03	2.62E−03	3.25E−03	3.15E−03	3.19E−03	2.84E−03	2.94E−03
5%	4.07E−03	3.01E−03	4.32E−03	4.33E−03	4.11E−03	3.75E−03	4.08E−03
10%	4.28E−03	3.14E−03	4.71E−03	4.65E−03	4.46E−03	4.04E−03	4.55E−03
15%	4.41E−03	3.22E−03	4.94E−03	4.91E−03	4.68E−03	4.24E−03	4.97E−03
20%	4.62E−03	3.33E−03	5.21E−03	5.15E−03	4.94E−03	4.40E−03	5.23E−03
25%	4.77E−03	3.40E−03	5.46E−03	5.33E−03	5.17E−03	4.57E−03	5.48E−03
30%	4.90E−03	3.48E−03	5.71E−03	5.63E−03	5.42E−03	4.73E−03	5.80E−03
35%	5.03E−03	3.57E−03	5.96E−03	5.88E−03	5.74E−03	4.90E−03	6.12E−03
40%	5.16E−03	3.67E−03	6.19E−03	6.14E−03	6.05E−03	5.05E−03	6.38E−03
45%	5.30E−03	3.75E−03	6.44E−03	6.40E−03	6.33E−03	5.21E−03	6.73E−03
50%	5.45E−03	3.84E−03	6.75E−03	6.74E−03	6.59E−03	5.37E−03	6.99E−03
55%	5.66E−03	3.97E−03	7.10E−03	7.00E−03	6.88E−03	5.52E−03	7.29E−03
60%	5.84E−03	4.07E−03	7.48E−03	7.26E−03	7.20E−03	5.77E−03	7.78E−03
65%	6.10E−03	4.19E−03	7.83E−03	7.60E−03	7.48E−03	6.03E−03	8.21E−03
70%	6.39E−03	4.33E−03	8.20E−03	7.99E−03	7.93E−03	6.28E−03	8.75E−03
75%	6.70E−03	4.45E−03	8.75E−03	8.55E−03	8.50E−03	6.50E−03	9.44E−03
80%	7.06E−03	4.65E−03	9.43E−03	9.10E−03	9.13E−03	6.82E−03	1.01E−02
85%	7.64E−03	4.92E−03	1.05E−02	1.01E−02	9.94E−03	7.26E−03	1.10E−02
90%	8.44E−03	5.27E−03	1.15E−02	1.13E−02	1.11E−02	7.81E−03	1.21E−02
95%	1.01E−02	5.91E−03	1.37E−02	1.33E−02	1.33E−02	8.98E−03	1.49E−02
Maximum	1.85E−02	1.02E−02	2.45E−02	2.30E−02	2.63E−02	1.67E−02	2.73E−02

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0306MWDBGSMF.001 [DIRS 163816]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150].

NOTE: See Excel file *GW BDCF Realizations_MC and FC_Rev 3.xls* in Appendix B for details of calculations.

STD = standard deviation.

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

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226
Mean	8.77E−06	1.77E−05	4.97E−05	1.52E−04	2.07E−06	4.71E−03	3.10E−04	4.33E−05	3.66E−04	8.18E−03	7.37E−02
STD	6.67E−06	3.79E−05	8.73E−05	2.09E−05	2.13E−06	3.02E−03	9.10E−05	3.14E−05	1.76E−04	2.85E−03	3.83E−02
Minimum	3.78E−06	3.19E−06	8.85E−06	1.22E−04	1.16E−06	1.53E−04	2.17E−04	1.03E−05	1.22E−04	5.68E−03	2.21E−03
5%	4.61E−06	4.48E−06	1.32E−05	1.29E−04	1.26E−06	8.26E−04	2.33E−04	1.53E−05	1.73E−04	6.04E−03	2.73E−02
10%	4.89E−06	5.05E−06	1.53E−05	1.32E−04	1.30E−06	1.43E−03	2.41E−04	1.79E−05	1.94E−04	6.17E−03	3.38E−02
15%	5.13E−06	5.54E−06	1.67E−05	1.35E−04	1.34E−06	1.90E−03	2.47E−04	2.02E−05	2.14E−04	6.30E−03	3.90E−02
20%	5.33E−06	6.09E−06	1.82E−05	1.37E−04	1.37E−06	2.34E−03	2.52E−04	2.23E−05	2.31E−04	6.42E−03	4.24E−02
25%	5.56E−06	6.53E−06	1.94E−05	1.38E−04	1.41E−06	2.62E−03	2.57E−04	2.45E−05	2.47E−04	6.54E−03	4.71E−02
30%	5.77E−06	7.16E−06	2.13E−05	1.40E−04	1.45E−06	2.84E−03	2.62E−04	2.59E−05	2.61E−04	6.65E−03	5.04E−02
35%	5.98E−06	7.95E−06	2.26E−05	1.42E−04	1.49E−06	3.11E−03	2.67E−04	2.85E−05	2.73E−04	6.78E−03	5.48E−02
40%	6.19E−06	8.60E−06	2.46E−05	1.44E−04	1.53E−06	3.47E−03	2.72E−04	3.08E−05	2.91E−04	6.92E−03	5.88E−02
45%	6.47E−06	9.55E−06	2.63E−05	1.46E−04	1.58E−06	3.75E−03	2.78E−04	3.28E−05	3.07E−04	7.12E−03	6.28E−02
50%	6.70E−06	1.06E−05	2.85E−05	1.48E−04	1.63E−06	4.06E−03	2.85E−04	3.51E−05	3.26E−04	7.27E−03	6.70E−02
55%	6.99E−06	1.16E−05	3.12E−05	1.50E−04	1.69E−06	4.38E−03	2.94E−04	3.87E−05	3.41E−04	7.49E−03	7.07E−02
60%	7.46E−06	1.26E−05	3.36E−05	1.52E−04	1.75E−06	4.79E−03	3.01E−04	4.07E−05	3.60E−04	7.70E−03	7.45E−02
65%	8.04E−06	1.42E−05	3.68E−05	1.54E−04	1.82E−06	5.19E−03	3.08E−04	4.32E−05	3.85E−04	7.98E−03	8.08E−02
70%	8.50E−06	1.62E−05	4.27E−05	1.57E−04	1.95E−06	5.63E−03	3.21E−04	4.63E−05	4.08E−04	8.27E−03	8.58E−02
75%	9.25E−06	1.82E−05	4.80E−05	1.59E−04	2.07E−06	6.27E−03	3.35E−04	4.99E−05	4.39E−04	8.67E−03	9.25E−02
80%	1.03E−05	2.14E−05	5.60E−05	1.63E−04	2.25E−06	6.95E−03	3.48E−04	5.63E−05	4.71E−04	9.10E−03	1.00E−01
85%	1.15E−05	2.51E−05	7.07E−05	1.69E−04	2.56E−06	7.77E−03	3.69E−04	6.48E−05	5.13E−04	9.84E−03	1.07E−01
90%	1.37E−05	3.22E−05	9.23E−05	1.76E−04	3.13E−06	8.86E−03	3.98E−04	7.95E−05	5.80E−04	1.09E−02	1.25E−01
95%	2.03E−05	4.47E−05	1.40E−04	1.91E−04	3.93E−06	1.07E−02	4.57E−04	9.82E−05	6.99E−04	1.35E−02	1.44E−01
Maximum	9.32E−05	7.32E−04	1.73E−03	3.47E−04	5.44E−05	1.85E−02	1.61E−03	3.29E−04	1.49E−03	3.08E−02	3.71E−01

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

	Ra-226 +Pb-210	Ac-227	Th-229	Th-230	Th-232	Pa-231	U-232	U-233	U-234	U-236	U-238
Mean	8.19E−02	2.33E−02	2.53E−02	2.23E−02	3.30E−02	7.58E−02	4.38E−03	1.40E−03	9.57E−04	8.50E−04	8.50E−04
STD	3.86E−02	7.30E−03	1.45E−02	1.99E−02	1.77E−02	5.04E−02	1.68E−03	1.70E−03	8.52E−04	7.22E−04	7.11E−04
Minimum	1.04E−02	1.27E−02	4.50E−03	8.89E−04	5.63E−03	9.74E−03	1.70E−03	2.27E−04	2.23E−04	2.14E−04	2.11E−04
5%	3.51E−02	1.48E−02	9.60E−03	4.25E−03	1.29E−02	2.38E−02	2.28E−03	2.84E−04	2.84E−04	2.64E−04	2.66E−04
10%	4.15E−02	1.57E−02	1.14E−02	5.57E−03	1.54E−02	2.92E−02	2.59E−03	3.35E−04	3.17E−04	2.93E−04	2.96E−04
15%	4.67E−02	1.65E−02	1.28E−02	6.49E−03	1.73E−02	3.33E−02	2.81E−03	3.74E−04	3.53E−04	3.23E−04	3.24E−04
20%	5.11E−02	1.72E−02	1.42E−02	7.56E−03	1.91E−02	3.77E−02	3.00E−03	4.21E−04	3.82E−04	3.51E−04	3.53E−04
25%	5.49E−02	1.79E−02	1.55E−02	8.62E−03	2.05E−02	4.16E−02	3.17E−03	4.58E−04	4.19E−04	3.87E−04	3.82E−04
30%	5.86E−02	1.85E−02	1.67E−02	9.73E−03	2.19E−02	4.47E−02	3.36E−03	5.03E−04	4.51E−04	4.19E−04	4.14E−04
35%	6.26E−02	1.93E−02	1.79E−02	1.09E−02	2.36E−02	4.94E−02	3.53E−03	5.51E−04	4.89E−04	4.52E−04	4.49E−04
40%	6.65E−02	2.01E−02	1.91E−02	1.23E−02	2.54E−02	5.27E−02	3.71E−03	6.07E−04	5.29E−04	4.87E−04	4.89E−04
45%	7.06E−02	2.10E−02	2.02E−02	1.37E−02	2.71E−02	5.64E−02	3.88E−03	6.83E−04	5.85E−04	5.35E−04	5.44E−04
50%	7.51E−02	2.17E−02	2.17E−02	1.53E−02	2.86E−02	6.09E−02	4.06E−03	7.73E−04	6.48E−04	5.93E−04	5.99E−04
55%	7.85E−02	2.25E−02	2.31E−02	1.76E−02	3.08E−02	6.73E−02	4.23E−03	8.80E−04	7.13E−04	6.54E−04	6.57E−04
60%	8.30E−02	2.33E−02	2.48E−02	1.99E−02	3.30E−02	7.25E−02	4.47E−03	1.01E−03	7.95E−04	7.28E−04	7.36E−04
65%	8.94E−02	2.44E−02	2.65E−02	2.27E−02	3.50E−02	7.90E−02	4.70E−03	1.16E−03	8.94E−04	8.22E−04	8.29E−04
70%	9.50E−02	2.56E−02	2.88E−02	2.56E−02	3.73E−02	8.58E−02	4.91E−03	1.36E−03	1.02E−03	9.19E−04	9.20E−04
75%	1.01E−01	2.70E−02	3.08E−02	2.96E−02	4.05E−02	9.39E−02	5.15E−03	1.57E−03	1.19E−03	1.05E−03	1.07E−03
80%	1.09E−01	2.86E−02	3.39E−02	3.31E−02	4.40E−02	1.06E−01	5.50E−03	1.95E−03	1.37E−03	1.19E−03	1.18E−03
85%	1.17E−01	3.05E−02	3.77E−02	3.93E−02	4.91E−02	1.21E−01	5.93E−03	2.40E−03	1.63E−03	1.44E−03	1.41E−03
90%	1.33E−01	3.33E−02	4.25E−02	4.79E−02	5.78E−02	1.42E−01	6.56E−03	3.26E−03	1.98E−03	1.73E−03	1.76E−03
95%	1.53E−01	3.71E−02	5.70E−02	6.39E−02	6.63E−02	1.81E−01	7.54E−03	4.62E−03	2.65E−03	2.31E−03	2.29E−03
Maximum	3.80E−01	7.01E−02	9.81E−02	1.18E−01	1.12E−01	3.91E−01	1.37E−02	1.33E−02	6.27E−03	5.36E−03	5.02E−03

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

	Np-237	Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Am-243
Mean	5.92E−03	3.92E−03	7.36E−03	7.20E−03	7.10E−03	5.60E−03	7.60E−03
STD	2.05E−03	8.86E−04	2.90E−03	2.73E−03	2.78E−03	1.62E−03	3.14E−03
Minimum	3.60E−03	2.62E−03	3.20E−03	3.17E−03	3.06E−03	2.87E−03	2.90E−03
5%	4.00E−03	2.98E−03	4.27E−03	4.24E−03	4.06E−03	3.70E−03	4.02E−03
10%	4.21E−03	3.10E−03	4.57E−03	4.57E−03	4.36E−03	4.01E−03	4.49E−03
15%	4.35E−03	3.19E−03	4.79E−03	4.82E−03	4.62E−03	4.18E−03	4.79E−03
20%	4.49E−03	3.28E−03	5.05E−03	5.05E−03	4.86E−03	4.34E−03	5.08E−03
25%	4.66E−03	3.35E−03	5.30E−03	5.30E−03	5.15E−03	4.49E−03	5.34E−03
30%	4.77E−03	3.43E−03	5.55E−03	5.54E−03	5.36E−03	4.67E−03	5.69E−03
35%	4.94E−03	3.49E−03	5.82E−03	5.75E−03	5.60E−03	4.81E−03	5.98E−03
40%	5.07E−03	3.58E−03	6.10E−03	5.97E−03	5.84E−03	4.95E−03	6.26E−03
45%	5.20E−03	3.63E−03	6.34E−03	6.21E−03	6.10E−03	5.10E−03	6.53E−03
50%	5.38E−03	3.71E−03	6.59E−03	6.47E−03	6.41E−03	5.25E−03	6.79E−03
55%	5.56E−03	3.79E−03	6.89E−03	6.77E−03	6.67E−03	5.38E−03	7.20E−03
60%	5.71E−03	3.89E−03	7.18E−03	7.11E−03	6.99E−03	5.53E−03	7.63E−03
65%	5.90E−03	4.00E−03	7.63E−03	7.48E−03	7.40E−03	5.75E−03	8.05E−03
70%	6.15E−03	4.12E−03	8.06E−03	7.84E−03	7.83E−03	5.96E−03	8.52E−03
75%	6.55E−03	4.28E−03	8.49E−03	8.38E−03	8.32E−03	6.26E−03	9.05E−03
80%	6.92E−03	4.44E−03	9.16E−03	8.91E−03	8.80E−03	6.67E−03	9.76E−03
85%	7.34E−03	4.65E−03	1.01E−02	9.82E−03	9.56E−03	7.06E−03	1.06E−02
90%	8.17E−03	4.99E−03	1.13E−02	1.09E−02	1.08E−02	7.69E−03	1.17E−02
95%	9.89E−03	5.55E−03	1.31E−02	1.25E−02	1.28E−02	8.79E−03	1.36E−02
Maximum	2.34E−02	1.25E−02	2.36E−02	2.40E−02	2.05E−02	1.52E−02	3.10E−02

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0306MWDBGSMF.001 [DIRS 163816]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150].

NOTE: See Excel file GW BDCF Realizations_MC and FC_Rev 3.xls in Appendix B for details of calculations.

STD = standard deviation.

.

Some of the BDCFs for the groundwater scenario are correlated (Table 6.2-8). To show correlations between the BDCFs, rank correlation coefficients for present-day climate BDCFs were calculated for selected radionuclides. These calculations were done using Excel (*Correlations for Groundwater BDCFs MC_Rev 3.xls*; Appendix B). 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 Present-Day Climate Biosphere Dose Conversion Factors for Individual Radionuclides

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226	Ac-227	Th-229	Th-230
C-14	1.000													
Cl-36	0	1.000												
Se-79	0	0.211	1.000											
Sr-90	0	0.390	0.197	1.000										
Tc-99	0	0.494	0.196	0.388	1.000									
Sn-126	0	0.226	0.213	0.155	0.193	1.000								
I-129	0	0.301	0.171	0.318	0.328	0.117	1.000							
Cs-135	0.129	0.108	0.128	0.147	0	0.154	0.096	1.000						
Cs-137	0	0	0	0.252	0	0	0	0.693	1.000					
Pb-210	0	0	0	0.159	0	0	0.131	0.140	0.189	1.000				
Ra-226	0	0	0.210	0.154	0	0.429	0.100	0.203	0.152	0.085	1.000			
Ac-227	0	0	0	0.126	0.101	0	0	0	0.179	0	0.086	1.000		
Th-229	0	0.126	0.190	0.111	0.127	0.323	0.088	0.197	0.111	0	0.424	0.389	1.000	
Th-230	0	0.122	0.231	0	0.105	0.458	0.104	0.236	−0.091	0	0.704	0	0.676	1.000
Th-232	0	0.134	0.212	0.121	0.136	0.385	0.105	0.218	0.102	0	0.507	0.304	0.976	0.780
Pa-231	0	0.132	0.194	0.109	0.156	0.362	0.085	0.163	0	0	0.423	0.186	0.752	0.538
U-232	0	0.146	0	0.156	0.166	0	0	0	0.129	0	0.083	0.675	0.336	0
U-233	0	0.187	0	0	0.179	0.163	0	0.090	0	0	0.115	0.243	0.328	0.255
U-234	0	0.174	0	0.089	0.175	0.142	0	0.084	0	0	0.112	0.317	0.310	0.209
U-236	0	0.168	0	0.093	0.169	0.127	0	0	0	0	0.093	0.338	0.308	0.177
U-238	0	0.171	0	0.095	0.171	0.128	0	0	0	0	0.093	0.319	0.294	0.176
Np-237	0	0.389	0.170	0.249	0.385	0.188	0.187	0.098	0	0	0.147	0.500	0.413	0.225
Pu-238	0	0	0	0.196	0.108	0	0	0.098	0.284	0.111	0.150	0.764	0.490	0
Pu-239	0	0.153	0.163	0.132	0.162	0.329	0.099	0.190	0	0	0.412	0.368	0.784	0.514
Pu-240	0	0.151	0.159	0.138	0.162	0.320	0.098	0.188	0	0	0.406	0.383	0.784	0.497
Pu-242	0	0.153	0.164	0.130	0.163	0.332	0.099	0.191	0	0	0.414	0.363	0.783	0.520
Am-241	0	0.130	0.142	0.218	0.161	0.217	0.118	0.139	0.209	0	0.293	0.549	0.675	0.263
Am-243	0	0.139	0.187	0.151	0.152	0.335	0.113	0.171	0	0	0.392	0.307	0.678	0.470

Table 6.2-8. Rank Correlations Coefficients for the Present-Day Climate Biosphere Dose Conversion Factors for Individual Radionuclides (Continued)

	Th-232	Pa-231	U-232	U-233	U-234	U-236	U-238	Np-237	Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Am-243
C-14														
Cl-36														
Se-79														
Sr-90														
Tc-99														
Sn-126														
I-129														
Cs-135														
Cs-137														
Pb-210														
Ra-226														
Ac-227														
Th-229														
Th-230														
Th-232	1.000													
Pa-231	0.729	1.000												
U-232	0.271	0.204	1.000											
U-233	0.314	0.295	0.790	1.000										
U-234	0.286	0.271	0.836	0.991	1.000									
U-236	0.276	0.267	0.852	0.984	0.998	1.000								
U-238	0.266	0.257	0.845	0.986	0.998	0.999	1.000							
Np-237	0.368	0.361	0.445	0.326	0.344	0.349	0.339	1.000						
Pu-238	0.392	0.342	0.554	0.205	0.260	0.284	0.267	0.425	1.000					
Pu-239	0.740	0.753	0.329	0.333	0.329	0.331	0.317	0.448	0.617	1.000				
Pu-240	0.737	0.749	0.340	0.331	0.329	0.332	0.319	0.452	0.639	0.999	1.000			
Pu-242	0.742	0.754	0.325	0.333	0.329	0.330	0.317	0.447	0.610	1.000	0.999	1.000		
Am-241	0.600	0.569	0.462	0.286	0.313	0.329	0.314	0.489	0.624	0.658	0.668	0.654	1.000	
Am-243	0.655	0.643	0.283	0.288	0.285	0.284	0.273	0.417	0.384	0.665	0.663	0.665	0.902	1.000

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0306MWDBGSMF.001 [DIRS 163816]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150].

NOTE: See Excel file *Correlations for Groundwater BDCFs MC_Rev 3.xls* in Appendix B 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_Rev 3.xls* in Appendix B 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-LA model, which uses BDCFs as input parameters. The TSPA-LA 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-LA model. The total annual dose is calculated (BSC 2004 [DIRS 169460], 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/yr)

$BDCF_i$ = 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 equilibrium concentration of radionuclides in soil has been reached. Equilibrium 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 equilibrium concentrations. In the event that equilibrium conditions for a radionuclide have not been reached and groundwater concentrations are increasing, this approximation will result in overestimating the dose for that radionuclide (BSC 2004 [DIRS 169460], Section 6.3.1.4). If concentrations in groundwater are decreasing, the dose may be underestimated (BSC 2004 [DIRS 169460], Section 6.3.1.4). However, it is unlikely that groundwater concentrations will decrease until long after the period of 20,000 years used for the TSPA-LA. 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 equilibrium 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 present-day climate BDCFs are presented in Table 6.2-10. These calculations were performed using Excel (*GW BDCF Pathway Analysis MC_Rev 3.xls*; Appendix B).

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 ^{14}C, isotopes of cesium, and ^{210}Pb. 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 (*GW BDCF Pathway Analysis FC_Rev 3.xls*; Appendix B).

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

Radio-nuclide	External exposure	Inhalation			Ingestion										
		Particul. Matter	**Evap. Cooler**	**Radon**	**Water**	**Leafy Veget.**	**Other Veget.**	**Fruit**	**Grain**	**Meat**	**Milk**	**Poultry**	**Eggs**	**Fish**	**Soil**
C-14	0.0	0.0	0.0	0.0	16.8	2.8	5.0	13.0	0.6	7.0	3.3	0.6	5.5	45.3	0.0
Cl-36	0.1	0.0	0.2	0.0	10.7	3.2	4.9	16.5	2.6	22.7	18.5	0.0	9.0	11.4	0.0
Se-79	0.0	0.1	0.0	0.0	10.3	0.7	0.5	1.6	0.1	55.1	3.2	2.0	21.9	3.8	0.6
Sr-90	0.5	0.1	0.3	0.0	68.2	6.6	3.7	6.2	0.6	3.0	3.7	0.0	1.6	5.1	0.4
Tc-99	0.0	0.0	0.7	0.0	47.2	12.0	2.1	7.7	0.5	4.3	13.5	0.2	10.0	1.6	0.0
Sn-126	98.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	1.0	0.0
I-129	0.1	0.1	0.1	0.0	59.9	2.6	0.7	3.0	0.4	5.0	7.5	0.2	14.2	5.4	0.8
Cs-135	0.0	0.1	0.0	0.0	9.3	1.4	0.9	4.2	0.2	10.3	5.8	7.3	5.5	54.0	1.1
Cs-137	43.0	0.0	0.0	0.0	7.6	0.4	0.1	0.5	0.0	1.7	1.0	0.9	0.7	44.1	0.1
Pb-210	0.0	0.2	0.5	0.0	58.8	2.6	0.6	2.3	0.3	0.3	0.2	0.1	1.4	32.4	0.4
Ra-226	6.8	0.3	0.0	89.2	1.0	0.3	0.2	0.6	0.0	0.1	0.1	0.0	0.7	0.1	0.6
Ac-227	0.3	16.8	42.6	0.0	34.7	1.4	0.3	1.2	0.1	0.1	0.0	0.0	0.0	2.2	0.2
Th-229	3.0	71.9	12.5	0.0	8.6	0.5	0.1	0.4	0.0	0.1	0.0	0.0	0.0	1.8	0.9
Th-230	5.7	13.6	2.2	74.5	1.4	0.3	0.1	0.6	0.0	0.1	0.1	0.0	0.6	0.3	0.6
Th-232	25.0	53.9	8.8	0.0	8.2	0.7	0.2	0.6	0.1	0.1	0.1	0.0	0.0	1.5	0.9
Pa-231	1.3	84.7	2.5	0.0	7.7	0.6	0.2	0.8	0.1	0.1	0.0	0.0	0.0	0.2	1.8
U-232	12.3	20.6	33.9	0.0	26.6	1.1	0.3	0.9	0.1	0.1	0.1	0.2	0.8	2.7	0.3
U-233	1.3	68.3	14.3	0.0	11.4	0.6	0.2	0.6	0.1	0.1	0.1	0.2	1.6	0.3	0.9
U-234	0.4	52.3	20.4	4.9	16.2	0.8	0.2	0.7	0.1	0.1	0.1	0.3	2.2	0.5	0.7
U-236	0.0	54.9	21.7	0.0	17.3	0.8	0.2	0.8	0.1	0.1	0.2	0.4	2.3	0.5	0.8
U-238	3.7	52.1	20.6	0.0	17.3	0.8	0.2	0.8	0.1	0.1	0.2	0.4	2.4	0.5	0.8
Np-237	2.6	22.5	15.2	0.0	46.5	2.6	1.0	4.3	0.2	0.9	0.0	0.0	0.0	3.0	1.2
Pu-238	0.0	20.6	16.4	0.0	49.8	2.1	0.5	1.7	0.2	0.0	0.0	0.0	0.0	7.3	1.1
Pu-239	0.0	52.5	9.1	0.0	27.9	1.5	0.3	1.3	0.2	0.0	0.0	0.0	0.1	4.1	2.9
Pu-240	0.0	51.5	9.4	0.0	28.7	1.5	0.3	1.3	0.2	0.0	0.0	0.0	0.1	4.2	2.8
Pu-242	0.0	53.1	9.1	0.0	27.5	1.5	0.3	1.3	0.2	0.0	0.0	0.0	0.1	4.1	2.9
Am-241	0.1	38.2	12.8	0.0	39.0	1.8	0.4	1.6	0.2	0.1	0.0	0.0	0.0	3.7	2.1
Am-243	5.6	49.0	9.1	0.0	27.7	1.5	0.3	1.3	0.1	0.1	0.0	0.0	0.0	2.6	2.7

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0306MWDBGSMF.001 [DIRS 163816]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150].

NOTES: See Excel file *GW BDCF Pathway Analysis MC_Rev 3.xls* in Appendix B for details of calculations.
Particul. = Particulate; Evap. = Evaporative; Veget. = Vegetables

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

Radio-nuclide	External exposure	Inhalation			Ingestion										
		Particul. Matter	Evap. Cooler	Radon	Water	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs	Fish	Soil
C-14	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	48.6	0.0
Cl-36	0.1	0.0	0.1	0.0	15.2	3.4	5.1	17.3	2.7	23.5	19.0	0.0	10.6	9.4	0.0
Se-79	0.0	0.1	0.0	0.0	15.0	0.7	0.4	1.4	0.1	48.6	2.9	1.7	19.1	3.2	0.5
Sr-90	0.3	0.1	0.1	0.0	78.4	4.8	2.4	3.9	0.4	2.1	2.6	0.0	1.2	3.4	0.2
Tc-99	0.0	0.0	0.2	0.0	56.4	10.7	1.8	6.3	0.5	3.8	11.8	0.2	9.2	1.1	0.0
Sn-126	97.7	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
I-129	0.1	0.1	0.0	0.0	69.0	2.1	0.5	1.9	0.3	3.9	5.8	0.2	11.6	3.6	0.6
Cs-135	0.0	0.1	0.0	0.0	15.1	1.3	0.8	3.7	0.2	9.4	5.2	6.6	5.0	51.1	1.0
Cs-137	37.9	0.0	0.0	0.0	12.6	0.4	0.1	0.5	0.0	1.7	1.0	0.9	0.7	42.7	0.1
Pb-210	0.0	0.1	0.1	0.0	71.1	2.2	0.4	1.4	0.2	0.2	0.1	0.0	1.2	22.6	0.3
Ra-226	6.1	0.3	0.0	89.4	1.7	0.3	0.1	0.5	0.0	0.1	0.1	0.0	0.6	0.1	0.5
Ac-227	0.3	15.8	16.4	0.0	61.6	1.8	0.3	1.0	0.2	0.1	0.0	0.0	0.0	2.3	0.2
Th-229	3.0	72.2	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
Th-230	5.3	12.6	0.8	77.6	2.4	0.3	0.1	0.5	0.0	0.1	0.1	0.0	0.5	0.3	0.6
Th-232	24.5	52.9	3.5	0.0	14.9	0.8	0.2	0.5	0.1	0.1	0.1	0.0	0.0	1.6	0.9
Pa-231	1.3	81.4	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
U-232	12.1	20.3	13.2	0.0	47.5	1.4	0.2	0.9	0.2	0.1	0.1	0.2	1.0	2.8	0.3
U-233	1.4	72.3	5.8	0.0	21.1	0.8	0.2	0.6	0.1	0.1	0.1	0.3	1.8	0.4	0.9
U-234	0.4	54.0	8.1	5.8	29.7	1.0	0.2	0.7	0.1	0.1	0.2	0.4	2.4	0.5	0.8
U-236	0.0	57.0	8.7	0.0	31.8	1.1	0.2	0.8	0.1	0.1	0.2	0.4	2.6	0.6	0.8
U-238	3.8	53.6	8.2	0.0	31.7	1.0	0.2	0.8	0.1	0.1	0.2	0.4	2.6	0.6	0.8
Np-237	2.2	18.9	4.5	0.0	63.7	2.4	0.8	3.6	0.2	0.8	0.0	0.0	0.0	2.4	1.0
Pu-238	0.0	15.2	5.0	0.0	69.2	2.1	0.3	1.2	0.2	0.0	0.0	0.0	0.0	5.9	0.8
Pu-239	0.0	44.4	3.1	0.0	43.5	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.7	2.5
Pu-240	0.0	43.3	3.2	0.0	44.4	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.8	2.4
Pu-242	0.0	45.0	3.1	0.0	43.0	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.7	2.5
Am-241	0.1	30.3	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
Am-243	4.8	41.6	3.1	0.0	43.5	1.5	0.3	1.0	0.2	0.1	0.0	0.0	0.0	2.4	2.3

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0306MWDBGSMF.001 [DIRS 163816]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150].

NOTES: See Excel file *GW BDCF Pathway Analysis FC_Rev 3.xls* in Appendix B for details of calculations
Particul. = Particulate; Evap. = Evaporative; Veget. = Vegetables

.

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 [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**	**Applicable Limit**
					Alpha	Electron	Photon		
Carbon-14	β-			1	-	0.049	-	5730 years	0.04 mSv (4 mrem) per year; β, γ
Chlorine-36	EC β+ β-			1	-	0.274	<	3.01E+05 years	0.04 mSv (4 mrem) per year; β, γ
Selenium-79	β-			1	-	0.056	-	6.50E+04 years	0.04 mSv (4 mrem) per year; β, γ
Strontium-90	β-			1	-	0.196	-	29.12 years	0.04 mSv (4 mrem) per year; β, γ
		Yttrium-90	β-	1	-	0.935	<	64.0 hours	0.04 mSv (4 mrem) per year; β, γ
Technetium-99	β-			1	-	0.101	-	2.13E+05 years	0.04 mSv (4 mrem) per year; β, γ
Tin-126	β-			1	-	0.172	0.057	1.0E+05 years	0.04 mSv (4 mrem) per year; β, γ
		Antimony-126m	IT β-	1	-	0.591	1.548	19.0 minutes	0.04 mSv (4 mrem) per year; β, γ
		Antimony-126	β-	0.14	-	0.283	2.834	12.4 days	0.04 mSv (4 mrem) per year; β, γ
Iodine-129	β-			1	-	0.064	0.025	1.57E+07 years	0.04 mSv (4 mrem) per year; β, γ
Cesium-135	β-			1	-	0.067	-	2.3E+06 years	0.04 mSv (4 mrem) per year; β, γ
Cesium-137	β-			1	-	0.187	-	30.0 years	0.04 mSv (4 mrem) per year; β, γ
		Barium-137m	IT	0.946	-	0.065	0.597	2.552 minutes	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 years	15 pCi/L; α
Uranium-236	α			1	4.505	0.011	0.002	2.3415E+07 year	excluded
Thorium-232	α			1	3.996	0.012	0.001	1.405E+10 years	15 pCi/L; α
Radium-228	β-			1	-	0.017	<	5.75E+00 years	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 hours	0.04 mSv (4 mrem) per year; β, γ
Uranium-232	α			1	5.302	0.017	0.002	72 years	excluded
Thorium-228	α			1	5.400	0.021	0.003	1.9131 years	15 pCi/L; α
		Radium-224	α	1	5.674	0.002	0.010	3.66 days	15 pCi/L; α
		Radon-220	α	1	6.288	<	<	55.6 seconds	excluded
		Polonium-216	α	1	6.779	<	<	0.15 seconds	15 pCi/L; α

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

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	Applicable Limit
					Alpha	Electron	Photon		
		Lead-212	β-	1	-	0.176	0.148	10.64 hours	0.04 mSv (4 mrem) per year; β, γ
		Bismuth-212	β- α	1	2.174	0.472	0.186	60.55 minutes	15 pCi/L; α
									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 minutes	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 years	15 pCi/L; α
Neptunium-237	α			1	4.769	0.070	0.035	2.14E+06 years	15 pCi/L; α
		Protactinium-233	β-	1	-	0.196	0.204	27.0 days	0.04 mSv (4 mrem) per year; β, γ
Uranium-233	α			1	4.817	0.006	0.001	1.585E+05 years	excluded
Thorium-229	α			1	4.873	0.116	0.096	7340 years	15 pCi/L; α
		Radium-225	β-	1	-	0.107	0.014	14.8 days	0.04 mSv (4 mrem) per year; β, γ
		Actinium-225	α	1	5.787	0.022	0.018	10.0 days	15 pCi/L; α
		Francium-221	α	1	6.304	0.010	0.031	4.8 minutes	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 minutes	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 minutes	0.04 mSv (4 mrem) per year; β, γ
		Lead-209	β-	-	-	0.198	-	3.253 hours	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 years	15 pCi/L; α
Uranium-238	SF α			1	4.187	0.010	0.001	4.468E+09 years	excluded
		Thorium-234	β-	1	-	0.060	0.009	24.10 days	0.04 mSv (4 mrem) per year; β, γ
		Protactinium-234m	β- IT	99.80	-	0.822	0.012	1.17 minutes	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 and Mode of Decay		Short-lived Decay Product and Mode of Decay		BF	Type and Energy of Radiation (MeV per nuclear transformation)			Half-life	Applicable Limit
					Alpha	Electron	Photon		
		Protactinium-234	β-	0.33	-	0.494	1.919	6.70 hours	0.04 mSv (4 mrem) per year; β, γ
Plutonium-238	SF α			1	5.487	0.011	0.002	87.74 years	15 pCi/L; α
Uranium-234	α			1	4.758	0.013	0.002	2.445E+05 years	excluded
Thorium-230	α			1	4.671	0.015	0.002	7.7E+04 years	15 pCi/L; α
Radium-226	α			1	4.774	0.004	0.007	1600 years	5 pCi/L of Ra-226 + Ra-228 15 pCi/L; α
		Radon-222	α	1	5.489	<	<	3.8235 days	excluded
		Polonium-218	α	1	6.001	<	<	3.05 minutes	15 pCi/L; α
		Lead-214	β-	0.9998	-	0.293	0.250	26.8 minutes	0.04 mSv (4 mrem) per year; β, γ
		Astatine-218	α	0.0002	6.697	0.040	0.007	2 seconds	15 pCi/L; α
		Bismuth-214	β-	1	-	0.659	1.508	19.9 minutes	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 minutes	0.04 mSv (4 mrem) per year; β, γ
Lead-210	β-			1	-	0.038	0.005	22.3 years	0.04 mSv (4 mrem) per year; β, γ
		Bismuth-210	β-	1	-	0.389	-	5.012 days	0.04 mSv (4 mrem) per year; β, γ
		Polonium-210	α	1	5.297	<	<	138.38 days	15 pCi/L; α
Actinium Series (4n + 3)									
Americium-243	α			1	5.270	0.022	0.056	7380 years	15 pCi/L; α
		Neptunium-239	β-	1	-	0.260	0.173	2.355 days	0.04 mSv (4 mrem) per year; β, γ
Plutonium-239	α			1	5.148	0.007	<	2.4065E+04 years	15 pCi/L; α
Uranium-235	α			1	4.396	0.049	0.156	7.038E+08 years	excluded
		Thorium-231	β-	1	-	0.165	0.026	25.52 hours	0.04 mSv (4 mrem) per year; β, γ
Protactinium-231	α			1	4.969	0.065	0.048	3.276E+04 years	15 pCi/L; α
Actinium-227	β- α			1	0.068	0.016	<	21.773 years	15 pCi/L; α 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 and Mode of Decay	Short-lived Decay Product and Mode of Decay		BF	Type and Energy of Radiation (MeV per nuclear transformation)			Half-life	Applicable Limit
				Alpha	Electron	Photon		
	Thorium-227	α	0.9862	5.884	0.053	0.110	18.718 days	15 pCi/L; α
	Francium-223	β-	0.0138	-	0.400	0.059	21.8 minutes	0.04 mSv (4 mrem) per year; β, γ
	Radium-223	α	1	5.667	0.076	0.134	11.434 days	15 pCi/L; α
	Radon-219	α	1	6.757	0.006	0.056	3.96 seconds	excluded
	Polonium-215	α	1	7.386	<	<	1.78 ms	15 pCi/L; α
	Lead-211	β-	1	-	0.456	0.051	36.1 minutes	0.04 mSv (4 mrem) per year; β, γ
	Bismuth-211	α β-	1	6.550	0.010	0.047	2.14 minutes	15 pCi/L; α
	Thallium-207	β-	0.9972	-	0.493	0.002	4.77 minutes	0.04 mSv (4 mrem) per year; β, γ
	Polonium-211	α	0.0028	7.442	<	0.008	0.516 seconds	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 modeled 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 2004 [DIRS 169460], Section 6.3.1.4), short-lived decay products of a primary radionuclide are modeled 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 × 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% [a]			1
Uranium-236 [b]	(100%)			0 [b]
Thorium-232 [c]	100%			1
Uranium-232 [b, d]	(100%)			0 [b]
Thorium-228 [c, d]	100%			4 [b]
		Radium-224	100%	
		Radon-220 [b]	(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 [b]	(100%)			0 [b]
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 [b]	(100%)			0 [b]
Plutonium-238	100%			1
Uranium-234 [b]	(100%)			0 [b]
Thorium-230	100%			1
Radium-226	100%			3 [b]
		Radon-222 [b]	(100%)	
		Polonium-218	99.98%	
		Astatine-218	0.02%	
		Bismuth-214	0.02%	
		Polonium-214	99.98%	
Lead-210	β-			1 [e]
		Polonium-210	100%	
Actinium Series (4n + 3)				
Americium-243	100%			1
Plutonium-239	100%			1
Uranium-235 [b]	(100%)			0 [b]
Protactinium-231	100%			1
Actinium-227	1.38%			4 [b]
		Thorium-227	98.62%	
		Radium-223	100%	
		Radon-219 [b]	(100%)	
		Polonium-215	100%	
		Bismuth-211	99.73%	
		Polonium-211	0.273%	

[a] Percent alpha particles emitted per disintegration.
[b] Isotopes of radon and uranium have been excluded, per 10 CFR 63.331 [DIRS 156605].
[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 number of alpha particles for ^{228}Th should be added to that for ^{232}Th for a total of 5. (^{228}Ra and its decay product ^{228}Ac are beta-emitters so they do not contribute to the alpha particle number.)
[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 number of alpha particles for ^{228}Th should be attributed to that for ^{232}U for a total of 4.
[e] If concentration of ^{210}Pb in groundwater is not calculated, it can be assumed that ^{210}Pb is in radioactive equilibrium with ^{226}Ra. If this is the case, the number of alpha particles for ^{210}Pb should be added to that for ^{226}Ra for a total of 4.

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 (Bq/m^3 or pCi/L)
Cw_i = activity concentration of a primary radionuclide *i* in groundwater (Bq/m^3 or pCi/L)
$N_{\alpha, i}$ = number of alpha particles attributed to one decay of a primary radionuclide *i* (from Table 6.3-3)

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 FGR 11 (DOE 2004 [DIRS 169713]). 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 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 percent or more; e.g., ^{218}Po, 99.98 percent α; ^{211}Bi, 99.73 percent α), are not included in calculating beta-photon dose; primary radionuclides that were included are listed in Table 6.3-4.

Table 6.3-4. Radionuclides and Their Decay Products Included in Calculation of Conversion Factors for Beta-Photon Emitters

Primary Radionuclide and Mode of Decay		Short-lived Decay Product and Mode of Decay	
Carbon-14	β-		
Chlorine-36	EC, β+, β-		
Selenium-79	β-		
Strontium-90	β-	Yttrium-90	β-
Technetium-99	β-		
Tin-126	β-	Antimony-126m	IT, β-
		Antimony-126	β-
Iodine-129	β-		
Cesium-135	β-		
Cesium-137	β-	Barium-137m	IT
Thorium Series (4n)			
Radium-228 [a]	β-	Actinium-228	β-
Thorium-228 [a]	α	Lead-212	β-
		Bismuth-212	β- α
		Thallium-208	β-
Neptunium Series (4n + 1)			
Neptunium-237	α	Protactinium-233	β-
Thorium-229	α	Radium-225	β-
		Bismuth-213	β- α
		Thallium-209	β-
		Lead-209	β-
Uranium Series (4n + 2)			
Uranium-238	SF, α	Thorium-234	β-
		Protactinium-234m	β- IT
		Protactinium-234	β-
Radium-226	α	Lead-214	β-
		Bismuth-214	β-
		Thallium-210	β-
Lead-210	β-	Bismuth-210	β-
Actinium Series (4n + 3)			
Americium-243	α	Neptunium-239	β-
Actinium-227	β- α	Francium-223	β-
		Lead-211	β-
		Thallium-207	β-

[a] ^{228}Ra and ^{228}Th are not primary radionuclides (their concentration in groundwater are not calculated in TSPA) but they are treated as primary radionuclides in the biosphere model, as described in Section 6.1.1.
EC = electron capture, IT = isomeric transformation, SF = spontaneous fission.

The annual dose from drinking 2 liters of water per day for a given concentration of a primary beta-photon-emitting radionuclide in groundwater is calculated as

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

$$or \qquad \text{(Eq. 6.3-2)}$$

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

where

D_i = annual dose (committed effective dose equivalent or committed organ 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/m^3 or pCi/L, depending on the set of units used)

CF_i = conversion factor for calculating beta-photon dose from radionuclide *i* (Sv/yr per Bq/m^3 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 ingesting beta-gamma emitters in the groundwater 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 weighted sum of the organ or whole body dose conversion factors for a primary radionuclide and its short-lived decay products, with the weights corresponding to the branching fractions:

$$EDCF_i = DCF_i + \sum_s DCF_{s,i} \times BF_{s,i} \qquad \text{(Eq. 6.3-5)}$$

where

DCF	=	dose conversion factor for primary radionuclide *i* (Sv/Bq), equal to zero if a primary radionuclide is not a beta-photon emitter
$DCF_{s,i}$	=	dose conversion factor for short-lived beta-photon emitting radionuclide *s* in a decay chain of a primary radionuclide *i* (Sv/Bq)
$BF_{s,i}$	=	branching fraction for short-lived beta-photon emitting radionuclide *s* in a decay chain of a primary radionuclide *i* (dimensionless)

In this case, the effective dose conversion factors account only for contributions from beta- and photon-emitting radionuclides. Alpha emitters with a fraction of alpha decays greater than 99 percent are not included. Effective dose conversion factors for calculating annual beta-photon dose resulting from consumption of 2 liters of water per day are summarized in Table 6.3-5. The calculations were carried out in Excel (see file *Conversion Factors for Groundwater Protection Standard_Rev 3.xls* in Appendix B for details).

The effective dose conversion factor for ^{232}Th includes contributions from ^{228}Ra and ^{228}Th and their short-lived decay products. ^{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). The effective dose conversion factor for ^{232}Th is calculated for the conditions of radioactive equilibrium between ^{232}Th, ^{228}Ra, and ^{228}Th. ^{232}Th itself is an alpha emitter, so it does not contribute to the value of its effective dose conversion factor.

Similarly, ^{232}U is accompanied in the groundwater by its relatively long-lived decay product, ^{228}Th (and its short-lived decay products). The effective dose conversion factor attributable to ^{232}U is calculated by including the contribution from ^{228}Th and its short-lived decay products under the conditions of radioactive equilibrium between ^{232}U and ^{228}Th. ^{232}U is an alpha emitter, so by itself does not contribute to the value of its effective dose conversion factor.

Table 6.3-5 includes the value of the effective dose conversion factor for ^{226}Ra (and its short-lived decay products), ^{210}Pb (and its short-lived decay products) and, separately, the value for ^{226}Ra that includes a contribution from ^{210}Pb. The latter value was developed so that the contribution of this relatively long-lived radionuclide to the beta-photon dose is accounted for, in case its concentration in groundwater is not calculated in TSPA. ^{210}Pb was screened out from the TSPA-LA calculations for the period of up to 20,000 years (BSC 2004 [DIRS 169460], Section 6.1.3).

Tables 6.3-6 and 6.3-7 list conversion factors for calculating the beta-photon doses expressed in the units of Sv/yr per Bq/m^3 and mrem/yr per pCi/L, respectively. The conversion factors were calculated using Equation 6.3-3 as shown in Appendix B.

Table 6.3-5. Effective Dose Conversion Factors (Sv/Bq) for Radionuclides Included in Calculation of Conversion Factors

Organ or Tissue	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Th-232
Adrenal	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	9.21E−10	1.32E−10	1.91E−09	1.50E−08	1.60E−07
Urinary Bladder	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	1.18E−09	1.35E−10	1.91E−09	1.41E−08	1.59E−07
Bone Surface	5.64E−10	7.99E−10	9.06E−10	4.19E−07	6.04E−11	5.09E−09	2.17E−10	1.91E−09	1.26E−08	5.99E−06
Brain	5.64E−10	7.99E−10	9.06E−10	1.26E−14	6.04E−11	7.30E−10	0.00E+00	0.00E+00	0.00E+00	2.54E−13
Breast	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	8.47E−10	3.31E−10	1.91E−09	1.24E−08	1.59E−07
Esophagus	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	5.37E−10	3.51E−10	1.91E−09	1.24E−08	1.59E−07
Stomach Wall	5.64E−10	1.11E−09	9.70E−10	2.82E−09	3.39E−09	2.02E−09	2.19E−10	1.99E−09	1.39E−08	1.62E−07
Small Intestine Wall	5.64E−10	7.99E−10	9.38E−10	4.53E−09	1.19E−10	4.99E−09	1.41E−10	1.91E−09	1.44E−08	1.66E−07
Upper Large Intestine Wall	5.64E−10	7.99E−10	1.10E−09	1.89E−08	4.05E−10	1.69E−08	1.42E−10	1.91E−09	1.42E−08	1.83E−07
Lower Large Intestine Wall	5.64E−10	7.99E−10	1.48E−09	5.13E−08	1.10E−09	4.60E−08	1.39E−10	1.91E−09	1.44E−08	2.00E−07
Kidney	5.64E−10	7.99E−10	1.25E−08	1.51E−09	6.04E−11	8.79E−10	1.34E−10	1.91E−09	1.37E−08	1.69E−07
Liver	5.64E−10	7.99E−10	6.48E−09	1.51E−09	8.23E−11	7.30E−10	1.38E−10	1.91E−09	1.36E−08	1.80E−07
Lung	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	6.10E−10	1.65E−10	1.91E−09	1.27E−08	1.59E−07
Muscle	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	8.47E−10	3.31E−10	1.91E−09	1.24E−08	1.59E−07
Ovaries	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	2.82E−09	1.38E−10	1.91E−09	1.29E−08	1.60E−07
Pancreas	5.64E−10	7.99E−10	3.89E−09	1.51E−09	6.04E−11	8.47E−10	1.41E−10	1.91E−09	1.34E−08	1.59E−07
Red Bone Marrow	5.64E−10	7.99E−10	9.06E−10	1.94E−07	6.04E−11	2.81E−09	2.21E−10	1.91E−09	1.32E−08	6.68E−07
Skin	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	5.67E−10	2.11E−10	1.91E−09	1.04E−08	1.59E−07
Spleen	5.64E−10	7.99E−10	4.32E−09	1.51E−09	6.04E−11	7.80E−10	1.40E−10	1.91E−09	1.37E−08	1.59E−07
Testes	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	7.19E−10	1.29E−10	1.91E−09	1.39E−08	1.59E−07
Thymus	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	5.37E−10	3.51E−10	1.91E−09	1.24E−08	1.59E−07
Thyroid	5.64E−10	7.99E−10	9.06E−10	1.51E−09	1.62E−09	5.54E−10	2.48E−06	1.91E−09	1.26E−08	1.59E−07
Uterus	5.64E−10	7.99E−10	9.06E−10	1.51E−09	6.04E−11	1.44E−09	1.38E−10	1.91E−09	1.44E−08	1.59E−07
Whole Body	5.64E−10	8.18E−10	2.35E−09	4.14E−08	3.95E−10	5.70E−09	7.46E−08	1.91E−09	1.35E−08	4.01E−07

Table 6.3-5. Effective Dose Conversion Factors (Sv/Bq) for Radionuclides Included in Calculation of Conversion Factors (Continued)

Organ or Tissue	U-232	Np-237	Th-229	U-238	Ra-226	Pb-210	Ra-226 + Pb-210	Am-243	Ac-227
Adrenal	1.67E−09	1.25E−11	3.37E−08	1.76E−12	2.86E−11	1.25E−07	1.25E−07	7.91E−12	4.40E−10
Urinary Bladder	1.72E−09	7.58E−11	3.37E−08	9.45E−12	2.69E−11	1.25E−07	1.25E−07	4.74E−11	1.04E−10
Bone Surface	1.66E−07	1.02E−10	1.78E−06	2.09E−11	1.10E−09	2.16E−05	2.16E−05	3.59E−11	6.73E−05
Brain	0.00E+00	3.41E−13	0.00E+00	1.48E−15	0.00E+00	0.00E+00	0.00E+00	7.93E−14	1.31E−10
Breast	1.68E−09	2.71E−11	3.37E−08	3.73E−12	2.67E−11	1.25E−07	1.25E−07	1.72E−11	1.92E−10
Esophagus	1.64E−09	1.41E−12	3.37E−08	4.35E−13	2.32E−11	1.25E−07	1.25E−07	8.13E−13	1.42E−10
Stomach Wall	4.53E−09	2.92E−10	3.53E−08	9.98E−10	1.74E−09	1.25E−07	1.27E−07	3.46E−10	1.40E−09
Small Intestine Wall	6.84E−09	8.02E−10	3.51E−08	2.55E−09	7.94E−10	1.26E−07	1.27E−07	8.76E−10	8.96E−10
Upper Large Intestine Wall	1.74E−08	3.62E−09	3.99E−08	1.47E−08	3.08E−10	1.32E−07	1.32E−07	3.85E−09	1.78E−09
Lower Large Intestine Wall	2.00E−08	1.02E−08	6.42E−08	4.30E−08	5.62E−11	1.45E−07	1.45E−07	8.72E−09	7.73E−09
Kidney	1.20E−08	3.40E−11	3.43E−08	3.98E−12	1.04E−10	2.82E−06	2.82E−06	2.05E−11	3.54E−10
Liver	2.21E−08	2.41E−11	3.37E−08	4.36E−12	6.00E−11	6.08E−06	6.08E−06	1.54E−11	1.54E−05
Lung	1.64E−09	3.70E−12	3.37E−08	7.55E−13	2.56E−11	1.25E−07	1.25E−07	2.40E−12	2.71E−10
Muscle	1.68E−09	2.71E−11	3.37E−08	3.73E−12	2.67E−11	1.25E−07	1.25E−07	1.72E−11	1.92E−10
Ovaries	1.99E−09	2.58E−10	3.37E−08	3.23E−11	3.71E−11	1.25E−07	1.25E−07	1.62E−10	8.31E−07
Pancreas	1.72E−09	2.93E−11	3.37E−08	3.84E−12	5.44E−11	1.25E−07	1.25E−07	2.16E−11	3.77E−10
Red Bone Marrow	1.51E−08	6.89E−11	1.68E−07	1.87E−11	1.14E−10	1.48E−06	1.48E−06	4.66E−11	5.40E−06
Skin	1.65E−09	8.58E−12	3.37E−08	1.37E−12	2.39E−11	1.25E−07	1.25E−07	5.04E−12	1.37E−10
Spleen	1.69E−09	2.16E−11	3.37E−08	3.13E−12	4.08E−11	1.25E−07	1.25E−07	1.51E−11	1.59E−10
Testes	1.66E−09	2.10E−11	3.37E−08	2.61E−12	2.29E−11	1.25E−07	1.25E−07	1.14E−11	8.31E−07
Thymus	1.64E−09	1.41E−12	3.37E−08	4.35E−13	2.32E−11	1.25E−07	1.25E−07	8.13E−13	1.42E−10
Thyroid	1.63E−09	4.81E−13	3.37E−08	2.94E−13	2.23E−11	1.25E−07	1.25E−07	2.07E−13	1.26E−10
Uterus	1.80E−09	1.03E−10	3.37E−08	1.32E−11	3.53E−11	1.25E−07	1.25E−07	6.88E−11	1.22E−10
Whole Body	1.26E−08	9.81E−10	1.04E−07	3.69E−09	2.45E−10	1.45E−06	1.45E−06	8.82E−10	3.80E−06

NOTE: Calculated in Excel using Equation 6.3-5; file name *Conversion Factors for Groundwater Protection Standard_Rev 3.xls* – see Appendix B

Table 6.3-6. Conversion Factors (Sv/y per Bq/m3) for Calculating Annual Beta-Gamma Dose for Evaluation of Compliance with the Groundwater Protection Standard

Organ or Tissue	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Th-232/Ra-228
Adrenal	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	6.73E−10	9.64E−11	1.40E−09	1.10E−08	1.17E−07
Urinary Bladder	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	8.64E−10	9.86E−11	1.40E−09	1.03E−08	1.16E−07
Bone Surface	4.12E−10	5.84E−10	6.62E−10	3.06E−07	4.41E−11	3.72E−09	1.59E−10	1.40E−09	9.20E−09	4.37E−06
Brain	4.12E−10	5.84E−10	6.62E−10	9.20E−15	4.41E−11	5.33E−10	0.00E+00	0.00E+00	0.00E+00	1.86E−13
Breast	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	6.19E−10	2.42E−10	1.40E−09	9.06E−09	1.16E−07
Esophagus	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	3.92E−10	2.56E−10	1.40E−09	9.06E−09	1.16E−07
Stomach Wall	4.12E−10	8.11E−10	7.09E−10	2.06E−09	2.48E−09	1.48E−09	1.60E−10	1.45E−09	1.02E−08	1.18E−07
Small Intestine Wall	4.12E−10	5.84E−10	6.85E−10	3.31E−09	8.69E−11	3.64E−09	1.03E−10	1.40E−09	1.05E−08	1.21E−07
Upper Large Intestine Wall	4.12E−10	5.84E−10	8.04E−10	1.38E−08	2.96E−10	1.24E−08	1.04E−10	1.40E−09	1.04E−08	1.34E−07
Lower Large Intestine Wall	4.12E−10	5.84E−10	1.08E−09	3.75E−08	8.04E−10	3.36E−08	1.02E−10	1.40E−09	1.05E−08	1.46E−07
Kidney	4.12E−10	5.84E−10	9.13E−09	1.10E−09	4.41E−11	6.42E−10	9.79E−11	1.40E−09	1.00E−08	1.23E−07
Liver	4.12E−10	5.84E−10	4.73E−09	1.10E−09	6.01E−11	5.33E−10	1.01E−10	1.40E−09	9.93E−09	1.31E−07
Lung	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	4.46E−10	1.21E−10	1.40E−09	9.28E−09	1.16E−07
Muscle	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	6.19E−10	2.42E−10	1.40E−09	9.06E−09	1.16E−07
Ovaries	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	2.06E−09	1.01E−10	1.40E−09	9.42E−09	1.17E−07
Pancreas	4.12E−10	5.84E−10	2.84E−09	1.10E−09	4.41E−11	6.19E−10	1.03E−10	1.40E−09	9.79E−09	1.16E−07
Red Bone Marrow	4.12E−10	5.84E−10	6.62E−10	1.42E−07	4.41E−11	2.05E−09	1.61E−10	1.40E−09	9.64E−09	4.88E−07
Skin	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	4.14E−10	1.54E−10	1.40E−09	7.60E−09	1.16E−07
Spleen	4.12E−10	5.84E−10	3.16E−09	1.10E−09	4.41E−11	5.70E−10	1.02E−10	1.40E−09	1.00E−08	1.16E−07
Testes	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	5.25E−10	9.42E−11	1.40E−09	1.02E−08	1.16E−07
Thymus	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	3.92E−10	2.56E−10	1.40E−09	9.06E−09	1.16E−07
Thyroid	4.12E−10	5.84E−10	6.62E−10	1.10E−09	1.18E−09	4.04E−10	1.81E−06	1.40E−09	9.20E−09	1.16E−07
Uterus	4.12E−10	5.84E−10	6.62E−10	1.10E−09	4.41E−11	1.05E−09	1.01E−10	1.40E−09	1.05E−08	1.16E−07
Whole body	4.12E−10	5.98E−10	1.72E−09	3.03E−08	2.89E−10	4.16E−09	5.45E−08	1.40E−09	9.86E−09	2.93E−07

Table 6.3-6. Conversion Factors (Sv/y per Bq/m^3) for Calculating Annual Beta-Gamma Dose to Demonstrate Compliance with the Groundwater Protection Standard (Continued)

Organ or Tissue	U-232	Np-237	Th-229	U-238	Ra-226	Pb-210	Ra-226+Pb-210	Am-243	Ac-227
Adrenal	1.22E−09	9.13E−12	2.46E−08	1.29E−12	2.09E−11	9.13E−08	9.13E−08	5.78E−12	3.22E−10
Urinary bladder	1.26E−09	5.54E−11	2.46E−08	6.90E−12	1.97E−11	9.13E−08	9.13E−08	3.46E−11	7.63E−11
Bone surface	1.21E−07	7.45E−11	1.30E−06	1.53E−11	8.04E−10	1.58E−05	1.58E−05	2.62E−11	4.92E−05
Brain	0.00E+00	2.49E−13	0.00E+00	1.08E−15	0.00E+00	0.00E+00	0.00E+00	5.79E−14	9.58E−11
Breast	1.23E−09	1.98E−11	2.46E−08	2.73E−12	1.95E−11	9.13E−08	9.13E−08	1.26E−11	1.40E−10
Esophagus	1.20E−09	1.03E−12	2.46E−08	3.18E−13	1.69E−11	9.13E−08	9.13E−08	5.94E−13	1.04E−10
Stomach wall	3.31E−09	2.13E−10	2.58E−08	7.29E−10	1.27E−09	9.17E−08	9.29E−08	2.53E−10	1.02E−09
Small intestine wall	5.00E−09	5.86E−10	2.56E−08	1.87E−09	5.80E−10	9.21E−08	9.27E−08	6.40E−10	6.55E−10
Upper large intestine wall	1.27E−08	2.64E−09	2.91E−08	1.07E−08	2.25E−10	9.63E−08	9.65E−08	2.81E−09	1.30E−09
Lower large intestine wall	1.46E−08	7.45E−09	4.69E−08	3.14E−08	4.11E−11	1.06E−07	1.06E−07	6.37E−09	5.65E−09
Kidney	8.77E−09	2.48E−11	2.51E−08	2.91E−12	7.61E−11	2.06E−06	2.06E−06	1.50E−11	2.59E−10
Liver	1.62E−08	1.76E−11	2.46E−08	3.19E−12	4.39E−11	4.44E−06	4.44E−06	1.12E−11	1.12E−05
Lung	1.20E−09	2.70E−12	2.46E−08	5.51E−13	1.87E−11	9.13E−08	9.13E−08	1.75E−12	1.98E−10
Muscle	1.23E−09	1.98E−11	2.46E−08	2.73E−12	1.95E−11	9.13E−08	9.13E−08	1.26E−11	1.40E−10
Ovaries	1.45E−09	1.88E−10	2.46E−08	2.36E−11	2.71E−11	9.13E−08	9.14E−08	1.18E−10	6.07E−07
Pancreas	1.26E−09	2.14E−11	2.46E−08	2.80E−12	3.97E−11	9.13E−08	9.14E−08	1.58E−11	2.75E−10
Red bone marrow	1.10E−08	5.03E−11	1.23E−07	1.36E−11	8.36E−11	1.08E−06	1.08E−06	3.40E−11	3.94E−06
Skin	1.20E−09	6.27E−12	2.46E−08	1.00E−12	1.74E−11	9.13E−08	9.13E−08	3.68E−12	1.00E−10
Spleen	1.24E−09	1.58E−11	2.46E−08	2.29E−12	2.98E−11	9.13E−08	9.14E−08	1.10E−11	1.16E−10
Testes	1.21E−09	1.53E−11	2.46E−08	1.90E−12	1.68E−11	9.13E−08	9.13E−08	8.33E−12	6.07E−07
Thymus	1.20E−09	1.03E−12	2.46E−08	3.18E−13	1.69E−11	9.13E−08	9.13E−08	5.94E−13	1.04E−10
Thyroid	1.19E−09	3.51E−13	2.46E−08	2.15E−13	1.63E−11	9.13E−08	9.13E−08	1.51E−13	9.23E−11
Uterus	1.32E−09	7.52E−11	2.46E−08	9.65E−12	2.58E−11	9.13E−08	9.14E−08	5.03E−11	8.90E−11
Whole body	9.19E−09	7.17E−10	7.62E−08	2.70E−09	1.79E−10	1.06E−06	1.06E−06	6.44E−10	2.78E−06

NOTE: Calculated in Excel using Equation 6.3-3; file name *Conversion Factors for Groundwater Protection Standard_Rev 3.xls* – see Appendix B

Table 6.3-7. Conversion Factors (mrem/yr per pCi/L) for Calculating Annual Beta-Gamma Dose to Evaluate Compliance with the Groundwater Protection Standard

Organ or Tissue	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Th-232/Ra-228
Adrenal	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	2.49E−03	3.57E−04	5.16E−03	4.05E−02	4.32E−01
Urinary bladder	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	3.20E−03	3.65E−04	5.16E−03	3.81E−02	4.29E−01
Bone surface	1.52E−03	2.16E−03	2.45E−03	1.13E+00	1.63E−04	1.38E−02	5.87E−04	5.16E−03	3.41E−02	1.62E+01
Brain	1.52E−03	2.16E−03	2.45E−03	3.41E−08	1.63E−04	1.97E−03	0.00E+00	0.00E+00	0.00E+00	6.87E−07
Breast	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	2.29E−03	8.95E−04	5.16E−03	3.35E−02	4.29E−01
Esophagus	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	1.45E−03	9.49E−04	5.16E−03	3.35E−02	4.29E−01
Stomach wall	1.52E−03	3.00E−03	2.62E−03	7.62E−03	9.16E−03	5.47E−03	5.92E−04	5.38E−03	3.76E−02	4.38E−01
Small intestine wall	1.52E−03	2.16E−03	2.54E−03	1.22E−02	3.22E−04	1.35E−02	3.81E−04	5.16E−03	3.89E−02	4.49E−01
Upper large intestine wall	1.52E−03	2.16E−03	2.97E−03	5.12E−02	1.09E−03	4.57E−02	3.84E−04	5.16E−03	3.84E−02	4.94E−01
Lower large intestine wall	1.52E−03	2.16E−03	4.00E−03	1.39E−01	2.97E−03	1.24E−01	3.76E−04	5.16E−03	3.89E−02	5.40E−01
Kidney	1.52E−03	2.16E−03	3.38E−02	4.08E−03	1.63E−04	2.37E−03	3.62E−04	5.16E−03	3.70E−02	4.57E−01
Liver	1.52E−03	2.16E−03	1.75E−02	4.08E−03	2.22E−04	1.97E−03	3.73E−04	5.16E−03	3.68E−02	4.86E−01
Lung	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	1.65E−03	4.46E−04	5.16E−03	3.43E−02	4.29E−01
Muscle	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	2.29E−03	8.95E−04	5.16E−03	3.35E−02	4.29E−01
Ovaries	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	7.62E−03	3.73E−04	5.16E−03	3.49E−02	4.33E−01
Pancreas	1.52E−03	2.16E−03	1.05E−02	4.08E−03	1.63E−04	2.29E−03	3.81E−04	5.16E−03	3.62E−02	4.29E−01
Red bone marrow	1.52E−03	2.16E−03	2.45E−03	5.24E−01	1.63E−04	7.58E−03	5.97E−04	5.16E−03	3.57E−02	1.81E+00
Skin	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	1.53E−03	5.70E−04	5.16E−03	2.81E−02	4.29E−01
Spleen	1.52E−03	2.16E−03	1.17E−02	4.08E−03	1.63E−04	2.11E−03	3.78E−04	5.16E−03	3.70E−02	4.29E−01
Testes	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	1.94E−03	3.49E−04	5.16E−03	3.76E−02	4.29E−01
Thymus	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	1.45E−03	9.49E−04	5.16E−03	3.35E−02	4.29E−01
Thyroid	1.52E−03	2.16E−03	2.45E−03	4.08E−03	4.38E−03	1.50E−03	6.70E+00	5.16E−03	3.41E−02	4.29E−01
Uterus	1.52E−03	2.16E−03	2.45E−03	4.08E−03	1.63E−04	3.89E−03	3.73E−04	5.16E−03	3.89E−02	4.29E−01
Whole body	1.52E−03	2.21E−03	6.35E−03	1.12E−01	1.07E−03	1.54E−02	2.02E−01	5.16E−03	3.65E−02	1.08E+00

Table 6.3-7. Conversion Factors (mrem/yr per pCi/L) for Calculating Annual Beta-Gamma Dose to Evaluate Compliance with the Groundwater Protection Standard (Continued)

Organ or Tissue	U-232	Np-237	Th-229	U-238	Ra-226	Pb-210	Ra-226+Pb-210	Am-243	Ac-227
Adrenal	4.52E−03	3.38E−05	9.11E−02	4.76E−06	7.73E−05	3.38E−01	3.38E−01	2.14E−05	1.19E−03
Urinary bladder	4.66E−03	2.05E−04	9.11E−02	2.55E−05	7.28E−05	3.38E−01	3.38E−01	1.28E−04	2.82E−04
Bone surface	4.49E−01	2.76E−04	4.81E+00	5.65E−05	2.98E−03	5.84E+01	5.84E+01	9.70E−05	1.82E+02
Brain	0.00E+00	9.22E−07	0.00E+00	4.00E−09	0.00E+00	0.00E+00	0.00E+00	2.14E−07	3.54E−04
Breast	4.55E−03	7.32E−05	9.11E−02	1.01E−05	7.23E−05	3.38E−01	3.38E−01	4.65E−05	5.19E−04
Esophagus	4.43E−03	3.81E−06	9.11E−02	1.18E−06	6.27E−05	3.38E−01	3.38E−01	2.20E−06	3.84E−04
Stomach wall	1.22E−02	7.89E−04	9.54E−02	2.70E−03	4.70E−03	3.39E−01	3.44E−01	9.35E−04	3.78E−03
Small intestine wall	1.85E−02	2.17E−03	9.48E−02	6.91E−03	2.15E−03	3.41E−01	3.43E−01	2.37E−03	2.42E−03
Upper large intestine wall	4.69E−02	9.78E−03	1.08E−01	3.98E−02	8.31E−04	3.56E−01	3.57E−01	1.04E−02	4.81E−03
Lower large intestine wall	5.41E−02	2.76E−02	1.73E−01	1.16E−01	1.52E−04	3.93E−01	3.93E−01	2.36E−02	2.09E−02
Kidney	3.25E−02	9.19E−05	9.27E−02	1.08E−05	2.82E−04	7.61E+00	7.61E+00	5.54E−05	9.58E−04
Liver	5.98E−02	6.51E−05	9.11E−02	1.18E−05	1.62E−04	1.64E+01	1.64E+01	4.16E−05	4.16E+01
Lung	4.43E−03	1.00E−05	9.11E−02	2.04E−06	6.91E−05	3.38E−01	3.38E−01	6.49E−06	7.33E−04
Muscle	4.55E−03	7.32E−05	9.11E−02	1.01E−05	7.23E−05	3.38E−01	3.38E−01	4.65E−05	5.19E−04
Ovaries	5.37E−03	6.97E−04	9.11E−02	8.73E−05	1.00E−04	3.38E−01	3.38E−01	4.38E−04	2.25E+00
Pancreas	4.65E−03	7.92E−05	9.11E−02	1.04E−05	1.47E−04	3.38E−01	3.38E−01	5.84E−05	1.02E−03
Red bone marrow	4.08E−02	1.86E−04	4.54E−01	5.04E−05	3.09E−04	4.00E+00	4.00E+00	1.26E−04	1.46E+01
Skin	4.46E−03	2.32E−05	9.11E−02	3.71E−06	6.46E−05	3.38E−01	3.38E−01	1.36E−05	3.71E−04
Spleen	4.57E−03	5.84E−05	9.11E−02	8.47E−06	1.10E−04	3.38E−01	3.38E−01	4.08E−05	4.29E−04
Testes	4.48E−03	5.68E−05	9.11E−02	7.05E−06	6.20E−05	3.38E−01	3.38E−01	3.08E−05	2.25E+00
Thymus	4.43E−03	3.81E−06	9.11E−02	1.18E−06	6.27E−05	3.38E−01	3.38E−01	2.20E−06	3.84E−04
Thyroid	4.40E−03	1.30E−06	9.11E−02	7.95E−07	6.01E−05	3.38E−01	3.38E−01	5.59E−07	3.41E−04
Uterus	4.87E−03	2.78E−04	9.11E−02	3.57E−05	9.53E−05	3.38E−01	3.38E−01	1.86E−04	3.29E−04
Whole body	3.40E−02	2.65E−03	2.82E−01	9.98E−03	6.63E−04	3.92E+00	3.92E+00	2.38E−03	1.03E+01

NOTE: Calculated in Excel using Equation 6.3-5; file name *Conversion Factors for Groundwater Protection Standard_Rev 3.xls* – see Appendix B

INTENTIONALLY LEFT BLANK

7. CONCLUSIONS

This section summarizes the derivation of BDCFs for the groundwater exposure scenario and the methods for calculating values for evaluation of compliance with the groundwater protection standard. The output of this analysis is included in several data sets, as shown in Table 7-1.

Table 7-1. Output Data Tracking Numbers

DTN	DTN Title	DTN Description and Comments
MO0307MWDNPBDC.001	Nominal Performance Biosphere Dose Conversion Factors	BDCFs for groundwater exposure scenario and conversion factors for evaluating compliance with groundwater protection standard developed in revision 2 of this analysis (BSC 2003 [DIRS 164403]). This set includes conversion factors for calculating alpha activity concentration in groundwater and conversion factors for calculating whole body dose from beta-photon emitting radionuclides from drinking 2 liters of water per day.
MO0402SPABPHER.000	Conversion Factors for Beta-Photon Emitting Radionuclides for Groundwater Protection Standard	Conversion factors for organs or whole body for calculating beta-photon dose from drinking 2 liters of water per day. The conversion factors for the whole body included in this set are equivalent to the conversion factors included in DTN: MO0307MWDNPBDC.001. (There are differences in the last significant digit between some values of the whole body conversion factors in these two sets that are due to rounding. These differences are negligible.)
MO0407MWDBDCFG.000	Biosphere Dose Conversion Factors for the Groundwater Exposure Scenario	BDCFs for the groundwater exposure scenario developed in this analysis
MO0407SPACFCAC.000	Conversion Factors for Calculating Alpha Activity Concentration in Groundwater	Multipliers to be used with activity concentration of a primary radionuclide in groundwater to obtain alpha activity concentration associated with this radionuclide. The values are identical to those in DTN: MO0307MWDNPBDC.001.
MO0407MWDGSBMF.000	GoldSim Biosphere Model Files for Calculating Biosphere Dose Conversion Factors for Groundwater Exposure Scenario	GoldSim files generated in this analysis. This data set also includes selected GoldSim files generated in the previous revision of this analysis because they are used in impact analysis (Appendix C).

The output of this analysis includes the new data developed in this analysis (DTNs: MO0402SPABPHER.000, MO0407MWDBDCFG.000, MO0407SPACFCAC.000, MO0407MWDGSBMF.000) as well as the re-qualified results from the previous revision of the analysis (DTN: MO0307MWDNPBDC.001). The output of the previous analysis was included in one DTN consisting of the following three data sets: BDCFs for the groundwater exposure scenario, conversion factors for beta-photon emitting radionuclides, and the conversion factors for calculating alpha activity concentration in groundwater. In this analysis, these three component data sets are reported in separate DTNs.

Re-qualification of DTN: MO0307MWDNPBDC.001 was conducted using a corroborating data approach. The BDCFs from DTN: MO0307MWDNPBDC.001 were compared to the new BDCFs developed in this analysis (DTN: MO0407MWDBDCFG.000) in Appendix C with the conclusions given in Section C.3. The results of analyses concerning the BDCF values, presented in Appendix C indicate that the differences between the BDCFs included in DTN: MO0307MWDNPBDC.001 and those in DTN: MO0407MWDBDCFG.000 are negligible and either DTNs can be used in the TSPA-LA model. The impact was evaluated by comparing the mean, 5th percentile and 95th percentile values for the BDCFs for the present-day climate. The differences exceeded 10 percent for ^{126}Sn and 4 isotopes of uranium (^{233}U, ^{236}U, ^{234}U, and ^{238}U). The greatest difference was for ^{233}U (about 23 percent).

The values of the BDCFs were developed using the ERMYN biosphere model and remain valid within the application and validation limits of the model (BSC 2004 [DIRS 169460], Section 8.1). Specifically, the BDCFs were developed for a specific assessment context, described in (BSC (2004 [DIRS 169460]), the reference biosphere, and the receptor. If used for other situations, the BDCFs may not apply, as further discussed in Section 7.1.3.

The DTN: MO0307MWDNPBDC.001 includes conversion factors for beta-photon emitting radionuclides, and the conversion factors for calculating alpha activity concentration in groundwater. The alpha activity conversion factors included in DTN: MO0407SPACFCAC.000 are the same as those included in DTN: MO0307MWDNPBDC.001. The conversion factors for beta-photon emitting radionuclides included in DTN: MO0307MWDNPBDC.001 applied only to the whole body. The beta-photon conversion factor set in DTN: MO0402SPABPHER.000 also includes the conversion factors for individual organs and tissues. For a few radionuclides, there are differences of less than half of a percent between the whole body conversion factors in the two sets due to rounding. These differences are negligible and both sets can be used interchangeably.

7.1 ANALYSIS SUMMARY

7.1.1 Incorporation of Uncertainty in Biosphere Dose Conversion Factors

The 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 present-day climate, the monsoon climate, and the glacial transition climate (Section 6.2.2). 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.

7.1.2 Biosphere Dose Conversion Factors for the Groundwater Exposure Scenario and Their Use in TSPA

Some BDCFs (radionuclide specific) include contributions from decay products (Section 6.1.1). The primary radionuclides and the decay products that were included in the BDCF with the primary radionuclides are presented in Table 7.1-1.

Table 7.1-1. Primary Radionuclides and Decay Products Included in the Biosphere Dose Conversion Factors

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

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-LA (Sv/yr)

$BDCF_i$ = climate-specific biosphere dose conversion factor for radionuclide *i* (Sv/yr per Bq/m^3)

$Cw_i(t)$ = 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.

As shown in Table 7.1-1, BDCFs for ^{226}Ra and ^{210}Pb are calculated separately, although ^{210}Pb is a decay product of ^{226}Ra. If the activity concentration of ^{210}Pb in the groundwater is not calculated by the TSPA-LA model, the BDCF for ^{210}Pb should be added to that of ^{226}Ra to account for that part of the uranium decay chain. This summation is based on the condition of radioactive equilibrium between ^{226}Ra, ^{210}Pb, and their short-lived decay products.

7.1.3 Limitations of Biosphere Modeling

The ERMYN model applies to the specific environments identified in 10 CFR 63.305 [DIRS 156605]. It uses certain approximations and simplifications. Therefore, the ERMYN model only applies within a certain assessment context (BSC 2004 [DIRS 169460], 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-LA (BSC 2004 [DIRS 169460], Section 6.1.3). 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 equilibrium conditions. If soils are not at equilibrium 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.

7.1.4 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 present-day 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 present-day 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 ^{14}C, isotopes of cesium, and ^{210}Pb. Consumption pathways generally are more important for radionuclides with atomic numbers less than about 88.

7.1.5 Performance Assessment Calculations for Groundwater Protection Standard

For calculating alpha activity concentration in groundwater and the annual dose from beta- and photon-emitting radionuclides for evaluation of compliance with the groundwater protection standard, the methods and the conversion factor values described in Section 6.3 should be used (DTNs: MO0307MWDNPBDC.001 and MO0402SPABPHER.000, for alpha and beta-photon parts of the standard, respectively). 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 6.3-6 or 6.3-7.

7.2 HOW THE ACCEPTANCE CRITERIA ARE ADDRESSED

The primary function of this analysis was to calculate BDCFs for the groundwater exposure scenario. As noted before, this analysis integrates the model (BSC 2004 [DIRS 169460]) and the model input parameters (BSC 2004 [DIRS 169671]; BSC 2004 [DIRS 169672]; BSC 2004 [DIRS 169673]; BSC 2004 [DIRS 169458]; BSC 2004 [DIRS 169459]) to produce the output of the biosphere model. All ACs addressed by the model and input parameters reports are implicitly included in this analysis and the modeling results.

In addition, the ACs identified as applicable to this analysis in Section 4.2, that are related to the model abstraction were addressed. The biosphere modeling does not utilize the model abstraction step, but rather, the BDCFs are calculated as the model output. In this sense, the BDCFs, which are the input to the TSPA-LA model, serve as a collapsed model abstraction. The uncertainty in the model and its input parameters is propagated onto and reflected in the BDCFs through the development of the BDCF vectors representing individual model realizations (see Section 7.1.2), consistent with ACs 2.2.1.3.13.3, 2.2.1.3.13.4, and 2.2.1.3.14.3 (see Table 4.2-2).

The specific ACs were addressed as follows:

Section 2.2.1.3.13.3: Redistribution of Radionuclides in Soils

AC 1 (1): As discussed in Sections 1 and 7.1.4, because the BDCFs are used directly in the TSPA, the TSPA adequately incorporates the results of human exposures to groundwater.

AC 1(2): By including the BDCFs for disruptive events, the TSPA identifies and describes an aspect of radionuclide redistribution in soil that is important to repository performance. See, Section 7.1.2 and 7.1.3. The technical bases for the groundwater exposure scenario are adequately described in Section 6.1.2.

AC 1 (3): Relevant site FEPs (Section 1), including climate change (Section 6.1.3), receptor characteristics (Section 6.1.4), and the biosphere model (Section 6.1.5) have been appropriately modeled in the BDCFs. Sufficient technical bases are provided for the BDCFs.

AC 1 (4): This report was developed in accordance with the quality assurance (QA) procedures. It commits to NUREG-1297 and NUREG-1298. This commitment is implemented in project procedures. Compliance with project procedures is assessed through QA audits and other oversight activities.

AC 2 (1): The BDCF development process described in Section 6 shows that the BDCFs used in the license application are justified. Adequate descriptions of how data was used to develop BDCFs are presented in Section 6.2, which includes a pathway analysis (Section 6.2.4), climate change (Section 6.2.6), and uncertainty (Section 6.2.1).

AC 2 (2): As shown in Sections 4.1.1 and 6.3.1, sufficient data is available to adequately define the parameters for the BDCFs.

AC 3 (1): The calculations described in Section 6.2.2 for the incorporation of climate change, the resulting BDCFs presented in Section 6.2.3, and the development of dose factors described in Section 6.3 show that the parameter values are technically defensible, reasonably account for uncertainties, and do not result in an under-representation of the risk.

AC 3 (2): The model input data related to agriculatural parameters (Section 4.1) are consistent with the current farming practices. Data on the airborne particulate concentration is based on the resuspension of appropriate material in a climate and level of disturbance which is expected to be found at the location of the RMEI.

AC 3 (3): Sections 6.2.1 and 7.1.1 shows that uncertainty was adequately represented in the BDCFs by a probability distribution which was generated from a thousand realizations using a Monte Carlo technique.

Section 2.2.1.3.14.3: Biosphere Characteristics

AC 1 (3): Section 6.1.3 shows how the impact of climate change on the BDCFs is consistent with the three climate states used in other TSPA abstractions.

AC 1 (4): This report was developed in accordance with the QA procedures. It commits to NUREG-1297 and NUREG-1298. This commitment is implemented in project procedures. Compliance with project procedures is assessed through QA audits and other oversight activities.

AC 2 (1): The BDCF development process described in Section 6 shows that the BDCFs used in the license application are justified. Section 6.1.4 shows that the analysis is consistent with the definition of the RMEI. Adequate descriptions of how data was used to develop BDCFs are presented in Section 6.2, which includes a pathway analysis (Section 6.2.5), climate change (Section 6.2.2), and uncertainty (Section 6.2.1).

AC 2 (2): As shown in Sections 4.1.1 and 6.3.1, sufficient data is available to adequately define the degree to which the BDCFs incorporate FEPs and are consistent with the present knowledge of the conditions in the region surrounding Yucca Mountain.

AC 3 (1): Sections 6.6.2, 6.2.3, 6.3.2, and 6.1.4 show that the parameter values are technically defensible, reasonably account for uncertainties, do not result in an under-representation of the risk, and are consistent with the definition of the RMEI.

AC 3 (2): Section 4.1 shows that the technical bases for the parameter values and ranges used to generate the BDCFs are consistent with site characterization data and technically defensible.

AC 3 (4): Sections 6.2.1 and 7.1.1 show that uncertainty is adequately represented in parameter development through a Monte Carlo analysis.

INTENTIONALLY LEFT BLANK

8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

BSC (Bechtel SAIC Company) 2001. *FY01 Supplemental Science and Performance Analyses, Volume 2: Performance Analyses.* TDR-MGR-PA-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010724.0110. 154659

BSC (Bechtel SAIC Company) 2003. *Nominal Performance Biosphere Dose Conversion Factor Analysis.* ANL-MGR-MD-000009 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030728.0008. 164403

BSC (Bechtel SAIC Company) 2003. *Total System Performance Assessment-License Application Methods and Approach.* TDR-WIS-PA-000006 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031215.0001. 166296

BSC (Bechtel SAIC Company) 2004. *Agricultural and Environmental Input Parameters for the Biosphere Model.* ANL-MGR-MD-000006, Rev. 02. Las Vegas, Nevada: Bechtel SAIC Company. 169673

BSC (Bechtel SAIC Company) 2004. *Biosphere Model Report.* MDL-MGR-MD-000001, Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company. 169460

BSC (Bechtel SAIC Company) 2004. *Characteristics of the Receptor for the Biosphere Model.* ANL-MGR-MD-000005, Rev. 03. Las Vegas, Nevada: Bechtel SAIC Company. 169671

BSC (Bechtel SAIC Company) 2004. *Environmental Transport Input Parameters for the Biosphere Model.* ANL-MGR-MD-000007, Rev. 02. Las Vegas, Nevada: Bechtel SAIC Company. 169672

BSC (Bechtel SAIC Company) 2004. *Future Climate Analysis.* ANL-NBS-GS-000008, Rev. 01. Las Vegas, Nevada: Bechtel SAIC Company. 170002

BSC (Bechtel SAIC Company) 2004. *Inhalation Exposure Input Parameters for the Biosphere Model.* ANL-MGR-MD-000001, Rev. 03. Las Vegas, Nevada: Bechtel SAIC Company. 169458

BSC (Bechtel SAIC Company) 2004. *Q-List.* 000-30R-MGR0-00500-000-000 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040721.0007. 168361

BSC (Bechtel SAIC Company) 2004. *Soil-Related Input Parameters for the Biosphere Model.* ANL-NBS-MD-000009, Rev. 02. Las Vegas, Nevada: Bechtel SAIC Company. 169459

BSC (Bechtel SAIC Company) 2004. *Technical Work Plan for Biosphere Modeling and Expert Support.* TWP-NBS-MD-000004 REV 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040527.0004. 169573

Canori, G.F. and Leitner, M.M. 2003. *Project Requirements Document.* TER-MGR-MD-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031222.0006. 166275

[DOE (U.S. Department of Energy)] 2004. "FGR 11 Table 2.2. Ingestion Intakes (for various radionuclides)." [Oak Ridge, Tennessee: U.S. Department of Energy, Oak Ridge National Laboratory]. Accessed March 11, 2004. ACC: MOL.20040504.0294. http://www.ornl.gov/cgi-bin/cgiwrap?user=wlj&script=fgrx.pl 169713

Eckerman, K.F. and Ryman, J.C. 1993. *External Exposure to Radionuclides in Air, Water, and Soil, Exposure-to-Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance.* EPA 402-R-93-081. Federal Guidance Report No. 12. Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. TIC: 225472. 107684

GoldSim Technology Group. 2002. *GoldSim, Graphical Simulation Environment, User's Guide.* Version 7.40. Redmond, Washington: Golder Associates. TIC: 253564. 160643

Lide, D.R. and Frederikse, H.P.R., eds. 1997. *CRC Handbook of Chemistry and Physics.* 78th Edition. Boca Raton, Florida: CRC Press. TIC: 243741. 103178

NRC (U.S. Nuclear Regulatory Commission) 2003. *Yucca Mountain Review Plan, Final Report.* NUREG-1804, Rev. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. TIC: 254568. 163274

Steel, R.G.D. and Torrie, J.H. 1980. *Principles and Procedures of Statistics: A Biometrical Approach.* 2nd Edition. New York, New York: McGraw Hill. TIC: 6322. 150857

8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available. 156605

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

AP-2.22Q, Rev. 1, ICN 1. *Classification Analyses and Maintenance of the Q-List.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

AP-2.27Q, Rev. 1, ICN 3. *Planning for Science Activities.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

AP-SIII.2Q, Rev 1 ICN 2. *Qualification of Unqualified Data.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

AP-SIII.9Q, Rev.1, ICN 6. *Scientific Analyses*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

LP-SI.11Q-BSC Rev. 000. *Software Management.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

MO0305SPAINEXI.001. Inhalation Exposure Input Parameters for the Biosphere Model. Submittal date: 05/27/2003. 163808

MO0305SPASRPBM.001. Soil Related Parameters for the Biosphere Model. Submittal date: 05/28/2003. 163815

MO0306MWDBGSMF.001. Biosphere Goldsim Model Files. Submittal date: 06/13/2003. 163816

MO0306SPAAEIBM.001. Agricultural and Environmental Input Parameters for the Biosphere Model. Submittal date: 05/30/2003. 163812

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

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

MO0307MWDNPBDC.001. Nominal Performance Biosphere Dose Conversion Factors. Submittal date: 07/08/2003. 164615

MO0307SEPFEPS4.000. LA FEP List. Submittal date: 07/31/2003. 164527

MO0403SPAAEIBM.002. Agricultural and Environmental Input Parameters for 169392 the Biosphere Model. Submittal date: 03/22/2004.

MO0406SPAETPBM.002. Environmental Transport Input Parameters for the Biosphere Model. Submittal date: 06/24/2004. 170150

MO0407SEPFEPLA.000. LA FEP List. Submittal date: 07/20/2004. 170760

MO0407SPACRBSM.002. Characteristics of the Receptor for the Biosphere Model. Submittal date: 07/19/2004. 170677

MO0407SPAINEXI.002. Inhalation Exposure Input Parameters for the Biosphere Model. Submittal date: 07/12/2004. 170597

MO0407SPASRPBM.002. Soil Related Parameters for the Biosphere Model. Submittal date: 07/20/2004. 170755

8.4 SOFTWARE CODES

BSC (Bechtel SAIC Company) 2003. *Software Code: GoldSim.* V7.50.100. PC. 0344-.50.100-00. 161572

BSC (Bechtel SAIC Company) 2004. *Software Code: GoldSim.* V8.01 Service Pack 4. PC, Windows 2000. 10344-8.01SP4-00. 169695

8.5 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

MO0307MWDNPBDC.001	Nominal Performance Biosphere Dose Conversion Factors
MO0402SPABPHER.000	Conversion Factors for Beta-Photon Emitting Radionuclides for Groundwater Protection Standard
MO0407MWDBDCFG.000	Biosphere Dose Conversion Factors for the Groundwater Exposure Scenario
MO0407SPACFCAC.000	Conversion Factors for Calculating Alpha Activity Concentration in Groundwater
MO0407MWDGSBMF.000	GoldSim Biosphere Model Files for Calculating Biosphere Dose Conversion Factors for Groundwater Exposure Scenario

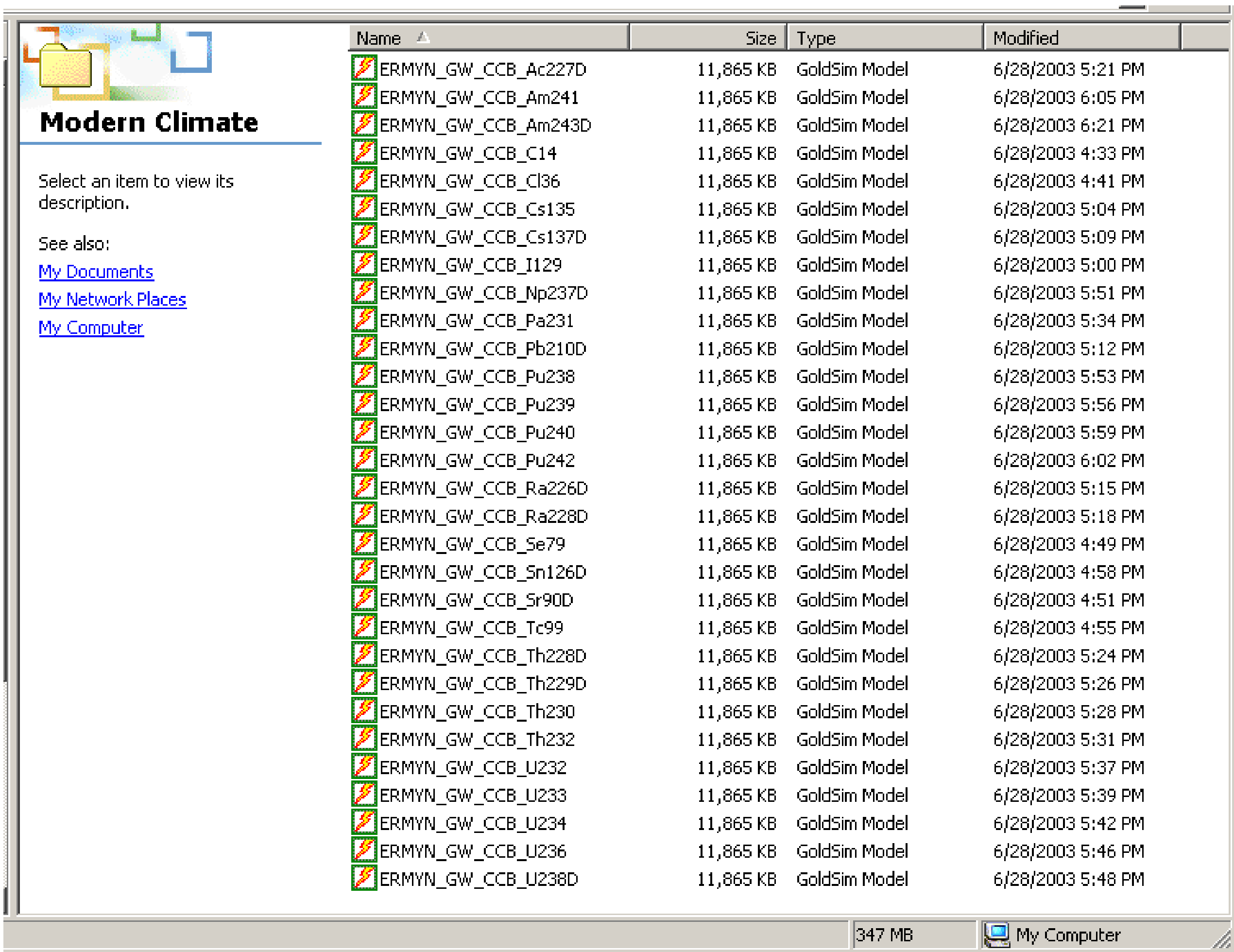
APPENDIX A

LIST AND DESCRIPTION OF GOLDSIM FILES GENERATED IN THIS ANALYSIS

A. LIST AND DESCRIPTION OF GOLDSIM FILES GENERATED IN THIS ANALYSIS

This appendix contains the list and description of GoldSim biosphere model files generated in this analysis. The files are included in DTN: MO0407MWDGSBMF.000.

Figure A-1 shows the list of GoldSim files for the present-day climate (file names ERMYN_GW_CCB_<radionuclide symbol>) generated using GoldSim 7.50.100 and the old input parameter values (DTN: MO0305SPAINEXI.001 [DIRS 163808], MO0305SPASRPBM.001 [DIRS 163815], MO0306SPAAEIBM.001 [DIRS 163812], MO0306SPACRBSM.001 [DIRS 163813], MO0306SPAETPBM.001 [DIRS 163814]).



Name	Size	Type	Modified
ERMYN_GW_CCB_Ac227D	11,865 KB	GoldSim Model	6/28/2003 5:21 PM
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
ERMYN_GW_CCB_C14	11,865 KB	GoldSim Model	6/28/2003 4:33 PM
ERMYN_GW_CCB_Cl36	11,865 KB	GoldSim Model	6/28/2003 4:41 PM
ERMYN_GW_CCB_Cs135	11,865 KB	GoldSim Model	6/28/2003 5:04 PM
ERMYN_GW_CCB_Cs137D	11,865 KB	GoldSim Model	6/28/2003 5:09 PM
ERMYN_GW_CCB_I129	11,865 KB	GoldSim Model	6/28/2003 5:00 PM
ERMYN_GW_CCB_Np237D	11,865 KB	GoldSim Model	6/28/2003 5:51 PM
ERMYN_GW_CCB_Pa231	11,865 KB	GoldSim Model	6/28/2003 5:34 PM
ERMYN_GW_CCB_Pb210D	11,865 KB	GoldSim Model	6/28/2003 5:12 PM
ERMYN_GW_CCB_Pu238	11,865 KB	GoldSim Model	6/28/2003 5:53 PM
ERMYN_GW_CCB_Pu239	11,865 KB	GoldSim Model	6/28/2003 5:56 PM
ERMYN_GW_CCB_Pu240	11,865 KB	GoldSim Model	6/28/2003 5:59 PM
ERMYN_GW_CCB_Pu242	11,865 KB	GoldSim Model	6/28/2003 6:02 PM
ERMYN_GW_CCB_Ra226D	11,865 KB	GoldSim Model	6/28/2003 5:15 PM
ERMYN_GW_CCB_Ra228D	11,865 KB	GoldSim Model	6/28/2003 5:18 PM
ERMYN_GW_CCB_Se79	11,865 KB	GoldSim Model	6/28/2003 4:49 PM
ERMYN_GW_CCB_Sn126D	11,865 KB	GoldSim Model	6/28/2003 4:58 PM
ERMYN_GW_CCB_Sr90D	11,865 KB	GoldSim Model	6/28/2003 4:51 PM
ERMYN_GW_CCB_Tc99	11,865 KB	GoldSim Model	6/28/2003 4:55 PM
ERMYN_GW_CCB_Th228D	11,865 KB	GoldSim Model	6/28/2003 5:24 PM
ERMYN_GW_CCB_Th229D	11,865 KB	GoldSim Model	6/28/2003 5:26 PM
ERMYN_GW_CCB_Th230	11,865 KB	GoldSim Model	6/28/2003 5:28 PM
ERMYN_GW_CCB_Th232	11,865 KB	GoldSim Model	6/28/2003 5:31 PM
ERMYN_GW_CCB_U232	11,865 KB	GoldSim Model	6/28/2003 5:37 PM
ERMYN_GW_CCB_U233	11,865 KB	GoldSim Model	6/28/2003 5:39 PM
ERMYN_GW_CCB_U234	11,865 KB	GoldSim Model	6/28/2003 5:42 PM
ERMYN_GW_CCB_U236	11,865 KB	GoldSim Model	6/28/2003 5:46 PM
ERMYN_GW_CCB_U238D	11,865 KB	GoldSim Model	6/28/2003 5:48 PM

Figure A-1. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim 7.50.100 with Old Input Parameters

Figure A-2 shows the list of GoldSim files for the present-day climate (file names ERMYN_GW_MC8_<radionuclide symbol>) generated using GoldSim 8.01 SP4 and the new input parameter values (DTN: MO0407SPAINEXI.002 [DIRS 170597], MO0407SPASRPBM.002 [DIRS 170755], MO0403SPAAEIBM.002 [DIRS 169392], MO0407SPACRBSM.002 [DIRS 170677], MO0406SPAETPBM.002 [DIRS 170150]).

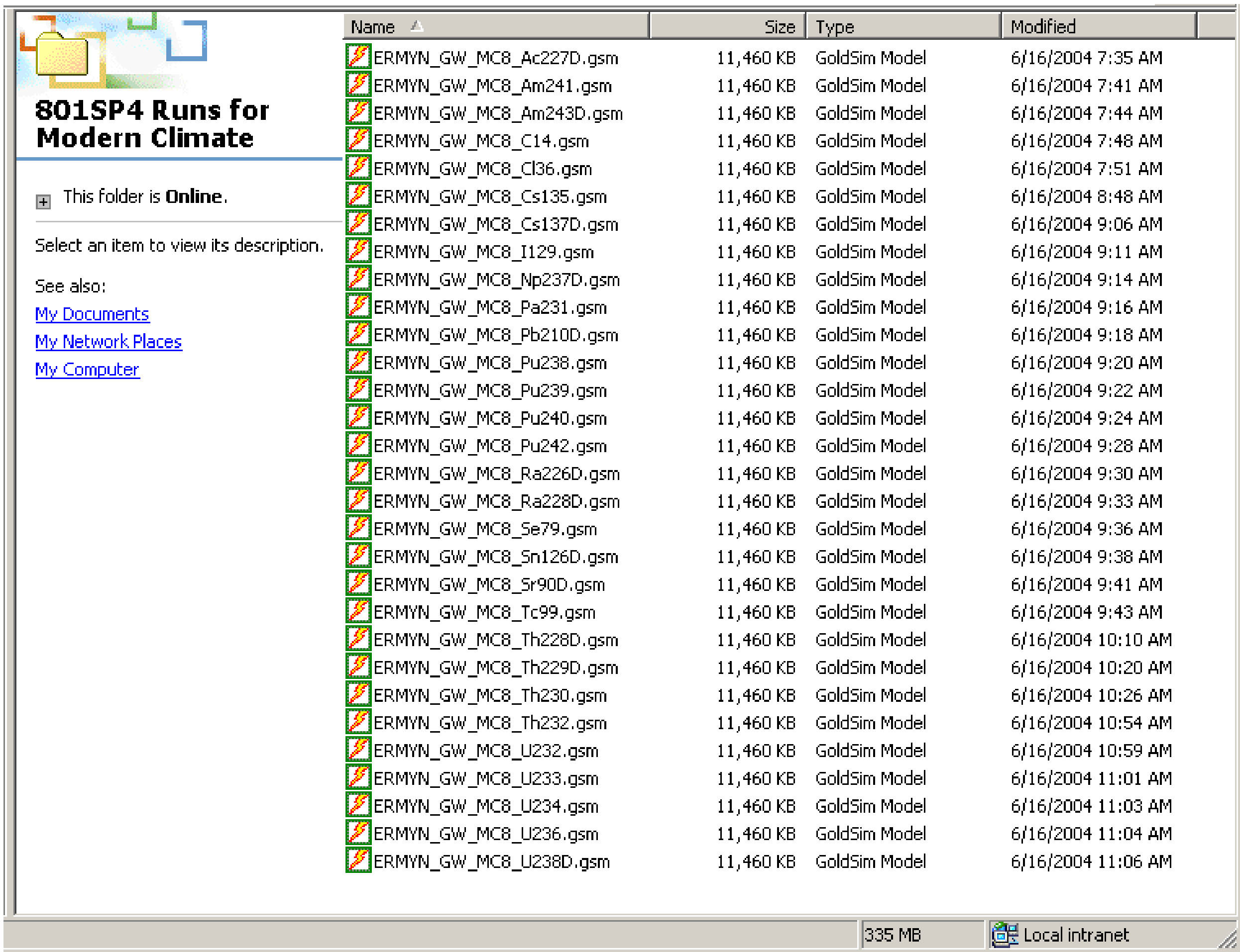
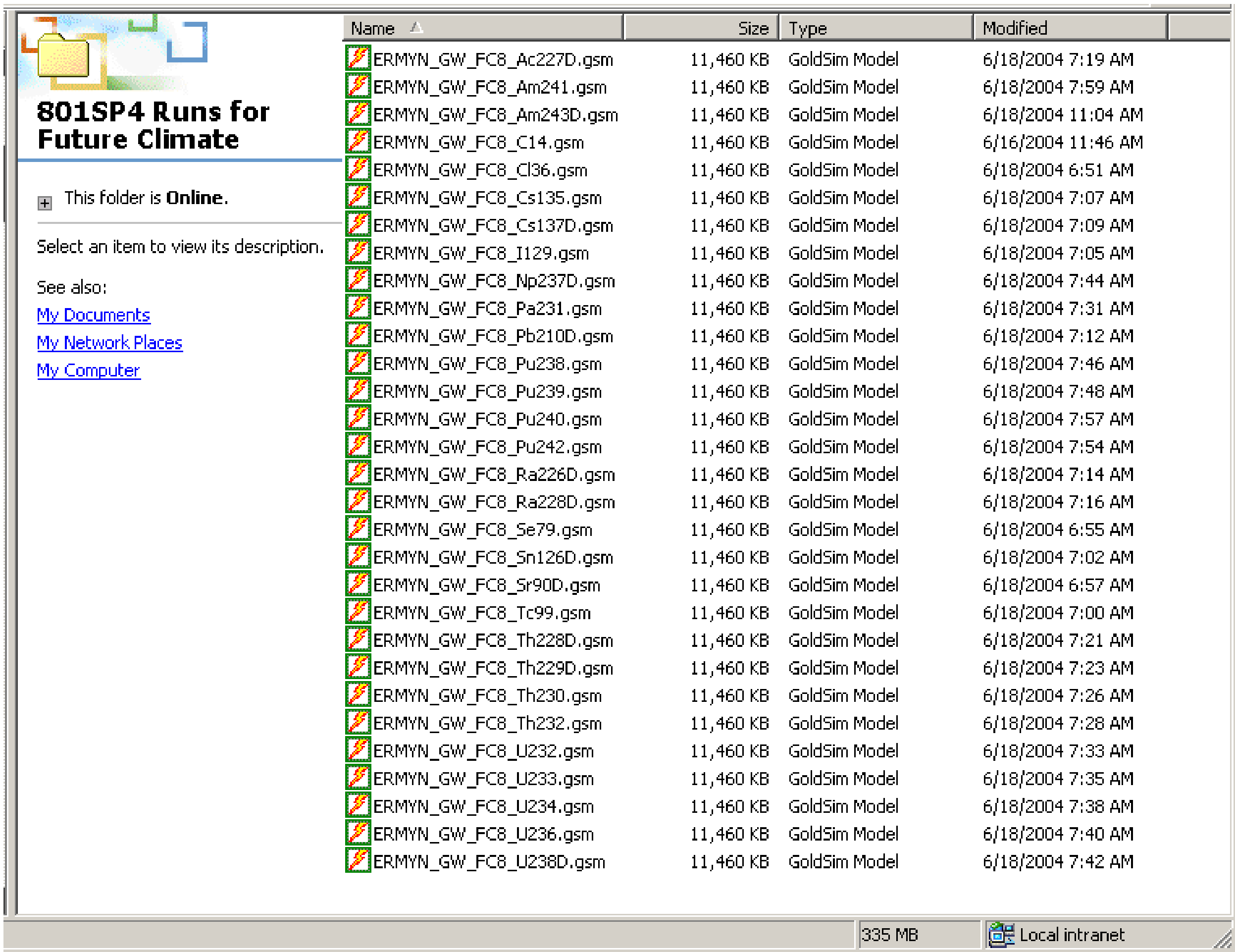


Figure A-2. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim 8.01 SP4 with New Input Parameters

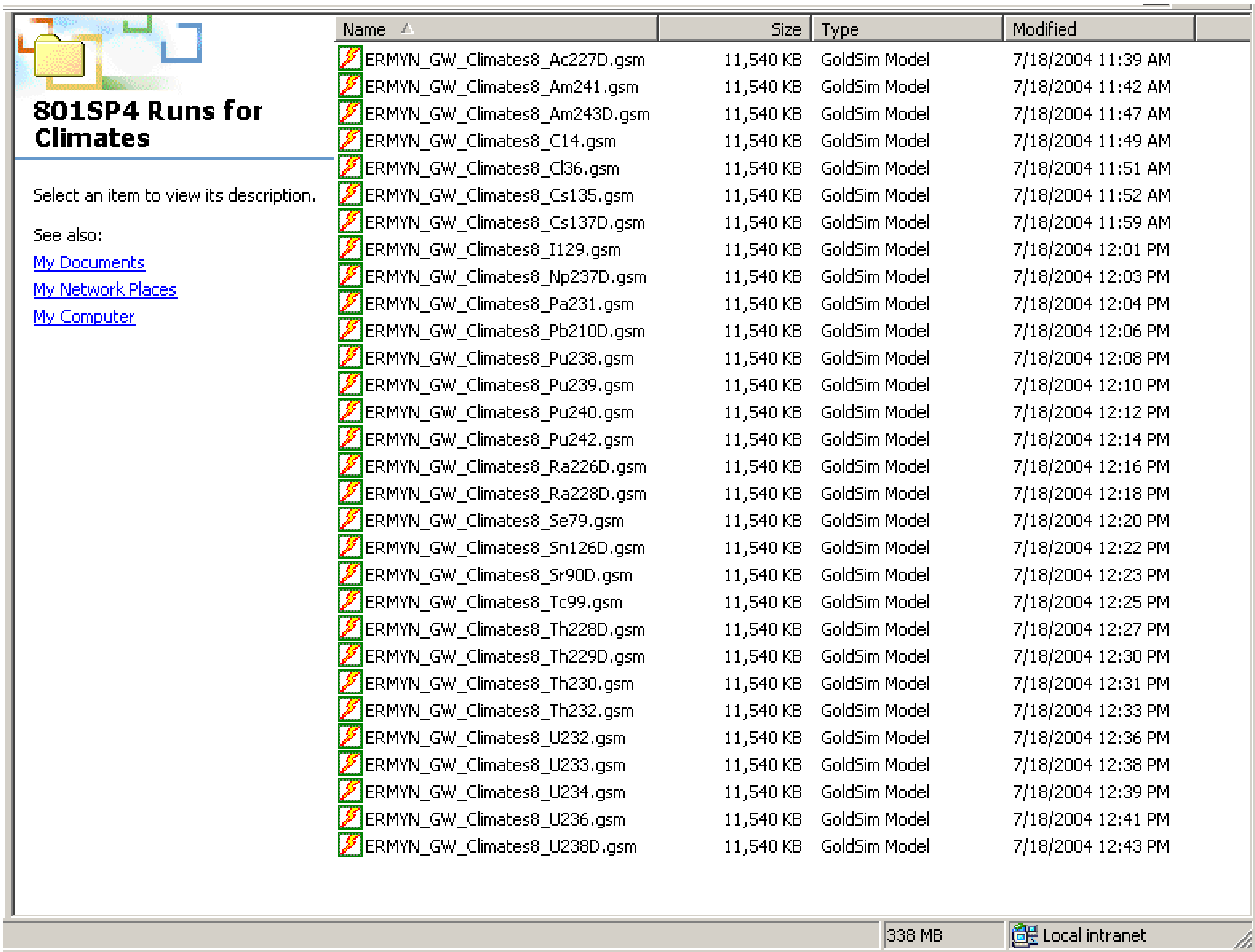
Figure A-3 shows the list of GoldSim files for the upper bound of the glacial transition climate (file names ERMYN_GW_FC8_<radionuclide symbol>) generated using GoldSim 8.01 SP4 and the new input parameter values.



Name	Size	Type	Modified
ERMYN_GW_FC8_Ac227D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:19 AM
ERMYN_GW_FC8_Am241.gsm	11,460 KB	GoldSim Model	6/18/2004 7:59 AM
ERMYN_GW_FC8_Am243D.gsm	11,460 KB	GoldSim Model	6/18/2004 11:04 AM
ERMYN_GW_FC8_C14.gsm	11,460 KB	GoldSim Model	6/16/2004 11:46 AM
ERMYN_GW_FC8_Cl36.gsm	11,460 KB	GoldSim Model	6/18/2004 6:51 AM
ERMYN_GW_FC8_Cs135.gsm	11,460 KB	GoldSim Model	6/18/2004 7:07 AM
ERMYN_GW_FC8_Cs137D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:09 AM
ERMYN_GW_FC8_I129.gsm	11,460 KB	GoldSim Model	6/18/2004 7:05 AM
ERMYN_GW_FC8_Np237D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:44 AM
ERMYN_GW_FC8_Pa231.gsm	11,460 KB	GoldSim Model	6/18/2004 7:31 AM
ERMYN_GW_FC8_Pb210D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:12 AM
ERMYN_GW_FC8_Pu238.gsm	11,460 KB	GoldSim Model	6/18/2004 7:46 AM
ERMYN_GW_FC8_Pu239.gsm	11,460 KB	GoldSim Model	6/18/2004 7:48 AM
ERMYN_GW_FC8_Pu240.gsm	11,460 KB	GoldSim Model	6/18/2004 7:57 AM
ERMYN_GW_FC8_Pu242.gsm	11,460 KB	GoldSim Model	6/18/2004 7:54 AM
ERMYN_GW_FC8_Ra226D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:14 AM
ERMYN_GW_FC8_Ra228D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:16 AM
ERMYN_GW_FC8_Se79.gsm	11,460 KB	GoldSim Model	6/18/2004 6:55 AM
ERMYN_GW_FC8_Sn126D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:02 AM
ERMYN_GW_FC8_Sr90D.gsm	11,460 KB	GoldSim Model	6/18/2004 6:57 AM
ERMYN_GW_FC8_Tc99.gsm	11,460 KB	GoldSim Model	6/18/2004 7:00 AM
ERMYN_GW_FC8_Th228D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:21 AM
ERMYN_GW_FC8_Th229D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:23 AM
ERMYN_GW_FC8_Th230.gsm	11,460 KB	GoldSim Model	6/18/2004 7:26 AM
ERMYN_GW_FC8_Th232.gsm	11,460 KB	GoldSim Model	6/18/2004 7:28 AM
ERMYN_GW_FC8_U232.gsm	11,460 KB	GoldSim Model	6/18/2004 7:33 AM
ERMYN_GW_FC8_U233.gsm	11,460 KB	GoldSim Model	6/18/2004 7:35 AM
ERMYN_GW_FC8_U234.gsm	11,460 KB	GoldSim Model	6/18/2004 7:38 AM
ERMYN_GW_FC8_U236.gsm	11,460 KB	GoldSim Model	6/18/2004 7:40 AM
ERMYN_GW_FC8_U238D.gsm	11,460 KB	GoldSim Model	6/18/2004 7:42 AM

Figure A-3. GoldSim Files for Calculating BDCFs for the Upper Bound Glacial Transition Climate Using GoldSim 8.01 SP4 with New Input Parameters

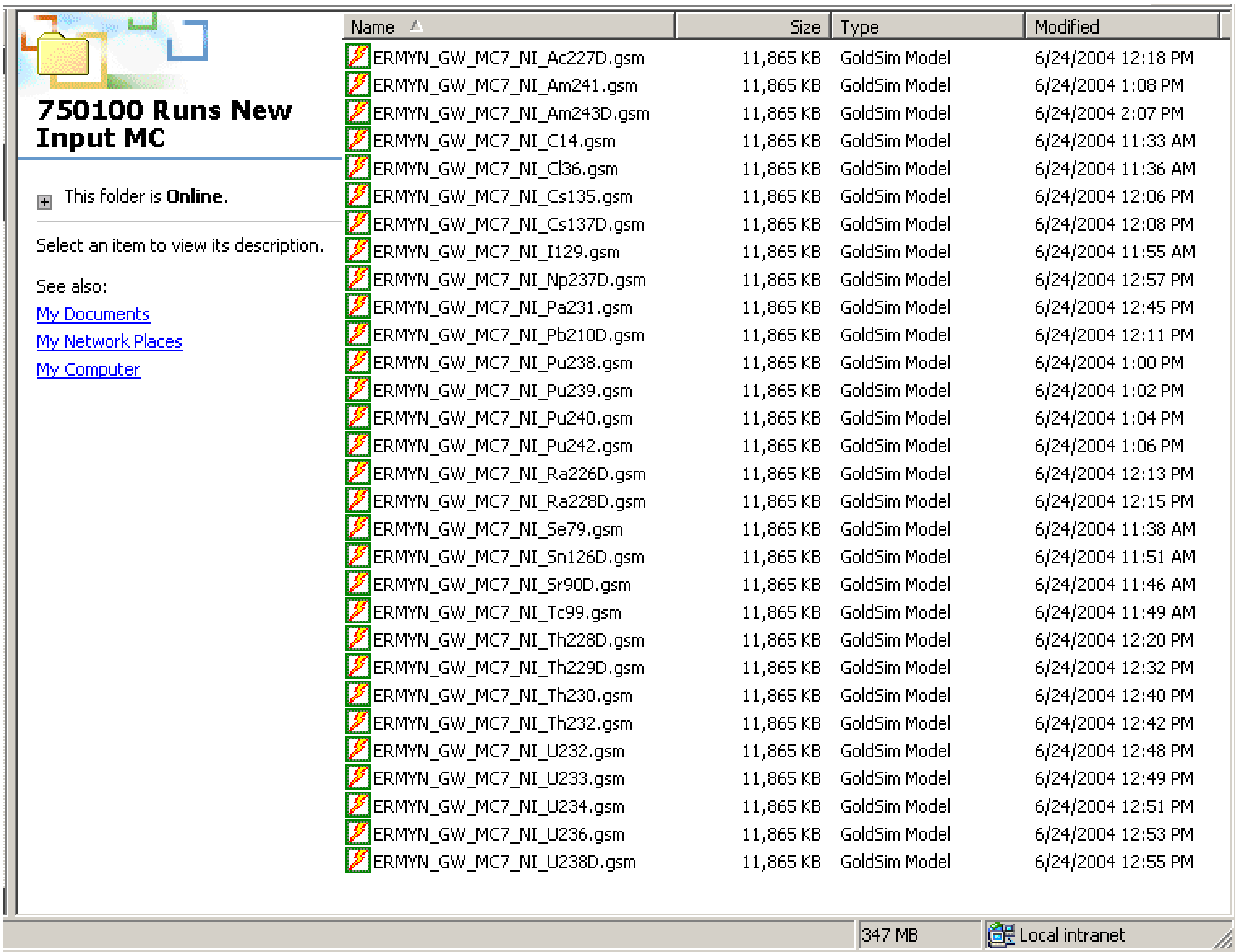
Figure A-4 shows the list of the GoldSim files with modified climate-dependent input parameters (file names ERMYN_GW_Climates8_<radionuclide symbol>), as described in Section 6.2.2 and in Appendix B. The files were generated using GoldSim 8.01 SP4 and the new inputs.



Name	Size	Type	Modified
ERMYN_GW_Climates8_Ac227D.gsm	11,540 KB	GoldSim Model	7/18/2004 11:39 AM
ERMYN_GW_Climates8_Am241.gsm	11,540 KB	GoldSim Model	7/18/2004 11:42 AM
ERMYN_GW_Climates8_Am243D.gsm	11,540 KB	GoldSim Model	7/18/2004 11:47 AM
ERMYN_GW_Climates8_C14.gsm	11,540 KB	GoldSim Model	7/18/2004 11:49 AM
ERMYN_GW_Climates8_Cl36.gsm	11,540 KB	GoldSim Model	7/18/2004 11:51 AM
ERMYN_GW_Climates8_Cs135.gsm	11,540 KB	GoldSim Model	7/18/2004 11:52 AM
ERMYN_GW_Climates8_Cs137D.gsm	11,540 KB	GoldSim Model	7/18/2004 11:59 AM
ERMYN_GW_Climates8_I129.gsm	11,540 KB	GoldSim Model	7/18/2004 12:01 PM
ERMYN_GW_Climates8_Np237D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:03 PM
ERMYN_GW_Climates8_Pa231.gsm	11,540 KB	GoldSim Model	7/18/2004 12:04 PM
ERMYN_GW_Climates8_Pb210D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:06 PM
ERMYN_GW_Climates8_Pu238.gsm	11,540 KB	GoldSim Model	7/18/2004 12:08 PM
ERMYN_GW_Climates8_Pu239.gsm	11,540 KB	GoldSim Model	7/18/2004 12:10 PM
ERMYN_GW_Climates8_Pu240.gsm	11,540 KB	GoldSim Model	7/18/2004 12:12 PM
ERMYN_GW_Climates8_Pu242.gsm	11,540 KB	GoldSim Model	7/18/2004 12:14 PM
ERMYN_GW_Climates8_Ra226D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:16 PM
ERMYN_GW_Climates8_Ra228D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:18 PM
ERMYN_GW_Climates8_Se79.gsm	11,540 KB	GoldSim Model	7/18/2004 12:20 PM
ERMYN_GW_Climates8_Sn126D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:22 PM
ERMYN_GW_Climates8_Sr90D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:23 PM
ERMYN_GW_Climates8_Tc99.gsm	11,540 KB	GoldSim Model	7/18/2004 12:25 PM
ERMYN_GW_Climates8_Th228D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:27 PM
ERMYN_GW_Climates8_Th229D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:30 PM
ERMYN_GW_Climates8_Th230.gsm	11,540 KB	GoldSim Model	7/18/2004 12:31 PM
ERMYN_GW_Climates8_Th232.gsm	11,540 KB	GoldSim Model	7/18/2004 12:33 PM
ERMYN_GW_Climates8_U232.gsm	11,540 KB	GoldSim Model	7/18/2004 12:36 PM
ERMYN_GW_Climates8_U233.gsm	11,540 KB	GoldSim Model	7/18/2004 12:38 PM
ERMYN_GW_Climates8_U234.gsm	11,540 KB	GoldSim Model	7/18/2004 12:39 PM
ERMYN_GW_Climates8_U236.gsm	11,540 KB	GoldSim Model	7/18/2004 12:41 PM
ERMYN_GW_Climates8_U238D.gsm	11,540 KB	GoldSim Model	7/18/2004 12:43 PM

Figure A-4. GoldSim Files for Calculating BDCFs Using Modified Climate-Dependent Parameters and GoldSim 8.01 SP4 with New Input Parameters

Figure A-5 shows the list of GoldSim files for the present-day climate (file names ERMYN_GW_MC7_NI_<radionuclide symbol>) generated using GoldSim 7.50.100 and the new input parameter values.



750100 Runs New Input MC

This folder is **Online**.

Select an item to view its description.

See also:
My Documents
My Network Places
My Computer

Name	Size	Type	Modified
ERMYN_GW_MC7_NI_Ac227D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:18 PM
ERMYN_GW_MC7_NI_Am241.gsm	11,865 KB	GoldSim Model	6/24/2004 1:08 PM
ERMYN_GW_MC7_NI_Am243D.gsm	11,865 KB	GoldSim Model	6/24/2004 2:07 PM
ERMYN_GW_MC7_NI_C14.gsm	11,865 KB	GoldSim Model	6/24/2004 11:33 AM
ERMYN_GW_MC7_NI_Cl36.gsm	11,865 KB	GoldSim Model	6/24/2004 11:36 AM
ERMYN_GW_MC7_NI_Cs135.gsm	11,865 KB	GoldSim Model	6/24/2004 12:06 PM
ERMYN_GW_MC7_NI_Cs137D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:08 PM
ERMYN_GW_MC7_NI_I129.gsm	11,865 KB	GoldSim Model	6/24/2004 11:55 AM
ERMYN_GW_MC7_NI_Np237D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:57 PM
ERMYN_GW_MC7_NI_Pa231.gsm	11,865 KB	GoldSim Model	6/24/2004 12:45 PM
ERMYN_GW_MC7_NI_Pb210D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:11 PM
ERMYN_GW_MC7_NI_Pu238.gsm	11,865 KB	GoldSim Model	6/24/2004 1:00 PM
ERMYN_GW_MC7_NI_Pu239.gsm	11,865 KB	GoldSim Model	6/24/2004 1:02 PM
ERMYN_GW_MC7_NI_Pu240.gsm	11,865 KB	GoldSim Model	6/24/2004 1:04 PM
ERMYN_GW_MC7_NI_Pu242.gsm	11,865 KB	GoldSim Model	6/24/2004 1:06 PM
ERMYN_GW_MC7_NI_Ra226D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:13 PM
ERMYN_GW_MC7_NI_Ra228D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:15 PM
ERMYN_GW_MC7_NI_Se79.gsm	11,865 KB	GoldSim Model	6/24/2004 11:38 AM
ERMYN_GW_MC7_NI_Sn126D.gsm	11,865 KB	GoldSim Model	6/24/2004 11:51 AM
ERMYN_GW_MC7_NI_Sr90D.gsm	11,865 KB	GoldSim Model	6/24/2004 11:46 AM
ERMYN_GW_MC7_NI_Tc99.gsm	11,865 KB	GoldSim Model	6/24/2004 11:49 AM
ERMYN_GW_MC7_NI_Th228D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:20 PM
ERMYN_GW_MC7_NI_Th229D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:32 PM
ERMYN_GW_MC7_NI_Th230.gsm	11,865 KB	GoldSim Model	6/24/2004 12:40 PM
ERMYN_GW_MC7_NI_Th232.gsm	11,865 KB	GoldSim Model	6/24/2004 12:42 PM
ERMYN_GW_MC7_NI_U232.gsm	11,865 KB	GoldSim Model	6/24/2004 12:48 PM
ERMYN_GW_MC7_NI_U233.gsm	11,865 KB	GoldSim Model	6/24/2004 12:49 PM
ERMYN_GW_MC7_NI_U234.gsm	11,865 KB	GoldSim Model	6/24/2004 12:51 PM
ERMYN_GW_MC7_NI_U236.gsm	11,865 KB	GoldSim Model	6/24/2004 12:53 PM
ERMYN_GW_MC7_NI_U238D.gsm	11,865 KB	GoldSim Model	6/24/2004 12:55 PM

347 MB Local intranet

Figure A-5. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim 7.50.100 with New Input Parameters

Figure A-6 shows the list of GoldSim files for the present-day climate (file names ERMYN_GW_CCB_<radionuclide symbol>_GS801SP4) generated using GoldSim 8.01 SP4 and the old input parameter values.

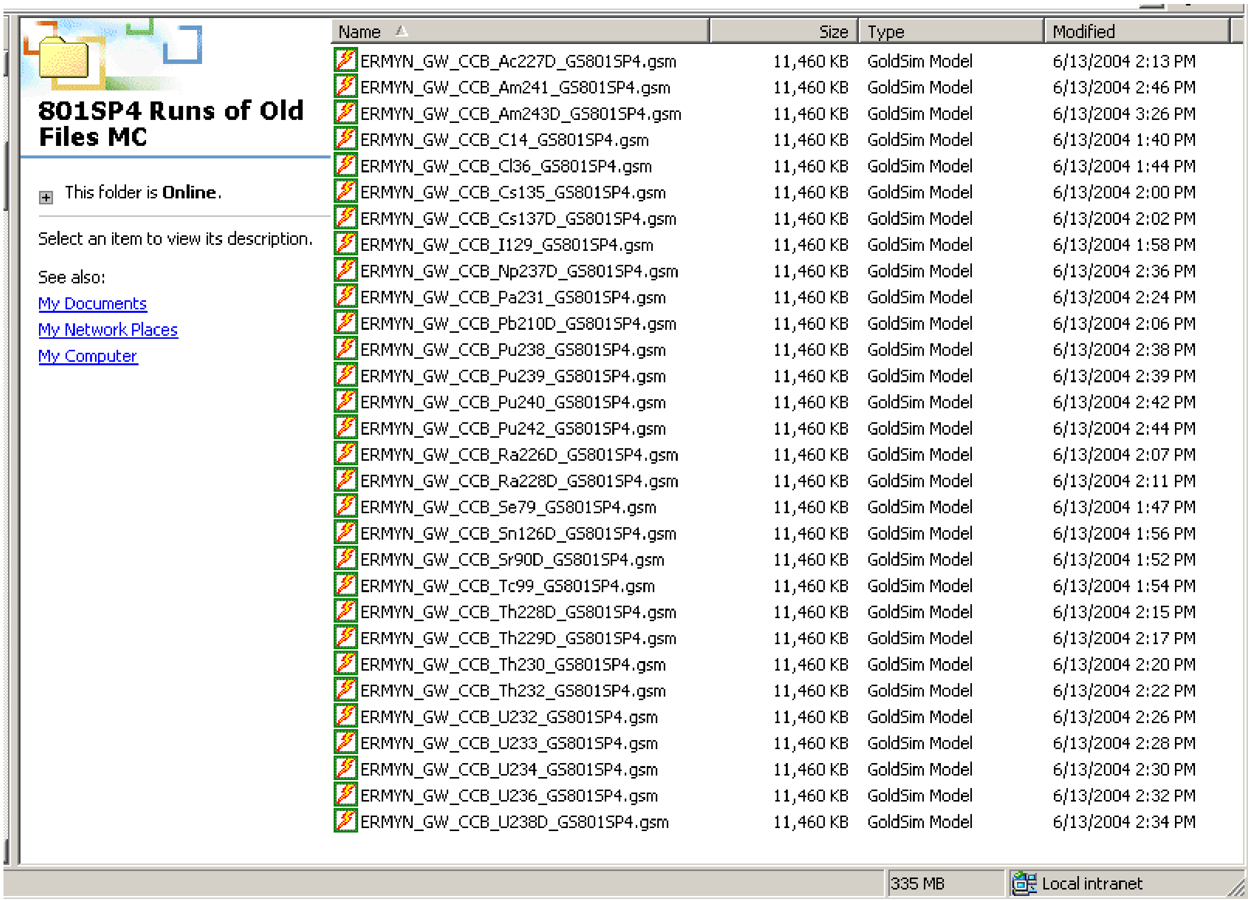


Figure A-6. GoldSim Files for Calculating BDCFs for the Present-Day Climate Using GoldSim 8.01 SP4 with Old Input Parameters

APPENDIX B

DESCRIPTION OF EXCEL FILES GENERATED IN THIS ANALYSIS

B. LIST AND DESCRIPTION OF EXCEL FILES GENERATED IN THIS ANALYSIS

This appendix contains descriptions of the Excel files that were used for calculations in this analysis. For the files that contain the stochastic results of the GoldSim runs, the values were copied from the RESULTS container of the appropriate GoldSim files and pasted into the worksheets.

B.1 LIST OF EXCEL FILES

Figure B-1 shows the list of the Excel files supporting this analysis. The description of the files follows in Section B.2.

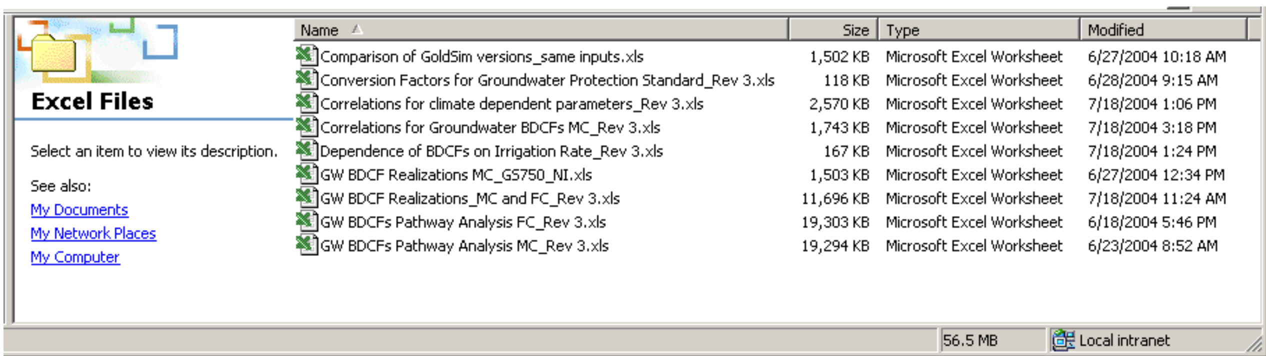


Figure B-1. List of Excel Files Supporting This Analysis

B.2 DESCRIPTION OF EXCEL FILES

GW BDCF Realizations_MC and FC_Rev 3.xls–This Excel file contains five worksheets. The worksheets *BDCF Calculations GS v 7.50.100* and *BDCF Calculations GS v 8.01 SP4* contain the results of 1,000 biosphere model realizations for the groundwater exposure scenario from files shown in Figures A-1 to A-4. These realizations generated BDCFs for the present-day climate and the upper bound of the glacial transition climate using GoldSim 7.50.100 and old inputs (DTN: MO0305SPAINEXI.001 [DIRS 163808]; MO0305SPASRPBM.001 [DIRS 163815]; MO0306SPAAEIBM.001 [DIRS 163812]; MO0306SPACRBSM.001 [DIRS 163813]; MO0306SPAETPBM.001 [DIRS 163814]) and GoldSim 8.01 SP4 with new inputs (DTN: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150]), respectively. 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 present-day 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 present-day 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

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

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 present-day (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

$$BDCF_{GTC,i\,j} = BDCF_{UBGT,i,j} + (BDCF_{IC,i,j} - BDCF_{UBGT,i,j})\,\frac{0.88-0.50}{0.95-0.50}\, RAND(0,1) \qquad \text{(Eq. B-2)}$$

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
$\frac{0.88-0.50}{0.95-0.50}$	=	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 present-day 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 for 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 for 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 for the specified cell range.

Rows 8 to 26 contain the percentiles, in 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 worksheets, *BDCF Values GS v 7.50.100* and *BDCF values GS v 8.01 SP4*, contain BDCF values copied from the worksheets, *BDCF Calculations GS v 7.50.100* and *BDCF Calculations GS v 8.01 SP4*, respectively. This was done to stabilize the results of random sampling executed in the first worksheet.

The statistics from rows 5 to 27 of the worksheets *BDCF Values GS v 7.50.100* and *BDCF values GS v 8.01 SP4* were copied and pasted into the worksheet, *Comparison*, rows 5 to 27 for GoldSim 7.50.100 with old values, and rows 33 to 55 for GoldSim 8.01 SP4 with new input values. In rows 60 to 82, percent relative difference between the statistics is calculated.

The *Comparison* worksheet also contains, in rows 98 to 125, calculation of the ratio of the mean BDCFs for the present-day climate and the upper bound of the glacial transition climate calculated using GoldSim 8.01 SP4 with new inputs.

Correlations for climate dependent parameters_Rev 3.xls—This Excel file 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 present-day 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 their 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, the values of rank correlation coefficients for the climate-dependent model input parameters and the BDCFs are shown, 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_Rev 3.xls—This Excel file 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_Rev 3.xls*, 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.

Correlations for Groundwater BDCFs MC_Rev 3.xls—This Excel file contains calculations of the rank correlation coefficients for groundwater exposure scenario BDCFs for different radionuclides for the present-day climate, calculated using GoldSim 8.01 SP4 with the new inputs. The BDCF values were copied from the GoldSim files shown in Figure A-3.

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.

GW BDCFs Pathway Analysis MC_Rev 3.xls and **GW BDCFs Pathway Analysis FC_Rev 3.xls—**These Excel files contain calculations of pathway contributions to BDCFs for the present-day climate and upper bound of the glacial transition climate, respectively. The files contain 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, in columns B to P for the GoldSim 7.50.100 runs with the old inputs and in columns S to AG for the GoldSim 8.01 SP4 runs with the new inputs. 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 A-1 and A-2 for GoldSim 7.50.100 and Figures A-3 and A-4 for GoldSim 8.01 SP4) 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 33). These values are in rows 9 to 40 for individual radionuclides, and in columns C to Q for individual exposure pathways for GoldSim 7.50.100 and in columns T to AH for GoldSim 8.01 SP4. Columns R and AI 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.

Comparison of GoldSim versions_same inputs.xls—This Excel file contains three worksheets: *BDCF Calculations GS v 7.50.100*, *BDCF Calculations GS v 8.01 SP4*, and *Comparison*. The first worksheet contains the results of 1,000 biosphere model realizations for the groundwater exposure scenario from GoldSim 7.50.100 files shown in Figure A-1. These realizations generated BDCFs for the present-day climate using old input parameter values (DTN: MO0305SPAINEXI.001 [DIRS 163808]; MO0305SPASRPBM.001 [DIRS 163815]; MO0306SPAAEIBM.001 [DIRS 163812]; MO0306SPACRBSM.001 [DIRS 163813]; MO0306SPAETPBM.001 [DIRS 163814]). The second worksheet contains BDCFs generated using same inputs and GoldSim version 8.01 SP4 (Figure A-7). The BDCFs are arranged by radionuclide in columns B to AG. The results of individual model realizations are in rows 31 to 1,030. Rows 5 to 27 contain statistics for the BDCFs for individual radionuclides. These statistics were copied and pasted into the third worksheet, *Comparison*, rows 6 to 28 for GoldSim 7.50.100 and rows 34 to 56 for GoldSim 8.01 SP4. In rows 62 to 84, percent relative difference between the statistics is calculated.

GW BDCF Realizations MC_GS750_NI.xls—This Excel file contains three worksheets: *BDCF GS 7.50.100 Old Inputs, BDCF GS 7.50.100 New Inputs*, and *Comparison*. The first worksheet contains the results of 1,000 biosphere model realizations for the groundwater exposure scenario, present-day climate from GoldSim 7.50.100 files shown in Figure A-1. These realizations generated BDCFs for the present-day climate using old input parameter values. The second worksheet contains BDCFs generated using the new inputs and the same version of GoldSim (Figure A-6). The BDCFs are arranged by radionuclide in columns B to AG. The results of individual model realizations are in rows 31 to 1,030. Rows 5 to 27 contain statistics for the BDCFs for individual radionuclides. These statistics were copied and pasted into the third worksheet, *Comparison*, rows 5 to 27 for old inputs and rows 31 to 53 for new inputs. In rows 57 to 79, percent relative difference between the statistics is calculated.

Conversion Factors for Groundwater Protection Standard.xls—This Excel file contains calculations of conversion factors for calculating beta-photon annual dose resulting from drinking 2 liters of water per day. The calculation of annual dose from beta-photon emitting radionuclides is conducted for evaluation of compliance with the groundwater protection standard. The calculations are performed for 18 radionuclides of importance during the compliance period. Column B to CO, rows 6 to 29 of the set *Organ Conversion Factors* contain calculation of the effective dose conversion factors for ingestion of radionuclides. The effective dose conversion factors are summarized in rows 35 to 58. The effective dose conversion factors are calculated by adding the dose conversion factors for beta-photon emitting radionuclides weighted by their branching fractions using equation 6.3-5. Rows 64 to 87 and 93 to 116 contain calculations of the conversion factors in units of Sv/yr per Bq/m^3 or in mrem/yr per pCi/L, respectively. The values are calculated using Equation 6.3-3.

INTENTIONALLY LEFT BLANK

APPENDIX C

ANALYSIS OF IMPACT OF SOFTWARE AND INPUT CHANGE ON MODELING RESULTS

C. ANALYSIS OF IMPACT OF SOFTWARE AND INPUT CHANGE ON THE MODELING RESULTS

This section presents the results of impact analysis regarding the input and software change between the Revision 2 of this analysis (BSC 2003 [DIRS 164403]) and the current revision. The comparison concerns the BDCFs included in DTN: MO0307MWDNPBDC.001 (from Revision 2) and those from DTN: MO0407MWDBDCFG.000 (current revision). As the result of source data change and other improvements, the input data changed for a few model input parameters. Also, an inconsistency was discovered in the Latin Hypercube sampling scheme that was used by GoldSim Version 7.50.100, which was used to execute the biosphere model in revision 2 of this analysis (BSC 2003 [DIRS 164403]). The inconsistency was corrected in GoldSim version 8.01.SP4, which was used to generate the groundwater exposure scenario BDCFs in this analysis. The comparison of the model output using the previous and the current set of the biosphere model input parameters is presented in Section C.1. Section C.2 contains an evaluation of impact from the GoldSim version update. Section C.3 evaluates the combined effect of the input and the software change. The results of the previous analysis were included in the DTN: MO0307MWDNPBDC.001 [DIRS 164615].

C.1 EVALUATION OF INPUT CHANGE IMPACT ON THE MODELING RESULTS

The differences between the old and new input data are shown in Section 4.1, Table 4.1-5. The differences in parameter values are generally very small. To evaluate the impact on the BDCFs, the biosphere model was executed using the new set of input parameters (DTN: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS 170150]) and the previously used version of software, i.e. GoldSim 7.50.100. Table C.1-1 shows the statistics for the BDCF generated in such a manner. These statistics were compared to the statistics for the BDCFs generated using the old input parameter values (DTN: MO0305SPAINEXI.001 [DIRS 163808]; MO0305SPASRPBM.001 [DIRS 163815]; MO0306SPAAEIBM.001 [DIRS 163812]; MO0306SPACRBSM.001 [DIRS 163813]; MO0306SPAETPBM.001 [DIRS 163814]). These are shown in Table C.1-2. The results of comparison in terms of percent relative difference between the BDCF statistics are shown in Table C.1-3.

The relative differences between the BDCFs resulting from the input change are very small, rarely exceeding 1 percent for the mean value, except for ^{135}Cs, where the difference is up to about 2 percent. The same is true for the other statistics shown in Table C.1-3. Except for ^{135}Cs, the differences are 1 percent or less. For ^{135}Cs the differences are up to about 4 percent. It can be concluded that the BDCF differences due to the input value changes are insignificant.

Table C.1-1. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and New Inputs, rem/yr per pCi/L.

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226
Mean	9.06E−06	1.96E−05	6.54E−05	1.64E−04	2.22E−06	6.35E−03	3.38E−04	5.71E−05	4.90E−04	9.05E−03	9.68E−02
STD	6.05E−06	2.87E−05	1.30E−04	2.47E−05	1.49E−06	3.99E−03	1.18E−04	4.11E−05	2.55E−04	3.48E−03	4.70E−02
Minimum	4.16E−06	3.23E−06	9.27E−06	1.21E−04	1.16E−06	1.44E−04	2.20E−04	8.88E−06	1.70E−04	5.71E−03	2.21E−03
5%	4.90E−06	4.87E−06	1.44E−05	1.34E−04	1.31E−06	1.01E−03	2.40E−04	1.97E−05	2.30E−04	6.21E−03	3.97E−02
10%	5.15E−06	5.58E−06	1.69E−05	1.38E−04	1.35E−06	1.86E−03	2.47E−04	2.28E−05	2.58E−04	6.36E−03	4.75E−02
15%	5.39E−06	6.30E−06	1.97E−05	1.42E−04	1.41E−06	2.42E−03	2.55E−04	2.55E−05	2.78E−04	6.57E−03	5.32E−02
20%	5.60E−06	6.83E−06	2.17E−05	1.45E−04	1.45E−06	3.12E−03	2.63E−04	2.82E−05	3.02E−04	6.74E−03	5.81E−02
25%	5.80E−06	7.76E−06	2.36E−05	1.47E−04	1.50E−06	3.60E−03	2.71E−04	3.05E−05	3.20E−04	6.91E−03	6.28E−02
30%	5.99E−06	8.49E−06	2.52E−05	1.50E−04	1.55E−06	4.04E−03	2.77E−04	3.32E−05	3.38E−04	7.07E−03	6.67E−02
35%	6.23E−06	9.48E−06	2.73E−05	1.52E−04	1.60E−06	4.52E−03	2.82E−04	3.58E−05	3.61E−04	7.26E−03	7.16E−02
40%	6.44E−06	1.03E−05	2.99E−05	1.54E−04	1.65E−06	4.85E−03	2.90E−04	3.90E−05	3.79E−04	7.46E−03	7.58E−02
45%	6.74E−06	1.13E−05	3.33E−05	1.57E−04	1.70E−06	5.16E−03	2.98E−04	4.12E−05	4.05E−04	7.68E−03	8.08E−02
50%	7.09E−06	1.22E−05	3.65E−05	1.60E−04	1.77E−06	5.47E−03	3.05E−04	4.47E−05	4.28E−04	7.92E−03	8.60E−02
55%	7.49E−06	1.34E−05	3.98E−05	1.62E−04	1.82E−06	5.88E−03	3.13E−04	4.82E−05	4.56E−04	8.18E−03	9.38E−02
60%	7.84E−06	1.50E−05	4.37E−05	1.65E−04	1.90E−06	6.29E−03	3.25E−04	5.27E−05	4.82E−04	8.62E−03	1.01E−01
65%	8.34E−06	1.70E−05	4.85E−05	1.68E−04	2.01E−06	6.95E−03	3.35E−04	5.67E−05	5.10E−04	8.94E−03	1.07E−01
70%	8.99E−06	1.92E−05	5.39E−05	1.71E−04	2.13E−06	7.68E−03	3.50E−04	6.15E−05	5.41E−04	9.40E−03	1.15E−01
75%	9.82E−06	2.18E−05	6.24E−05	1.75E−04	2.31E−06	8.46E−03	3.67E−04	6.97E−05	5.78E−04	9.96E−03	1.24E−01
80%	1.08E−05	2.53E−05	7.40E−05	1.81E−04	2.53E−06	9.33E−03	3.90E−04	7.84E−05	6.24E−04	1.06E−02	1.34E−01
85%	1.22E−05	3.10E−05	8.98E−05	1.88E−04	2.91E−06	1.04E−02	4.13E−04	8.94E−05	6.87E−04	1.13E−02	1.46E−01
90%	1.48E−05	3.86E−05	1.20E−04	1.96E−04	3.36E−06	1.21E−02	4.59E−04	1.04E−04	7.90E−04	1.28E−02	1.60E−01
95%	2.04E−05	5.41E−05	1.83E−04	2.11E−04	4.64E−06	1.44E−02	5.22E−04	1.37E−04	9.89E−04	1.56E−02	1.85E−01
Maximum	6.09E−05	4.48E−04	2.75E−03	2.89E−04	1.91E−05	2.14E−02	1.40E−03	3.14E−04	2.14E−03	3.43E−02	3.41E−01

Table C.1-1. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and New Inputs, rem/yr per pCi/L (Continued)

	Ac-227	Th-229	Th-230	Th-232	Pa-231	U-232	U-233	U-234	U-236	U-238	Np-237
Mean	3.10E−02	3.40E−02	2.90E−02	4.45E−02	1.00E−01	5.80E−03	1.75E−03	1.22E−03	1.09E−03	1.08E−03	6.94E−03
STD	1.09E−02	1.79E−02	2.44E−02	2.23E−02	6.38E−02	2.37E−03	2.06E−03	1.03E−03	8.66E−04	8.63E−04	2.29E−03
Minimum	1.26E−02	6.37E−03	1.12E−03	7.61E−03	1.46E−02	1.78E−03	2.43E−04	2.29E−04	2.16E−04	2.15E−04	3.70E−03
5%	1.71E−02	1.32E−02	5.35E−03	1.80E−02	2.97E−02	2.72E−03	3.51E−04	3.26E−04	3.08E−04	3.04E−04	4.31E−03
10%	1.86E−02	1.61E−02	7.52E−03	2.14E−02	3.70E−02	3.16E−03	4.20E−04	3.92E−04	3.68E−04	3.62E−04	4.61E−03
15%	2.02E−02	1.78E−02	8.84E−03	2.34E−02	4.38E−02	3.54E−03	4.86E−04	4.47E−04	4.20E−04	4.12E−04	4.84E−03
20%	2.17E−02	1.95E−02	1.02E−02	2.62E−02	4.92E−02	3.87E−03	5.28E−04	4.98E−04	4.68E−04	4.58E−04	5.14E−03
25%	2.29E−02	2.12E−02	1.17E−02	2.84E−02	5.49E−02	4.09E−03	5.87E−04	5.41E−04	5.05E−04	4.97E−04	5.36E−03
30%	2.43E−02	2.26E−02	1.34E−02	3.07E−02	6.12E−02	4.37E−03	6.52E−04	5.87E−04	5.45E−04	5.36E−04	5.56E−03
35%	2.56E−02	2.46E−02	1.52E−02	3.30E−02	6.55E−02	4.64E−03	7.21E−04	6.53E−04	6.05E−04	5.94E−04	5.77E−03
40%	2.69E−02	2.65E−02	1.72E−02	3.52E−02	7.13E−02	4.94E−03	8.10E−04	7.05E−04	6.57E−04	6.40E−04	5.94E−03
45%	2.81E−02	2.86E−02	1.95E−02	3.72E−02	7.62E−02	5.13E−03	8.95E−04	7.71E−04	7.19E−04	7.02E−04	6.15E−03
50%	2.90E−02	3.00E−02	2.11E−02	3.96E−02	8.32E−02	5.37E−03	1.01E−03	8.43E−04	7.82E−04	7.72E−04	6.44E−03
55%	3.05E−02	3.22E−02	2.32E−02	4.18E−02	8.91E−02	5.62E−03	1.19E−03	9.59E−04	8.83E−04	8.78E−04	6.65E−03
60%	3.16E−02	3.40E−02	2.60E−02	4.48E−02	9.83E−02	6.00E−03	1.35E−03	1.07E−03	9.76E−04	9.84E−04	6.95E−03
65%	3.34E−02	3.61E−02	2.89E−02	4.73E−02	1.07E−01	6.28E−03	1.58E−03	1.22E−03	1.10E−03	1.10E−03	7.24E−03
70%	3.53E−02	3.89E−02	3.33E−02	5.09E−02	1.17E−01	6.55E−03	1.86E−03	1.38E−03	1.24E−03	1.25E−03	7.58E−03
75%	3.72E−02	4.18E−02	3.85E−02	5.48E−02	1.28E−01	7.07E−03	2.18E−03	1.51E−03	1.38E−03	1.39E−03	7.97E−03
80%	3.91E−02	4.58E−02	4.41E−02	5.96E−02	1.40E−01	7.50E−03	2.55E−03	1.81E−03	1.58E−03	1.58E−03	8.44E−03
85%	4.16E−02	5.10E−02	5.19E−02	6.66E−02	1.60E−01	8.08E−03	3.13E−03	2.13E−03	1.85E−03	1.84E−03	9.01E−03
90%	4.48E−02	5.79E−02	6.26E−02	7.52E−02	1.83E−01	8.89E−03	3.88E−03	2.47E−03	2.15E−03	2.16E−03	9.85E−03
95%	5.14E−02	6.91E−02	8.03E−02	8.88E−02	2.29E−01	1.02E−02	5.33E−03	3.17E−03	2.78E−03	2.76E−03	1.13E−02
Maximum	8.22E−02	1.23E−01	1.86E−01	1.52E−01	4.43E−01	1.79E−02	2.36E−02	9.08E−03	7.00E−03	6.85E−03	2.24E−02

Table C.1-1. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and New Inputs, rem/yr per pCi/L (Continued)

	Pu-238	**Pu-239**	**Pu-240**	**Pu-242**	**Am-241**	**Am-243**
Mean	4.69E−03	9.21E−03	8.98E−03	8.88E−03	6.81E−03	9.48E−03
STD	1.13E−03	3.62E−03	3.40E−03	3.55E−03	1.94E−03	3.93E−03
Minimum	2.71E−03	3.74E−03	3.73E−03	3.55E−03	3.00E−03	3.03E−03
5%	3.33E−03	5.00E−03	4.96E−03	4.77E−03	4.32E−03	4.66E−03
10%	3.54E−03	5.49E−03	5.46E−03	5.24E−03	4.63E−03	5.33E−03
15%	3.68E−03	5.91E−03	5.87E−03	5.66E−03	4.94E−03	5.79E−03
20%	3.81E−03	6.33E−03	6.26E−03	6.05E−03	5.17E−03	6.25E−03
25%	3.92E−03	6.65E−03	6.58E−03	6.37E−03	5.44E−03	6.58E−03
30%	4.01E−03	7.07E−03	6.99E−03	6.77E−03	5.65E−03	7.01E−03
35%	4.13E−03	7.36E−03	7.26E−03	7.06E−03	5.88E−03	7.40E−03
40%	4.26E−03	7.74E−03	7.61E−03	7.42E−03	6.03E−03	7.90E−03
45%	4.36E−03	8.09E−03	7.93E−03	7.78E−03	6.23E−03	8.36E−03
50%	4.47E−03	8.47E−03	8.34E−03	8.16E−03	6.48E−03	8.77E−03
55%	4.58E−03	8.84E−03	8.65E−03	8.47E−03	6.69E−03	9.13E−03
60%	4.73E−03	9.26E−03	9.07E−03	8.94E−03	6.96E−03	9.75E−03
65%	4.87E−03	9.70E−03	9.45E−03	9.34E−03	7.22E−03	1.02E−02
70%	5.03E−03	1.01E−02	9.89E−03	9.79E−03	7.53E−03	1.07E−02
75%	5.19E−03	1.07E−02	1.05E−02	1.04E−02	7.86E−03	1.13E−02
80%	5.41E−03	1.14E−02	1.11E−02	1.10E−02	8.19E−03	1.21E−02
85%	5.70E−03	1.24E−02	1.20E−02	1.20E−02	8.64E−03	1.34E−02
90%	6.03E−03	1.38E−02	1.34E−02	1.33E−02	9.37E−03	1.48E−02
95%	6.66E−03	1.66E−02	1.59E−02	1.62E−02	1.06E−02	1.74E−02
Maximum	1.53E−02	2.92E−02	2.66E−02	2.90E−02	1.67E−02	2.98E−02

Source: MO0407SPAINEXI.002 [DIRS 170597]; MO0407SPASRPBM.002 [DIRS 170755]; MO0403SPAAEIBM.002 [DIRS 169392]; MO0407SPACRBSM.002 [DIRS 170677]; MO0406SPAETPBM.002 [DIRS170150]; and MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: STD = standard deviation. See Excel file *GW BDCF Realizations MC_GS750_NI.xls* in Appendix B for details of the calculations.

Table C.1-2. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and Old Inputs, rem/yr per pCi/L

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226
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

Table C.1-2. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and Old Inputs, rem/yr per pCi/L (Continued)

	Ac-227	**Th-229**	**Th-230**	**Th-232**	**Pa-231**	**U-232**	**U-233**	**U-234**	**U-236**	**U-238**	**Np-237**
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

Table C.1-2. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and Old Inputs, rem/yr per pCi/L (Continued)

	Pu-238	**Pu-239**	**Pu-240**	**Pu-242**	**Am-241**	**Am-243**
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: MO0307MWDNPBDC.001.

NOTE: STD = standard deviation. See Excel file *GW BDCF Realizations MC_GS750_NI.xls* in Appendix B for details of the calculations.

Table C.1-3. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and Old and New Inputs.

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226
Mean	−0.01	0.63	0.72	0.19	0.33	0.95	0.17	2.12	0.71	0.04	1.03
STD	0.01	1.00	0.88	0.73	0.82	1.02	0.68	2.84	0.45	0.02	1.03
Minimum	0.30	0.21	0.06	0.02	0.01	0.26	0.02	−3.16	−0.08	0.02	0.39
5%	0.13	0.27	0.38	0.10	0.07	0.80	0.00	−0.66	0.59	0.05	1.06
10%	−0.03	0.13	0.43	0.11	0.06	0.54	0.06	1.90	0.68	0.03	1.04
15%	0.17	0.35	0.18	0.12	0.08	0.70	0.09	−0.06	0.67	0.05	1.07
20%	−0.15	0.03	0.56	0.14	0.06	0.78	0.08	1.24	0.66	0.02	1.02
25%	0.04	0.10	0.52	0.17	0.17	1.09	0.07	0.79	0.45	0.05	0.97
30%	−0.08	0.09	0.46	0.10	0.09	1.05	0.06	0.07	0.84	0.07	1.06
35%	−0.08	0.19	0.65	0.15	0.11	0.74	0.07	1.03	0.72	0.06	1.09
40%	0.00	0.50	0.60	0.15	0.17	0.87	0.15	1.96	0.58	0.03	1.11
45%	0.06	0.43	0.69	0.14	0.31	0.88	0.12	1.12	0.77	0.06	1.05
50%	−0.12	0.14	0.60	0.22	0.17	1.11	0.20	1.49	1.13	0.09	1.06
55%	0.13	0.66	1.00	0.17	0.21	1.01	0.16	2.85	0.81	0.07	1.10
60%	0.02	0.58	0.95	0.19	0.22	1.07	0.10	3.27	1.15	0.10	1.08
65%	−0.04	0.85	1.05	0.22	0.32	0.96	0.08	1.81	0.58	0.10	1.13
70%	0.00	0.56	0.67	0.21	0.25	1.02	0.23	2.13	1.01	0.03	1.01
75%	−0.03	0.28	0.44	0.19	0.15	0.89	0.15	2.09	0.37	0.04	1.06
80%	0.14	0.61	0.63	0.22	0.39	0.96	0.28	2.23	0.80	0.06	0.83
85%	0.04	0.80	0.50	0.30	0.56	0.77	0.27	4.40	0.26	0.05	0.95
90%	−0.05	0.89	0.56	0.36	0.11	1.06	0.36	3.91	0.52	0.03	0.95
95%	−0.02	1.02	0.96	0.16	0.78	1.22	0.12	3.16	0.62	0.03	1.13
Maximum	0.01	1.11	0.97	0.14	1.00	0.97	0.66	0.84	0.09	0.01	1.00

Table C.1-3. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and Old and New Inputs (Continued)

	Ac-227	**Th-229**	**Th-230**	**Th-232**	**Pa-231**	**U-232**	**U-233**	**U-234**	**U-236**	**U-238**	**Np-237**
Mean	0.19	0.78	0.96	0.82	0.89	0.34	0.66	0.56	0.54	0.55	0.27
STD	0.13	1.00	1.02	1.02	1.02	0.58	0.98	0.95	0.95	0.95	0.83
Minimum	0.10	0.20	0.21	0.23	0.04	0.06	0.00	0.04	0.03	0.03	0.00
5%	0.27	0.58	0.60	0.70	0.76	0.12	0.34	0.01	0.02	0.05	0.00
10%	0.22	0.79	1.08	0.58	0.66	0.16	0.05	0.06	0.08	0.14	0.17
15%	0.23	0.74	0.86	0.23	0.60	0.16	0.13	0.18	0.04	0.14	0.06
20%	0.25	0.80	1.03	0.96	0.77	0.23	0.16	0.28	0.11	0.13	0.10
25%	0.19	0.56	0.85	0.68	0.84	0.23	0.03	0.11	0.11	0.12	0.03
30%	0.16	0.66	0.91	0.78	0.69	0.36	0.00	0.02	0.03	0.15	0.05
35%	0.19	0.82	0.97	0.69	0.80	0.40	0.10	0.15	0.14	0.24	0.19
40%	0.23	0.73	0.90	0.90	0.78	0.25	0.17	0.02	0.15	0.18	0.17
45%	0.15	0.79	1.00	0.68	0.75	0.18	0.38	0.26	0.17	0.08	0.25
50%	0.17	0.81	0.89	0.90	0.99	0.33	0.31	0.07	0.15	0.35	0.31
55%	0.21	0.62	1.05	0.87	0.89	0.15	0.58	0.45	0.49	0.26	0.25
60%	0.13	0.72	0.93	0.81	1.07	0.36	0.63	0.58	0.30	0.43	0.33
65%	0.20	0.78	1.02	0.91	1.03	0.38	0.42	0.56	0.47	0.61	0.34
70%	0.16	0.77	0.89	0.88	0.87	0.35	0.68	0.57	0.52	0.60	0.26
75%	0.09	0.81	0.97	0.84	0.87	0.34	0.53	0.67	0.35	0.65	0.35
80%	0.28	0.76	0.94	0.88	0.80	0.16	0.60	0.87	0.40	0.67	0.47
85%	0.23	0.96	0.88	0.95	0.96	0.29	0.77	0.65	0.64	0.69	0.30
90%	0.21	0.81	0.98	1.07	1.03	0.71	0.88	0.65	0.72	0.73	0.42
95%	0.10	0.83	1.19	1.00	0.95	0.38	0.76	0.88	0.46	0.52	0.67
Maximum	0.05	1.06	0.99	1.07	1.08	0.74	1.00	0.96	0.95	0.95	0.79

Table C.1-3. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and Old and New Inputs (Continued)

	Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Am-243
Mean	0.24	0.57	0.56	0.57	0.43	0.59
STD	0.36	0.93	0.92	0.93	0.90	1.01
Minimum	0.09	0.06	0.06	0.06	0.06	0.07
5%	0.22	0.35	0.22	0.36	0.15	0.04
10%	0.21	0.25	0.41	0.25	0.30	0.42
15%	0.17	0.33	0.31	0.41	0.24	0.35
20%	0.19	0.31	0.31	0.33	0.26	0.27
25%	0.23	0.51	0.40	0.33	0.33	0.37
30%	0.27	0.53	0.44	0.41	0.37	0.35
35%	0.21	0.40	0.40	0.45	0.28	0.42
40%	0.21	0.49	0.52	0.51	0.38	0.50
45%	0.16	0.52	0.45	0.66	0.45	0.57
50%	0.30	0.54	0.47	0.62	0.43	0.60
55%	0.19	0.41	0.44	0.40	0.47	0.52
60%	0.18	0.54	0.44	0.61	0.48	0.59
65%	0.29	0.58	0.48	0.60	0.45	0.55
70%	0.27	0.70	0.67	0.55	0.41	0.64
75%	0.23	0.71	0.56	0.53	0.30	0.69
80%	0.36	0.56	0.50	0.69	0.52	0.57
85%	0.23	0.71	0.61	0.81	0.45	0.79
90%	0.23	0.54	0.69	0.57	0.68	0.74
95%	0.32	0.83	0.88	0.82	0.67	0.76
Maximum	0.30	0.99	0.98	0.99	0.67	0.97

Source: Calculated using values from Tables C.1-1 and C.1-2. See Excel file *GW BDCF Realizations MC _GS750_NI.xls* in Appendix B for details of the calculations.

STD = standard deviation

C.2 EVALUATION OF SOFTWARE VERSION CHANGE IMPACT ON THE MODELING RESULTS

This section describes the assessment of the differences in the BDCF values resulting from the software change. The software used to calculate BDCFs in the previous revision of this analysis (BSC 2003 [DIRS 164403]) was GoldSim version 7.50.100. This version was subsequently replaced with the GoldSim version 8.01 SP4, which uses revised sampling algorithm for the Latin Hypercube sampling. Evaluation of the sampling algorithm effects on the biosphere model results was performed and is documented in this section. This evaluation corresponds to Action 001 in CR-2222. The following steps were delineated in the action description:

1. Using GoldSim Version 8.01 SP4 or higher, rerun all biosphere analyses that rely on Latin Hypercube sampling for selecting parameter-input values.

2. Compare the outputs from these runs with outputs from earlier versions of GoldSim used in the analysis and model reports.

3. Determine the amount of variation between the two outputs for the mean, 95th percentile, and 5th percentile values.

4. If the variation is less than 10 percent document the results of the comparison and submit the documentation to the records package for the analysis and model report.

5. If the variation is greater than 10 percent then submit the revised outputs to TSPA to evaluate the impact of the variation on the TSPA results.

6. Perform TSPA calculations with GoldSim Version 8.01 SP4 or higher using the revised inputs.

To evaluate the impact on the BDCFs, the biosphere model was executed using GoldSim 8.01 SP4 and the old set of input parameters (DTN: MO0305SPAINEXI.001 [DIRS 163808]; MO0305SPASRPBM.001 [DIRS 163815]; MO0306SPAAEIBM.001 [DIRS 163812]; MO0306SPACRBSM.001 [DIRS 163813]; MO0306SPAETPBM.001 [DIRS 163814]). Table C.2-1 shows the statistics for the BDCF generated in such a manner. These statistics were compared to the statistics for the BDCFs generated using GoldSim 7.50.100 and the old input parameter values (Table C.1-2). The results of comparison in terms of percent relative difference between the BDCF calculated using the two different version of GoldSim are presented in Table C.2-2.

The relative differences between the BDCFs resulting from the software change are usually small. The mean value changes are less than 6 percent. For 3 isotopes of uranium, the variation between the results obtained using different GoldSim versions exceeded the 10 percent threshold for the statistics listed in step 3 of Action 001 in CR-2222 and was up to about 21 percent (for the 95th percentile). Therefore, step 5 was performed and a new biosphere results were generated, as described in this report.

Table C.2-1. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 8.01 SP4 and Old Inputs, rem/yr per pCi/L.

	C-14	**Cl-36**	**Se-79**	**Sr-90**	**Tc-99**	**Sn-126**	**I-129**	**Cs-135**	**Cs-137**	**Pb-210**	**Ra-226**
Mean	9.10E−06	2.06E−05	6.15E−05	1.64E−04	2.25E−06	6.26E−03	3.36E−04	5.45E−05	4.78E−04	9.03E−03	9.59E−02
STD	6.67E−06	4.19E−05	1.05E−04	2.55E−05	2.36E−06	3.90E−03	1.13E−04	3.77E−05	2.27E−04	3.54E−03	4.72E−02
Minimum	4.14E−06	3.42E−06	9.70E−06	1.23E−04	1.18E−06	2.02E−04	2.21E−04	1.17E−05	1.51E−04	5.80E−03	2.47E−03
5%	4.93E−06	5.20E−06	1.49E−05	1.35E−04	1.31E−06	1.11E−03	2.43E−04	1.90E−05	2.30E−04	6.26E−03	3.85E−02
10%	5.20E−06	5.77E−06	1.76E−05	1.39E−04	1.36E−06	1.84E−03	2.50E−04	2.19E−05	2.57E−04	6.45E−03	4.64E−02
15%	5.47E−06	6.50E−06	1.97E−05	1.43E−04	1.42E−06	2.55E−03	2.58E−04	2.49E−05	2.80E−04	6.60E−03	5.21E−02
20%	5.66E−06	7.06E−06	2.17E−05	1.45E−04	1.46E−06	3.13E−03	2.64E−04	2.84E−05	2.98E−04	6.76E−03	5.74E−02
25%	5.91E−06	7.72E−06	2.37E−05	1.48E−04	1.50E−06	3.57E−03	2.70E−04	3.08E−05	3.24E−04	6.93E−03	6.19E−02
30%	6.09E−06	8.62E−06	2.64E−05	1.50E−04	1.55E−06	3.94E−03	2.77E−04	3.34E−05	3.44E−04	7.10E−03	6.68E−02
35%	6.34E−06	9.47E−06	2.81E−05	1.52E−04	1.61E−06	4.22E−03	2.83E−04	3.59E−05	3.62E−04	7.24E−03	7.13E−02
40%	6.55E−06	1.05E−05	3.02E−05	1.54E−04	1.67E−06	4.51E−03	2.91E−04	3.87E−05	3.82E−04	7.45E−03	7.66E−02
45%	6.83E−06	1.15E−05	3.26E−05	1.56E−04	1.72E−06	5.03E−03	2.98E−04	4.13E−05	4.00E−04	7.69E−03	8.11E−02
50%	7.04E−06	1.27E−05	3.54E−05	1.59E−04	1.78E−06	5.50E−03	3.08E−04	4.46E−05	4.23E−04	7.93E−03	8.71E−02
55%	7.37E−06	1.42E−05	3.81E−05	1.61E−04	1.85E−06	5.94E−03	3.16E−04	4.76E−05	4.46E−04	8.19E−03	9.23E−02
60%	7.76E−06	1.56E−05	4.22E−05	1.64E−04	1.93E−06	6.40E−03	3.28E−04	5.05E−05	4.71E−04	8.47E−03	9.83E−02
65%	8.36E−06	1.75E−05	4.73E−05	1.66E−04	2.03E−06	6.89E−03	3.39E−04	5.47E−05	5.04E−04	8.82E−03	1.05E−01
70%	8.85E−06	1.92E−05	5.30E−05	1.70E−04	2.14E−06	7.68E−03	3.50E−04	5.93E−05	5.35E−04	9.19E−03	1.13E−01
75%	9.55E−06	2.21E−05	6.12E−05	1.75E−04	2.29E−06	8.44E−03	3.63E−04	6.51E−05	5.67E−04	9.65E−03	1.20E−01
80%	1.06E−05	2.51E−05	7.16E−05	1.79E−04	2.48E−06	9.25E−03	3.81E−04	7.16E−05	6.16E−04	1.04E−02	1.30E−01
85%	1.19E−05	2.90E−05	8.97E−05	1.85E−04	2.83E−06	1.02E−02	4.06E−04	8.21E−05	6.73E−04	1.12E−02	1.43E−01
90%	1.40E−05	3.68E−05	1.19E−04	1.94E−04	3.44E−06	1.15E−02	4.49E−04	9.98E−05	7.48E−04	1.26E−02	1.61E−01
95%	2.05E−05	5.29E−05	1.65E−04	2.13E−04	4.38E−06	1.40E−02	5.16E−04	1.25E−04	9.23E−04	1.60E−02	1.82E−01
Maximum	9.35E−05	8.75E−04	1.87E−03	3.76E−04	6.13E−05	2.01E−02	1.96E−03	3.43E−04	1.69E−03	3.66E−02	4.23E−01

Table C.2-1. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 8.01 SP4 and Old Inputs, rem/yr per pCi/L (Continued)

	Ac-227	**Th-229**	**Th-230**	**Th-232**	**Pa-231**	**U-232**	**U-233**	**U-234**	**U-236**	**U-238**	**Np-237**
Mean	3.10E−02	3.39E−02	2.91E−02	4.41E−02	1.00E−01	5.80E−03	1.84E−03	1.27E−03	1.13E−03	1.12E−03	6.96E−03
STD	1.08E−02	1.84E−02	2.55E−02	2.26E−02	6.60E−02	2.31E−03	2.18E−03	1.12E−03	9.55E−04	9.47E−04	2.48E−03
Minimum	1.36E−02	4.78E−03	1.03E−03	6.59E−03	1.00E−02	1.83E−03	2.36E−04	2.29E−04	2.17E−04	2.17E−04	3.85E−03
5%	1.75E−02	1.27E−02	5.77E−03	1.80E−02	3.11E−02	2.72E−03	3.46E−04	3.29E−04	3.10E−04	3.06E−04	4.45E−03
10%	1.94E−02	1.53E−02	7.19E−03	2.08E−02	3.69E−02	3.22E−03	4.18E−04	3.97E−04	3.73E−04	3.68E−04	4.76E−03
15%	2.05E−02	1.73E−02	8.80E−03	2.38E−02	4.39E−02	3.54E−03	4.98E−04	4.57E−04	4.24E−04	4.19E−04	4.98E−03
20%	2.19E−02	1.95E−02	1.00E−02	2.63E−02	4.93E−02	3.90E−03	5.61E−04	5.09E−04	4.76E−04	4.69E−04	5.18E−03
25%	2.32E−02	2.10E−02	1.12E−02	2.85E−02	5.44E−02	4.15E−03	6.06E−04	5.62E−04	5.25E−04	5.17E−04	5.37E−03
30%	2.41E−02	2.28E−02	1.28E−02	3.05E−02	6.09E−02	4.45E−03	6.66E−04	6.06E−04	5.63E−04	5.56E−04	5.55E−03
35%	2.53E−02	2.44E−02	1.43E−02	3.18E−02	6.52E−02	4.71E−03	7.44E−04	6.56E−04	6.11E−04	5.94E−04	5.74E−03
40%	2.66E−02	2.63E−02	1.60E−02	3.47E−02	7.06E−02	4.90E−03	8.20E−04	7.25E−04	6.71E−04	6.57E−04	5.90E−03
45%	2.79E−02	2.83E−02	1.81E−02	3.68E−02	7.54E−02	5.17E−03	9.10E−04	7.89E−04	7.29E−04	7.23E−04	6.08E−03
50%	2.92E−02	2.98E−02	2.06E−02	3.97E−02	8.21E−02	5.44E−03	1.04E−03	8.55E−04	7.85E−04	7.81E−04	6.35E−03
55%	3.08E−02	3.16E−02	2.29E−02	4.20E−02	8.77E−02	5.67E−03	1.15E−03	9.82E−04	9.01E−04	8.96E−04	6.56E−03
60%	3.22E−02	3.34E−02	2.59E−02	4.41E−02	9.66E−02	5.97E−03	1.34E−03	1.08E−03	9.92E−04	9.86E−04	6.81E−03
65%	3.36E−02	3.60E−02	2.85E−02	4.67E−02	1.05E−01	6.32E−03	1.56E−03	1.21E−03	1.10E−03	1.10E−03	7.05E−03
70%	3.50E−02	3.85E−02	3.37E−02	4.97E−02	1.14E−01	6.66E−03	1.82E−03	1.35E−03	1.23E−03	1.23E−03	7.43E−03
75%	3.69E−02	4.16E−02	3.81E−02	5.40E−02	1.24E−01	7.10E−03	2.13E−03	1.54E−03	1.37E−03	1.39E−03	7.86E−03
80%	3.89E−02	4.52E−02	4.42E−02	5.91E−02	1.42E−01	7.48E−03	2.59E−03	1.81E−03	1.59E−03	1.61E−03	8.26E−03
85%	4.11E−02	5.01E−02	5.17E−02	6.58E−02	1.60E−01	7.92E−03	3.17E−03	2.11E−03	1.87E−03	1.88E−03	8.79E−03
90%	4.48E−02	5.77E−02	6.24E−02	7.42E−02	1.93E−01	8.74E−03	4.34E−03	2.71E−03	2.38E−03	2.33E−03	9.84E−03
95%	5.02E−02	7.04E−02	8.58E−02	8.73E−02	2.31E−01	9.96E−03	6.43E−03	3.60E−03	3.03E−03	3.04E−03	1.18E−02
Maximum	1.09E−01	1.19E−01	1.61E−01	1.45E−01	5.62E−01	1.67E−02	1.54E−02	7.69E−03	6.81E−03	6.62E−03	2.47E−02

Table C.2-1. Biosphere Dose Conversion Factors Statistics for the Present-Day Climate Calculated Using GoldSim 8.01 SP4 and Old Inputs, rem/yr per pCi/L (Continued)

	Pu-238	**Pu-239**	**Pu-240**	**Pu-242**	**Am-241**	**Am-243**
Mean	4.68E−03	9.20E−03	8.96E−03	8.86E−03	6.80E−03	9.51E−03
STD	1.13E−03	3.71E−03	3.49E−03	3.64E−03	2.04E−03	4.18E−03
Minimum	2.89E−03	3.72E−03	3.71E−03	3.55E−03	2.97E−03	2.96E−03
5%	3.36E−03	5.07E−03	5.02E−03	4.84E−03	4.28E−03	4.73E−03
10%	3.56E−03	5.53E−03	5.46E−03	5.29E−03	4.70E−03	5.34E−03
15%	3.67E−03	5.93E−03	5.84E−03	5.67E−03	5.00E−03	5.79E−03
20%	3.80E−03	6.26E−03	6.18E−03	5.99E−03	5.20E−03	6.23E−03
25%	3.90E−03	6.58E−03	6.49E−03	6.29E−03	5.38E−03	6.67E−03
30%	4.03E−03	6.82E−03	6.75E−03	6.52E−03	5.57E−03	6.99E−03
35%	4.12E−03	7.15E−03	7.05E−03	6.84E−03	5.84E−03	7.31E−03
40%	4.24E−03	7.56E−03	7.47E−03	7.25E−03	6.03E−03	7.67E−03
45%	4.34E−03	7.91E−03	7.76E−03	7.60E−03	6.23E−03	8.13E−03
50%	4.44E−03	8.31E−03	8.16E−03	7.98E−03	6.43E−03	8.57E−03
55%	4.55E−03	8.69E−03	8.52E−03	8.37E−03	6.60E−03	9.05E−03
60%	4.69E−03	9.09E−03	8.88E−03	8.72E−03	6.84E−03	9.42E−03
65%	4.81E−03	9.58E−03	9.32E−03	9.23E−03	7.05E−03	1.00E−02
70%	4.97E−03	1.02E−02	9.93E−03	9.80E−03	7.39E−03	1.06E−02
75%	5.17E−03	1.08E−02	1.06E−02	1.04E−02	7.71E−03	1.14E−02
80%	5.40E−03	1.16E−02	1.12E−02	1.12E−02	8.10E−03	1.23E−02
85%	5.65E−03	1.27E−02	1.22E−02	1.22E−02	8.64E−03	1.35E−02
90%	6.10E−03	1.41E−02	1.37E−02	1.38E−02	9.33E−03	1.48E−02
95%	6.81E−03	1.66E−02	1.61E−02	1.61E−02	1.07E−02	1.76E−02
Maximum	1.41E−02	2.74E−02	2.64E−02	2.66E−02	1.70E−02	3.65E−02

Source: MO0305SPAINEXI.001 [DIRS 163808]; MO0305SPASRPBM.001 [DIRS 163815]; MO0306SPAAEIBM.001 [DIRS 163812]; MO0306SPACRBSM.001 [DIRS 163813]; MO0306SPAETPBM.001 [DIRS 163814]; and MO0306MWDBGSMF.001 [DIRS 163816].

NOTE: See Excel file *Comparison of GoldSim versions_same inputs.xls* in Appendix B for details of the calculations.

STD = standard deviation.

Table C.2-2. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and GoldSim 8.01 SP4 and Old Inputs

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226
Mean	0.40	5.47	−5.30	−0.12	2.11	−0.38	−0.47	−2.55	−1.77	−0.10	0.12
STD	10.29	47.64	−18.93	3.65	59.62	−1.31	−3.77	−5.59	−10.61	1.50	1.52
Minimum	−0.19	6.12	4.74	1.43	1.05	40.35	0.46	28.00	−11.29	1.58	11.94
5%	0.62	7.01	4.06	0.63	0.22	11.40	1.27	−3.97	0.56	0.84	−2.00
10%	0.80	3.54	4.49	0.53	0.81	−0.40	1.37	−2.05	0.06	1.46	−1.40
15%	1.72	3.65	0.35	0.81	0.68	6.34	1.44	−2.29	1.44	0.53	−1.10
20%	0.92	3.38	0.30	0.00	0.53	0.97	0.56	1.93	−0.56	0.23	−0.28
25%	1.88	−0.37	0.97	0.42	0.49	0.41	−0.15	1.97	1.63	0.38	−0.61
30%	1.51	1.63	5.42	0.05	0.34	−1.37	0.29	0.59	2.75	0.57	1.27
35%	1.75	0.12	3.38	0.04	0.69	−6.07	0.48	1.08	1.02	−0.18	0.67
40%	1.58	2.54	1.91	−0.29	1.01	−6.08	0.36	1.21	1.51	0.00	2.14
45%	1.34	2.32	−1.25	−0.25	1.17	−1.65	0.27	1.52	−0.37	0.16	1.40
50%	−0.74	4.05	−2.34	−0.18	0.71	1.71	1.21	1.17	−0.06	0.28	2.37
55%	−1.54	6.56	−3.25	−0.51	1.55	2.00	0.91	1.71	−1.48	0.24	−0.56
60%	−0.97	4.06	−2.57	−0.56	1.79	2.86	1.03	−1.01	−1.15	−1.68	−1.45
65%	0.16	3.39	−1.47	−1.05	1.39	0.06	1.23	−1.70	−0.51	−1.19	−1.06
70%	−1.62	0.42	−0.97	−0.17	0.80	0.97	0.26	−1.61	−0.14	−2.22	−0.88
75%	−2.86	1.35	−1.55	−0.10	−0.36	0.62	−0.91	−4.66	−1.53	−3.08	−2.36
80%	−1.13	−0.40	−2.65	−1.20	−1.68	0.07	−1.86	−6.63	−0.57	−2.31	−1.91
85%	−1.89	−5.78	0.42	−1.41	−2.20	−1.31	−1.57	−4.18	−1.81	−1.05	−1.00
90%	−5.15	−3.74	−0.69	−0.78	2.50	−3.59	−1.95	−0.79	−4.78	−1.41	1.21
95%	0.72	−1.40	−8.74	0.77	−4.80	−1.08	−1.07	−5.51	−6.11	2.76	−0.36
Maximum	53.59	97.70	−31.20	30.46	224.54	−5.52	41.15	10.16	−21.09	6.77	25.26

Table C.2-2. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and GoldSim 8.01 SP4 and Old Inputs (Continued)

	Ac-227	Th-229	Th-230	Th-232	Pa-231	U-232	U-233	U-234	U-236	U-238	Np-237
Mean	0.15	0.42	1.22	0.02	1.04	0.39	5.81	4.65	4.52	4.37	0.58
STD	−0.66	4.25	5.57	2.36	4.51	−1.84	6.80	9.96	11.28	10.74	9.37
Minimum	8.11	−24.87	−7.59	−13.16	−31.22	2.96	−2.71	−0.10	0.67	0.67	4.12
5%	2.91	−2.99	8.50	0.90	5.45	0.15	−1.17	0.86	0.49	0.75	3.19
10%	4.19	−3.86	−3.37	−2.09	0.20	2.04	−0.34	1.54	1.52	1.99	3.47
15%	1.51	−1.68	0.33	1.82	0.63	0.35	2.79	2.56	1.04	1.82	2.95
20%	0.79	1.21	−0.54	1.31	1.08	1.03	6.41	2.42	1.81	2.57	0.91
25%	1.62	−0.70	−3.76	1.35	−0.14	1.62	3.30	3.94	4.02	4.09	0.13
30%	−0.66	1.42	−3.90	−0.02	0.19	2.17	2.06	3.22	3.31	3.73	−0.13
35%	−1.03	0.10	−4.92	−2.90	0.34	1.78	3.22	0.64	1.21	0.28	−0.45
40%	−1.03	0.22	−6.33	−0.55	−0.20	−0.57	1.39	2.78	2.40	2.79	−0.53
45%	−0.46	−0.42	−5.97	−0.48	−0.39	1.00	2.08	2.63	1.63	3.00	−0.93
50%	0.88	0.34	−1.33	1.02	−0.31	1.67	3.24	1.46	0.53	1.58	−1.10
55%	1.19	−1.23	−0.07	1.43	−0.63	1.02	−2.65	2.84	2.60	2.26	−1.17
60%	2.01	−1.14	0.48	−0.61	−0.59	−0.03	0.43	1.32	1.97	0.63	−1.76
65%	1.03	0.34	−0.57	−0.41	−0.89	1.02	−1.34	0.00	0.28	0.46	−2.28
70%	−0.65	−0.24	2.14	−1.46	−1.25	2.03	−1.93	−1.60	−0.59	−0.77	−1.70
75%	−0.71	0.29	−0.17	−0.55	−2.80	0.78	−1.93	2.19	−0.19	0.87	−1.08
80%	−0.26	−0.50	1.30	−0.09	2.56	−0.06	2.33	0.73	0.85	2.30	−1.67
85%	−0.90	−0.83	0.59	−0.25	0.69	−1.76	2.27	−0.17	1.67	3.11	−2.11
90%	0.26	0.47	0.61	−0.34	6.69	−1.07	12.84	10.51	11.66	8.88	0.30
95%	−2.30	2.69	8.04	−0.70	2.16	−1.90	21.43	14.54	9.35	10.85	4.79
Maximum	32.44	−2.57	−12.59	−3.90	28.33	−6.34	−34.40	−14.49	−1.83	−2.39	10.96

Table C.2-2. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 and GoldSim 8.01 SP4 and Old Inputs (Continued)

	Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Am-243
Mean	0.14	0.39	0.35	0.41	0.30	0.91
STD	0.29	3.51	3.58	3.49	6.04	7.47
Minimum	6.68	−0.30	−0.48	−0.20	−1.00	−2.36
5%	1.22	1.76	1.48	1.79	−0.81	1.65
10%	0.77	1.01	0.47	1.10	1.83	0.57
15%	−0.06	0.70	−0.13	0.70	1.46	0.34
20%	−0.23	−0.79	−0.90	−0.76	0.83	−0.10
25%	−0.18	−0.64	−0.87	−0.89	−0.78	1.83
30%	0.87	−3.10	−3.10	−3.27	−1.14	0.16
35%	0.10	−2.58	−2.51	−2.76	−0.36	−0.76
40%	−0.23	−1.81	−1.32	−1.76	0.41	−2.48
45%	−0.18	−1.79	−1.70	−1.70	0.52	−2.23
50%	−0.37	−1.44	−1.68	−1.63	−0.44	−1.72
55%	−0.47	−1.30	−1.00	−0.81	−0.85	−0.40
60%	−0.67	−1.29	−1.69	−1.83	−1.27	−2.76
65%	−1.08	−0.66	−0.93	−0.59	−1.79	−1.20
70%	−0.93	1.07	1.11	0.62	−1.45	0.21
75%	−0.16	1.15	1.66	1.28	−1.63	1.31
80%	0.05	2.19	1.29	2.62	−0.64	2.55
85%	−0.58	3.17	2.21	2.69	0.47	1.85
90%	1.36	2.53	3.54	4.14	0.18	1.09
95%	2.51	0.87	2.00	0.47	2.10	1.85
Maximum	−7.33	−5.25	0.40	−7.45	2.13	23.60

Source: Calculated using values from Tables C.1-2 and C.2-1. See Excel file *Comparison of GoldSim versions_same inputs.xls* in Appendix B for details of the calculations.

STD = standard deviation.

C.3 EVALUATION OF INPUT AND SOFTWARE VERSION CHANGE IMPACT ON THE MODELING RESULTS

This section describes the evaluation of the combined differences in the BDCF values resulting from the input and software change. The statistics for the BDCF values calculated using GoldSim version 7.50.100 are shown in Table C.1-2. The statistics for the BDCFs calculated using the new inputs and GoldSim version 8.01 SP4 are shown in Table 6.2-5. Table C.3-1 shows the results of comparison of these two data sets in terms of percent relative difference between the BDCFs.

As stated in Section C.1, the relative differences between the BDCFs resulting from the input change are negligibly small, on the order of one percent for all radionuclides except ^{135}Cs. It can be thus concluded that the BDCF differences are primarily due to the software changes. The relative differences between the BDCFs resulting from the input and software change are usually small.

Tables C.3-1 shows that the differences between the BDCF values calculated in the previous revision of this analysis and the new BDCF values are small. The mean BDCF values differ by less than 7 percent. The percentiles shown in Table C.3-1, between the 5th and 95th percentile, differ by less than 10 percent except for the uranium isotopes whose 95th percentiles show up to about 23 percent difference and the 5th percentile for ^{126}Sn (12 percent difference). Only the standard deviations and the far tails of the distributions are affected, with the differences up to about a factor of 2 for the maximum BDCF value for ^{99}Tc. The high maximum value for ^{99}Tc is due to one "outlier" data point.

Considering the uncertainty in the BDCF distributions (see Tables 6.2-5 to 6.2-7), such differences are insignificant. It can thus be concluded that the BDCFs calculated in the previous revision of this analysis and the new BDCF developed in this analysis are equivalent and can be used interchangeably.

Table C.3-1. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 with Old Inputs and GoldSim 8.01 SP4 with New Inputs

	C-14	Cl-36	Se-79	Sr-90	Tc-99	Sn-126	I-129	Cs-135	Cs-137	Pb-210	Ra-226
Mean	0.38	6.13	−4.66	0.07	2.48	0.58	−0.30	−0.35	−1.03	−0.05	1.15
STD	10.30	49.12	−18.37	4.43	61.22	−0.28	−3.14	0.36	−10.15	1.52	2.57
Minimum	0.07	6.41	4.86	1.45	1.11	41.20	0.48	25.56	−10.73	1.64	12.54
5%	0.41	7.22	4.37	0.75	0.23	12.09	1.33	−4.02	1.87	0.87	−0.95
10%	0.97	3.76	4.76	0.64	0.84	−0.12	1.45	−1.06	0.87	1.49	−0.34
15%	1.61	3.93	0.74	0.94	0.76	7.02	1.49	−0.68	2.71	0.56	−0.06
20%	0.79	3.43	0.97	0.12	0.64	1.83	0.63	1.16	0.36	0.25	0.75
25%	1.80	−0.21	2.02	0.60	0.67	1.33	−0.09	2.44	2.39	0.42	0.42
30%	1.59	2.07	6.00	0.16	0.39	−0.77	0.39	0.88	3.44	0.64	2.33
35%	1.69	0.58	3.99	0.19	0.92	−5.32	0.54	2.08	1.68	−0.15	1.66
40%	1.57	3.03	2.66	−0.15	1.22	−5.12	0.44	2.17	2.36	0.04	3.11
45%	1.28	2.91	−0.39	−0.11	1.20	−0.65	0.39	2.43	0.31	0.18	2.58
50%	−0.73	4.51	−1.67	−0.03	0.90	2.41	1.24	2.91	0.82	0.32	3.51
55%	−1.62	7.02	−2.44	−0.34	1.73	2.74	0.98	3.51	−0.46	0.27	0.57
60%	−0.71	4.68	−1.89	−0.34	1.93	3.95	1.22	1.37	−0.62	−1.60	−0.46
65%	0.12	4.06	−1.02	−0.80	1.52	1.11	1.33	0.05	0.30	−1.17	0.03
70%	−1.63	1.06	−0.45	0.07	0.96	1.96	0.33	0.98	0.38	−2.16	0.10
75%	−2.81	1.69	−1.00	0.08	0.01	1.72	−0.74	−3.30	−0.43	−3.06	−1.34
80%	−1.20	0.41	−1.90	−1.02	−1.27	1.16	−1.58	−4.22	0.28	−2.30	−0.75
85%	−1.97	−5.48	0.87	−1.17	−1.74	−0.33	−1.40	2.11	−1.39	−1.02	0.05
90%	−5.23	−2.85	−0.35	−0.39	3.15	−2.57	−1.73	3.21	−4.44	−1.38	2.34
95%	0.71	−0.48	−7.76	1.13	−4.11	−0.21	−0.71	−0.30	−5.56	2.81	0.64
Maximum	53.58	99.81	−30.74	31.04	227.81	−4.60	42.26	53.29	−21.04	6.78	26.68

Table C.3-1. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 with Old Inputs and GoldSim 8.01 SP4 with New Inputs (Continued)

	Ac-227	Th-229	Th-230	Th-232	Pa-231	U-232	U-233	U-234	U-236	U-238	Np-237
Mean	0.35	1.20	2.20	0.84	1.94	0.73	6.54	5.27	5.11	4.97	0.86
STD	−0.53	5.27	6.63	3.38	5.57	−1.24	7.85	11.04	12.38	11.84	10.31
Minimum	8.20	−24.61	−7.44	−13.06	−31.11	3.05	−2.66	−0.06	0.71	0.73	4.17
5%	3.15	−2.39	9.45	1.38	6.17	0.45	−1.13	0.88	0.65	0.91	3.26
10%	4.38	−3.33	−2.48	−1.48	0.87	2.12	−0.27	1.57	1.62	2.02	3.60
15%	1.78	−0.94	1.34	2.27	1.42	0.51	3.02	2.58	1.26	1.82	3.07
20%	0.94	1.55	0.31	2.13	1.70	1.35	6.41	2.70	1.85	2.72	0.95
25%	1.77	0.00	−2.86	2.01	0.74	1.89	3.31	3.97	4.29	4.12	0.21
30%	−0.42	2.15	−3.03	0.68	0.68	2.44	2.24	3.30	3.46	3.78	0.11
35%	−0.85	0.80	−4.23	−2.16	1.19	2.12	3.45	0.83	1.44	0.65	−0.28
40%	−0.88	0.86	−5.45	0.21	0.61	−0.41	1.64	3.15	2.40	2.95	−0.41
45%	−0.27	0.42	−5.07	0.41	0.60	1.15	2.48	2.75	1.87	3.28	−0.70
50%	1.24	0.95	−0.32	1.91	0.53	1.85	3.44	1.69	0.83	1.88	−0.82
55%	1.44	−0.37	0.94	2.23	0.25	1.38	−2.32	3.10	2.94	2.62	−1.02
60%	2.23	−0.49	1.43	0.18	0.36	0.33	1.17	1.95	2.29	1.06	−1.53
65%	1.18	1.08	0.36	0.48	−0.01	1.31	−1.03	0.50	0.75	0.68	−2.19
70%	−0.46	0.64	3.01	−0.56	−0.18	2.37	−1.19	−1.31	−0.03	−0.44	−1.53
75%	−0.59	1.03	0.74	0.26	−1.86	1.05	−1.14	2.68	0.64	1.62	−0.72
80%	0.01	0.29	2.38	0.68	3.48	0.25	2.89	1.36	1.45	2.95	−1.25
85%	−0.67	−0.03	1.73	0.61	1.75	−1.25	3.18	0.11	2.39	3.70	−1.79
90%	0.36	1.38	1.53	0.52	7.88	−0.76	13.57	11.53	12.37	9.77	0.80
95%	−2.09	3.71	9.21	0.24	3.31	−1.62	22.58	15.43	10.49	11.84	5.58
Maximum	32.49	−1.74	−11.63	−3.06	29.63	−5.47	−33.74	−13.70	−0.93	−1.49	11.74

Table C.3-1. Percent Relative Difference Between Biosphere Dose Conversion Factor Statistics for the Present-Day Climate Calculated Using GoldSim 7.50.100 with Old Inputs and GoldSim 8.01 SP4 with New Inputs (Continued)

	Pu-238	Pu-239	Pu-240	Pu-242	Am-241	Am-243
Mean	0.38	0.96	0.91	0.98	0.73	1.51
STD	0.66	4.47	4.54	4.45	7.01	8.54
Minimum	6.81	0.01	−0.18	0.11	−0.95	−2.32
5%	1.37	2.14	1.81	2.13	−0.54	1.92
10%	1.05	1.25	0.72	1.37	2.03	0.82
15%	0.19	1.17	0.31	1.21	1.79	0.68
20%	0.03	−0.56	−0.51	−0.47	1.10	0.28
25%	0.01	−0.22	−0.39	−0.47	−0.44	2.34
30%	1.06	−2.67	−2.68	−2.80	−0.93	0.54
35%	0.33	−2.17	−2.13	−2.38	0.02	−0.32
40%	0.08	−1.29	−0.84	−1.34	0.83	−1.93
45%	0.01	−1.18	−1.23	−1.09	0.87	−1.79
50%	−0.04	−0.97	−1.16	−1.15	0.01	−1.12
55%	−0.21	−0.91	−0.45	−0.30	−0.55	0.24
60%	−0.44	−0.75	−1.02	−1.30	−0.75	−2.15
65%	−0.67	−0.03	−0.34	0.04	−1.33	−0.57
70%	−0.59	1.66	1.65	1.04	−1.02	1.00
75%	0.19	1.77	2.29	1.87	−1.18	1.90
80%	0.41	2.92	1.92	3.36	−0.15	3.30
85%	−0.16	3.74	2.93	3.43	0.93	2.64
90%	1.71	3.24	4.34	4.81	0.74	1.87
95%	2.70	1.67	2.72	1.33	2.77	2.71
Maximum	−7.21	−4.66	1.03	−6.87	3.06	24.70

Source: Calculated using values from Tables C.1-2 and 6.2-5. See Excel file *GW BDCF Realizations_MC and FC_Rev 3.xls* in Appendix B for details of the calculations.

STD = standard deviation

INTENTIONALLY LEFT BLANK

APPENDIX D

DATA QUALIFICATION PLAN

D. DATA QUALIFICATION PLAN

BSC	DATA QUALIFICATION PLAN	QA: QA Page 1 of 1

Section I. Organizational Information

Qualification Title

Nominal Performance Biosphere Dose Conversion Factors

Requesting Organization

Regulatory Integration Team/Natural Systems/Biosphere

Section II. Process Planning Requirements

1. List of Unqualified Data to be Evaluated

DTN: MO0307MWDNPBDC.001, Nominal Performance Biosphere Dose Conversion Factors. This data set includes the results of *Nominal Performance Biosphere Dose Conversion Factor Analysis*, ANL-MGR-MD-000009 Rev 02 - it is a product output of this analysis. The DTN has been downgraded to unqualified due to the source data problems.

2. Type of Data Qualification Method(s) [Including rationale for selection of method(s) (Attachment 3) and qualification attributes (Attachment 4)]

The data will be qualified according to the corroborating data qualification method identified in AP-SIII.2Q, REV 1/ICN 2, or current version). This method was chosen to establish the confidence in the appropriateness of the data and to demonstrate that it is suitable for the intended use as input to the TSPA model. The attributes considered will be: (1) qualification of personnel or organizations generating the data (2) a corroborative comparison with the data developed under the OCRWM QA program to confirm that the data used are reasonable.

3. Data Qualification Team and Additional Support Staff Required

Maryla Wasiolek, Chairperson and Technical Representative. Maryla Wasiolek is a senior scientist with Bechtel SAIC Co., LLC (BSC) Regulatory Integration Team/Natural Systems/Biosphere. She has a M.Sc and Ph.D in applied nuclear physics/nuclear engineering.. Dr. Wasiolek has been involved in radiological assessment and radioecology for over 20 years. She has 7 years of experience on the Yucca Mountain Project.

Ernesto Faillace, Radiological Engineer. Ernesto Faillace is a certified health physicist with RCS Corporation and a member of the Regulatory Integration Team/Natural Systems/Biosphere. He has B.S. and M.S. degrees in nuclear engineering and a doctor of engineering degree with a health physics specialty. Dr. Faillace has 15 years of experience in radiological assessments, of which seven have been with the RESRAD pathways analysis model.

4. Data Evaluation Criteria

The data will be considered qualified for use as input to the TSPA model if the difference between the mean, 5th percentile and the 95th percentile of the BDCFs included in the data set being qualified and the BDCF data developed in *Nominal Performance Biosphere Dose Conversion Factor Analysis*, ANL-MGR-MD-000009 Rev 03 are not greater than 10 percent. This data evaluation criterion is consistent with the criterion established to evaluate an impact of software change from GoldSim 7.50.100 to GoldSim 8.01 SP4, as given in the condition report CR-2222, which is a primary reason for differences in the BDCF data. If the difference between the statistics is greater than 10 percent, the data may still be appropriate for the intended use, however the demonstration of applicability will need to be made by the TSPA staff. This will be noted in the discussion of limits or caveats that should be considered by potential users of the data.

5. Identification of Procedures Used

The primary procedure used to control the data qualification process will be AP-SIII.2Q, Qualification of Unqualified Data. The documentationof the qualification process and findings will be done in accordance with AP-SIII.9Q, Scientific Analyses. Other procedures will be followed as required by AP-SIII.9Q.

Section III. Approval

Qualification Chairperson Printed Name	Qualification Chairperson Signature	Date
Maryla Wasiolek	Maryla Wasiolek	7/20/2004
Responsible Manager Printed Name	**Responsible Manager Signature**	**Date**
Ming Zhu	Ahmed M Monib for Ming Zhu	7/20/04

AP-SIII.2Q PA_ASIII2-1 (Rev. 01/29/2004)

INTENTIONALLY LEFT BLANK

APPENDIX E

VERIFICATION OF ERMYN MODEL FILES FOR GOLDSIM VERSION 8.01 SP4

E. VERIFICATION OF ERMYN MODEL FILES FOR GOLDSIM VERSION 8.01 SP4

The ERMYN model for the groundwater exposure scenario (DTN: MO0306MWDBGSMF.001) was constructed and verified for GoldSim version 7.50.100. Verification was conducted for three radionuclides: ^{14}C, ^{226}Ra, and ^{239}Pu because these three radionuclides are representative of all environmental transport and exposure pathways included in the model for the groundwater exposure scenario. To verify the applicability of GoldSim version 8.01 SP4 as software supporting the biosphere model, the original model verification files were opened in GoldSim 8.01 SP4 and the verification calculations were repeated.

Figure E-1 shows the list of the original verification files as well as the model files generated in this analysis when the original files were run using GoldSim 8.01 SP4. The files that are labeled with *_GS801SP4.gsm correspond to runs performed using GoldSim Version 8.01 SP4; whereas, those without are runs performed using GoldSim Version 7.50.001. Table E-1 shows the results from the original verification files and their re-runs in GoldSim 8.01 SP4. The results are identical, so the model can be executed using GoldSim 8.01 SP4.

Figure E-1. Model Verification Files Obtained Using GoldSim Versions 7.50.100 and 8.01 SP4

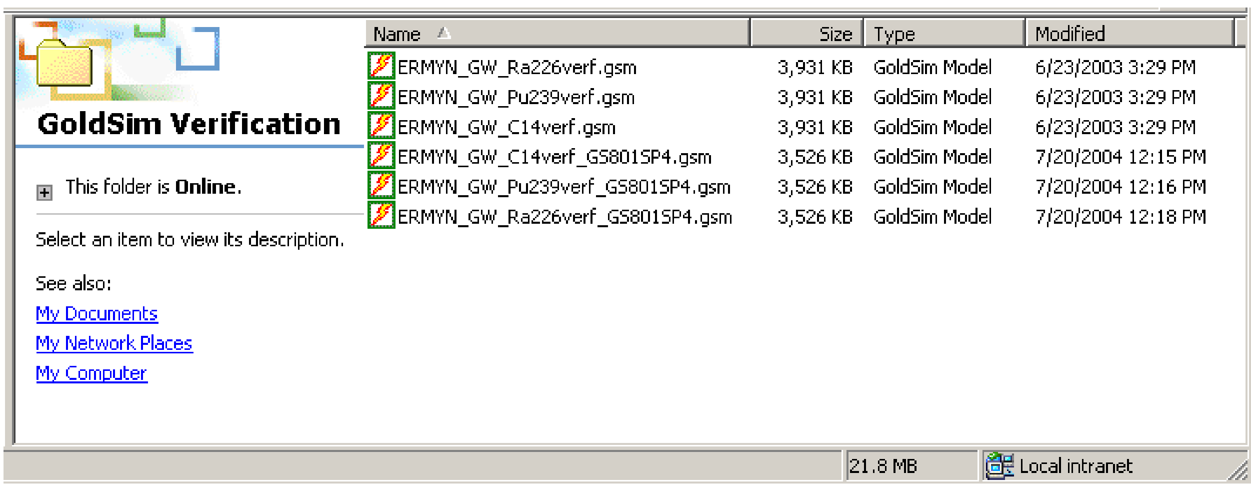


Table E-1. Results of Verification Runs Using GoldSim Versions 7.50.100 and 8.01 SP4

Radionuclide	Pathway	BDCF (rem/yr per pCi/L)	
		GoldSim 7.50.100	GoldSim 8.01 SP4
C-14	All pathways	7.14602E−06	7.14602E−06
	External	3.26180E−13	3.26180E−13
	Inhalation	1.63130E−09	1.63130E−09
	Evaporative Cooler	3.40450E−11	3.40450E−11
	Radon	0.00000E+00	0.00000E+00
	Water	1.52440E−06	1.52440E−06
	Leafy Vegetables	2.52710E−07	2.52710E−07
	Other Vegetables	4.42120E−07	4.42120E−07
	Fruit	1.15850E−06	1.15850E−06
	Grain	5.87210E−08	5.87210E−08
	Meat	6.31780E−07	6.31780E−07
	Milk	3.01670E−07	3.01670E−07
	Poultry	5.41440E−08	5.41440E−08
	Eggs	5.12430E−07	5.12430E−07
	Fish	2.20780E−06	2.20780E−06
	Soil Ingestion	8.67940E−12	8.67940E−12
	File name	ERMYN_GW_C14verf.gsm	ERMYN_GW_C14verf_GS801SP4.gsm
Pu-239	All pathways	7.63326E−03	7.63326E−03
	External	1.38220E−07	1.38220E−07
	Inhalation	3.92780E−03	3.92780E−03
	Evaporative Cooler	6.20940E−04	6.20940E−04
	Radon	0.00000E+00	0.00000E+00
	Water	2.58390E−03	2.58390E−03
	Leafy Vegetables	7.55490E−05	7.55490E−05
	Other Vegetables	1.52470E−05	1.52470E−05
	Fruit	4.95180E−05	4.95180E−05
	Grain	5.87800E−06	5.87800E−06
	Meat	2.57590E−07	2.57590E−07
	Milk	9.85630E−09	9.85630E−09
	Poultry	6.33900E−08	6.33900E−08
	Eggs	1.13320E−06	1.13320E−06
	Fish	1.38430E−04	1.38430E−04
	Soil Ingestion	2.14330E−04	2.14330E−04
	File name	ERMYN_GW_Pu239verf.gsm	ERMYN_GW_Pu239verf_GS801SP4.gsm
Ra-226	All pathways	7.45638E−02	7.45638E−02
	External	5.64900E−03	5.64900E−03
	Inhalation	2.44180E−04	2.44180E−04
	Evaporative Cooler	1.24400E−05	1.24400E−05
	Radon	6.66370E−02	6.66370E−02
	Water	9.68280E−04	9.68280E−04
	Leafy Vegetables	1.10450E−04	1.10450E−04

Table E-1. Results of Verification Runs Using GoldSim Versions 7.50.100 and 8.01 SP4 (Continued)

Radionuclide	Pathway	BDCF (rem/yr per pCi/L)	
		GoldSim 7.50.100	GoldSim 8.01 SP4
Ra-226 (cont.)	Other Vegetables	6.20040E−05	6.20040E−05
	Fruit	2.28720E−04	2.28720E−04
	Grain	1.54740E−05	1.54740E−05
	Meat	2.58540E−05	2.58540E−05
	Milk	2.39060E−05	2.39060E−05
	Poultry	2.55110E−06	2.55110E−06
	Eggs	6.36060E−05	6.36060E−05
	Fish	8.47680E−05	8.47680E−05
	Soil Ingestion	4.35430E−04	4.35430E−04
	File name	ERMYN_GW_Ra226verf.gsm	ERMYN_GW_Ra226verf_GS801SP4.gsm

INTENTIONALLY LEFT BLANK