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September 2004

Environmental Transport Input Parameters for the Biosphere Model

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11. Remarks

This report addresses errata generated as a result of Condition Report No. 186

Change History

12. Revision No.	13. Description of Change
REV 00 ICN 00	Initial issue
REV 00 ICN 01	Added value for crop resuspension factor for disruptive volcanic scenario, which was not included in the previous version. Added another value of crop resuspension factor for arid agricultural area for the nominal case. In addition, eliminated one parameter, absolute humidity, since it is not used in the BDCF calculations.
REV 01 ICN 00	Combine the analysis with the Transfer Coefficient Analysis, ANL-MGR-MD-000008 Rev 00/02. Extend the scope of both analyses to support parameter development for the new biosphere model. The entire analysis documentation was revised.
REV 02 ICN 00	Revision to incorporate Regulatory Integration Team review comments. Address errata 001 associated with CR-1861. Change bars were not used because changes were extensive.

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ACRONYMS AND ABBREVIATIONS

BDCF	biosphere dose conversion factor
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EEC	equilibrium equivalent (radon) concentration
ERMYN	Environmental Radiation Model for Yucca Mountain, Nevada
FEP	features, events, and processes
GM	geometric mean
GSD	geometric standard deviation
IAEA	International Atomic Energy Agency
IUR	International Union of Radioecology
LA	license application
NAHB	National Association of Home Builders
NCRP	National Council on Radiation Protection and Measurements
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
PAEC	potential alpha energy concentration
RMEI	reasonably maximally exposed individual
TC	transfer coefficient
TF	transfer factor
TSPA	total system performance assessment
TSPA-LA	total system performance assessment for the license application
TWP	technical work plan
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
YMP	Yucca Mountain Project

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1. PURPOSE

This analysis report is one of the technical reports documenting the Environmental Radiation Model for Yucca Mountain, Nevada (ERMYN), a biosphere model supporting the total system performance assessment for the license application (TSPA-LA) for the geologic repository at Yucca Mountain. A graphical representation of the documentation hierarchy for the ERMYN is presented in Figure 1-1. This figure shows relationships among the reports developed for biosphere modeling and biosphere abstraction products for the TSPA-LA, as identified in the *Technical Work Plan for Biosphere Modeling and Expert Support* (BSC 2004 [DIRS 169573]) (TWP). This figure provides an understanding of how this report contributes to biosphere modeling in support of the license application (LA). This report is one of the five reports that develop input parameter values for the biosphere model. The *Biosphere Model Report* (BSC 2004 [DIRS 169460]) describes the conceptual model and the 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. The output of this report is used as direct input in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* and in the *Disruptive Event Biosphere Dose Conversion Factor Analysis* that calculate the values of biosphere dose conversion factors (BDCFs) for the groundwater and volcanic ash exposure scenarios, respectively.

The purpose of this analysis was to develop biosphere model parameter values related to radionuclide transport and accumulation in the environment. These parameters support calculations of radionuclide concentrations in the environmental media (e.g., soil, crops, animal products, and air) resulting from a given radionuclide concentration at the source of contamination (i.e., either in groundwater or in volcanic ash). The analysis was performed in accordance with the TWP (BSC 2004 [DIRS 169573]).

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]). The treatment of these FEPs is described in *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.2). Parameter values developed in this report, and their relationship to FEPs, are listed in Table 1-1. The relationship between the parameters and FEPs was based on a comparison of the parameter definition and the FEP descriptions as presented in *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.2). The parameter values developed in this report support the biosphere model and are reflected in the TSPA-LA through the BDCFs.

The biosphere model was constructed for radionuclides screened in for the TSPA-LA (BSC 2004 [DIRS 169460], Section 6.3.5). The same list of radionuclides is used in this analysis (Section 6.1.4). The analysis considers two human exposure scenarios (groundwater and volcanic ash) and climate change (Section 6.1.5).

The environmental transport parameter values were developed specifically for use in the biosphere model and may not be appropriate for other applications.

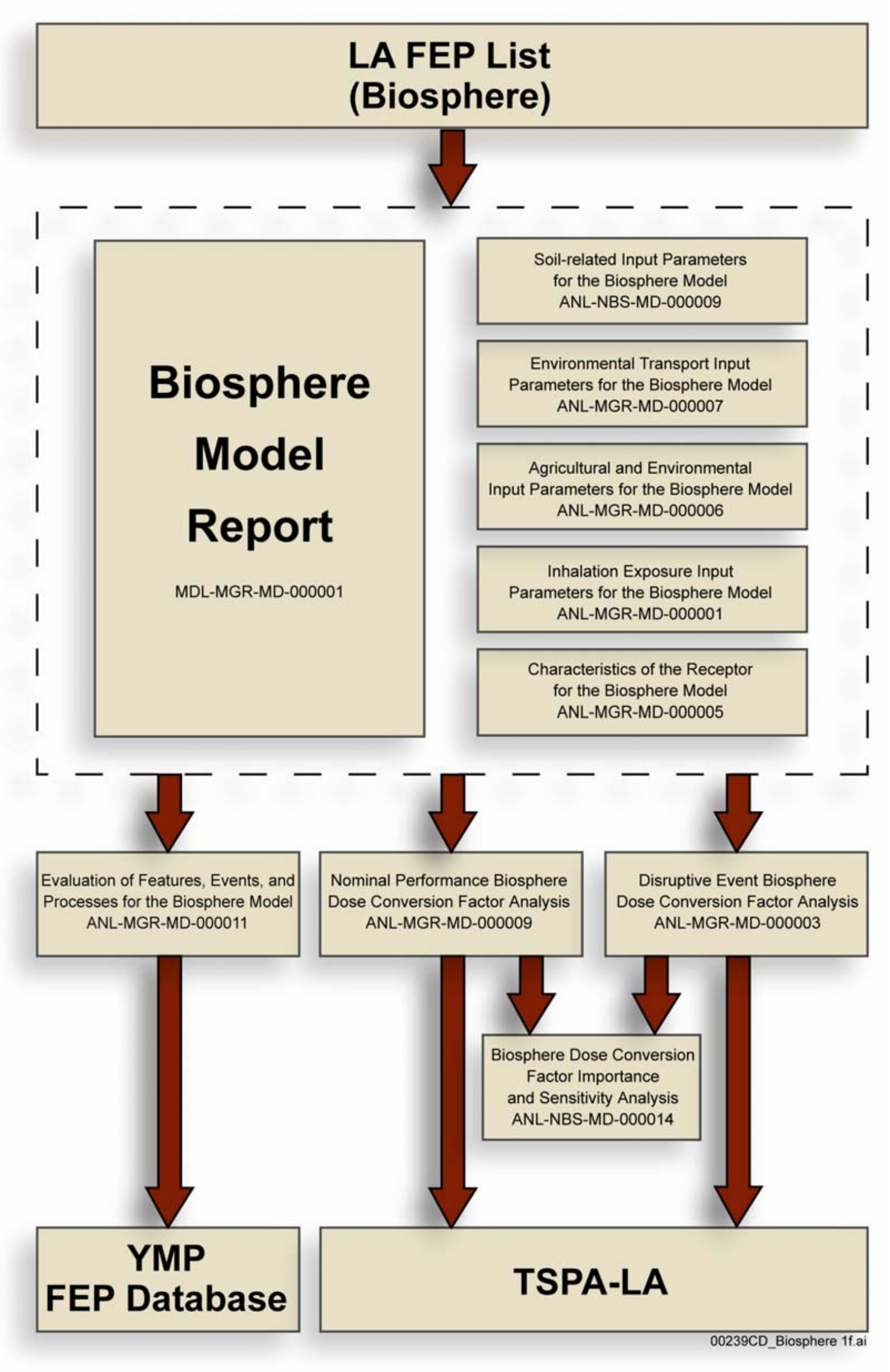

Figure 1-1. Overview of the Yucca Mountain Biosphere Model Documentation

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

Parameter(s)	FEP[a]	YMP FEP Number	Associated Submodel(s)	Summary of Disposition [b]
Soil-to-plant transfer factor (TF)	Ashfall	1.2.04.07.0A	Plant Uptake	Sections 6.2.1.2 to 6.2.1.5
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		
	Plant uptake	3.3.02.01.0A		
Dry deposition velocity	Soil and sediment transport in the biosphere	2.3.02.03.0A	Plant Uptake	Section 6.2.2.1
	Biosphere characteristics	2.3.13.01.0A		
	Plant uptake	3.3.02.01.0A		
Translocation factor	Plant uptake	3.3.02.01.0A	Plant Uptake	Section 6.2.2.2
Weathering rate constant	Plant uptake	3.3.02.01.0A	Plant Uptake	Section 6.2.2.3
Animal consumption rate of feed	Animal farms and fisheries	2.4.09.02.0A	Animal Uptake, Carbon-14	Section 6.3.2
	Animal uptake	3.3.02.02.0A		
Animal consumption rate of water	Agricultural land use and irrigation	2.4.09.01.0B	Animal Uptake, Carbon-14	Section 6.3.2
	Animal farms and fisheries	2.4.09.02.0A		
	Animal uptake	3.3.02.02.0A		
Animal consumption rate of soil	Animal farms and fisheries	2.4.09.02.0A	Animal Uptake, Carbon-14	Section 6.3.2
	Animal uptake	3.3.02.02.0A		
Animal diet-to-animal product transfer coefficient (TC)	Animal uptake	3.3.02.02.0A	Animal Uptake	Section 6.3.3
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		
Bioaccumulation factor for aquatic food (by element and climate)	Fish uptake	3.3.02.03.0A	Fish Uptake	Sections 6.4.3 and 6.4.4
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		
Water concentration modifying factor for fishpond water	Agricultural land use and irrigation	2.4.09.01.0B	Fish Uptake	Sections 6.4.3 to 6.4.5
	Climate change	1.3.01.00.0A		
	Water management activities	1.4.07.01.0A		
	Biosphere characteristics	2.3.13.01.0A		
	Animal farms and fisheries	2.4.09.02.0A		
	Fish uptake	3.3.02.03.0A		
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		

Table 1-1. Parameters and Related Features, Events, and Processes (Continued)

Parameter(s)	Included FEP[a]	YMP FEP Number	Associated Submodel(s)	Summary of Disposition [b]
Fraction of radionuclides in evaporative cooler water that is transferred into the air	Atmospheric transport of contaminants	3.2.10.00.0A	Air	Section 6.5.2
	Radon and radon daughter exposure	3.3.08.00.0A		
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		
Water evaporation rate for an evaporative cooler	Dwellings	2.4.07.00.0A	Air	Section 6.5.2
	Biosphere characteristics	2.3.13.01.0A		
	Urban and industrial land and water use	2.4.10.00.0A		
	Atmospheric transport of contaminants	3.2.10.00.0A		
Air flow rate for an evaporative cooler	Dwellings	2.4.07.00.0A	Air	Section 6.5.2
	Atmospheric transport of contaminants	3.2.10.00.0A		
Radon release factor (concentration ratio for ^{222}Rn in air to ^{226}Rn in soil)	Atmospheric transport of contaminants	3.2.10.00.0A	Air	Section 6.6.1
	Radon and radon daughter exposure	3.3.08.00.0A		
Ratio (conversion factor) of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil	Atmospheric transport of contaminants	3.2.10.00.0A	Air	Section 6.6.1
	Radon and radon daughter exposure	3.3.08.00.0A		
Fraction of ^{222}Rn flux from soil entering the house	Atmospheric transport of contaminants	3.2.10.00.0A	Air	Section 6.6.2
	Radon and radon daughter exposure	3.3.08.00.0A		
Interior wall height	Dwellings	2.4.07.00.0A	Air	Sections 6.5.2 and 6.6.2
	Radon and radon daughter exposure	3.3.08.00.0A		
	Atmospheric transport of contaminants	3.2.10.00.0A		
House ventilation rate	Dwellings	2.4.07.00.0A	Air	Section 6.6.2
	Atmospheric transport of contaminants	3.2.10.00.0A		
	Radon and radon daughter exposure	3.3.08.00.0A		
Equilibrium factor for radon decay products indoors	Radon and radon daughter exposure	3.3.08.00.0A	Inhalation	Section 6.6.3
	Inhalation	3.3.04.02.0A		
Equilibrium factor for radon decay products outdoors	Radon and radon daughter exposure	3.3.08.00.0A	Inhalation	Section 6.6.3
	Inhalation	3.3.04.02.0A		
Carbon emission rate constant for soil	Soil type	2.3.02.01.0A	Carbon-14	Section 6.7.1

Table 1-1. Parameters and Related Features, Events, and Processes (Continued)

Parameter(s)	Included FEP[a]	YMP FEP Number	Associated Submodel(s)	Summary of Disposition [b]
	Atmospheric transport of contaminants	3.2.10.00.0A		
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		
Surface area of irrigated land	Agricultural land use and irrigation	2.4.09.01.0B	Carbon-14	Section 6.7.2
	Atmospheric transport of contaminants	3.2.10.00.0A		
	Climate change	1.3.01.00.0A		
Mixing height of gaseous ^{14}C (CO_2)	Atmospheric transport of contaminants	3.2.10.00.0A	Carbon-14	Section 6.7.2
Annual average wind speed	Biosphere characteristics	2.3.13.01.0A	Carbon-14	Section 6.7.2
	Atmospheric transport of contaminants	3.2.10.00.0A		
Fraction of stable carbon in crops	Plant uptake	3.3.02.01.0A	Carbon-14	Section 6.7.3
Fraction of air-derived carbon in plants	Plant uptake	3.3.02.01.0A	Carbon-14	Section 6.7.3
	Animal uptake	3.3.02.02.0A		
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		
Fraction of soil-derived carbon in plants	Plant uptake	3.3.02.01.0A	Carbon-14	Section 6.7.3
	Animal uptake	3.3.02.02.0A		
	Radionuclide alteration during biosphere transport	2.3.13.02.0A		
Fraction of stable carbon in soil	Plant uptake	3.3.02.01.0A	Carbon-14	Section 6.7.3
Concentration of stable carbon in air	Atmospheric transport of contaminants	3.2.10.00.0A	Carbon-14	Section 6.7.3
	Plant uptake	3.3.02.01.0A		
Fraction of stable carbon in animal products	Animal uptake	3.3.02.02.0A	Carbon-14	Section 6.7.4
Concentration of stable carbon in water	Animal uptake	3.3.02.02.0A	Carbon-14	Section 6.7.4
Critical thickness of soil for resuspension	Radionuclide accumulation in soils	2.3.02.02.0A	Soil	Section 6.8
	Soil and sediment transport in the biosphere	2.3.02.03.0A		
	Inhalation	3.3.04.02.0A		
Correlation coefficient for transfer factors and partition coefficients	Radionuclide alteration during biosphere transport	2.3.13.02.0A	Plant Uptake	Section 6.2.1.5
	Plant uptake	3.3.02.01.0A		
Correlation coefficient for airflow and	Dwellings	2.4.07.00.0A	Air	Section 6.5.2

Table 1-1. Parameters and Related Features, Events, and Processes (Continued)

Parameter(s)	Included FEP[a]	YMP FEP Number	Associated Submodel(s)	Summary of Disposition [b]
water use in evaporative coolers	Atmospheric transport of contaminants	3.2.10.00.0A		

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

[b] This column gives the section number of this analysis where the treatment of this parameter is described. The effects of the FEPs are included in the TSPA-LA through the BDCFs. See *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.2) for a complete description of the inclusion and treatment of FEPs in the biosphere model.

2. QUALITY ASSURANCE

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

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

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3. USE OF SOFTWARE

The only software used during this analysis was the commercial, off-the-shelf product Microsoft® Excel 2000 (Version 9.0.3821 SR-1). Only standard functions were used to calculate values listed in tables throughout Section 6, as noted. The use of the standard functions (including formulas or algorithms, inputs, and outputs) is described in Appendix A.

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4. INPUTS

4.1 DIRECT INPUTS

The list of biosphere model parameters addressed in this analysis, and the sources of direct input used to develop the parameter values, are shown in Table 4-1. Descriptions of the direct input follow the same order in which the parameters appear in Table 4-1.

Table 4-1. Biosphere Model Input Parameters and Sources of Data Used to Develop Their Values and Distributions

Biosphere Model Input Parameter	Sources of Direct Input Used to Develop Parameter Value/Distribution	Description and Justification
Soil-to-plant transfer factors, by crop type and element	Baes et al. 1984 [DIRS 103766] BIOMASS 2001 [DIRS 159468] Davis et al. 1993 [DIRS 103767] IAEA 1994 [DIRS 100458] IAEA 2001 [DIRS 158519] Kennedy and Strenge 1992 [DIRS 103776] LaPlante and Poor 1997 [DIRS 101079] Lide and Frederikse 1997 [DIRS 103178] NCRP 1984 [DIRS 103784] NCRP 1996 [DIRS 101882] Peterson 1983 [DIRS 167077] Rittmann 1993 [DIRS 107744] Sheppard 1995 [DIRS 103789] Sheppard and Evenden 1997 [DIRS 160641] Wang et al. 1993 [DIRS 103839]	Section 4.1.1
Correlation coefficient for transfer factors and partition coefficients	Davis et al. 1993 [DIRS 103767] Karlsson et al. 2001 [DIRS 159470] Sheppard and Sheppard 1989 [DIRS 160644]	Section 4.1.1
Dry deposition velocity	DTN: MO04019SUM9397.000 [DIRS 167054] Summary of 1993-1997 Site 9 Meteorological Data Dorrian 1997 [DIRS 159476] NCRP 1984 [DIRS 103784] NCRP 1999 [DIRS 155894] Sehmel 1984 [DIRS 158693] Schery 2001 [DIRS 159478]	Section 4.1.2
Annual average wind speed	DTN: MO04019SUM9397.000 [DIRS 167054] Summary of 1993-1997 Site 9 Meteorological Data NCRP 1984 [DIRS 103784] Randerson 1984 [DIRS 109153] Sehmel 1984 [DIRS 158693] Stull 2001 [DIRS 159533]	Section 4.1.2
Critical thickness of soil	McCartin and Lee 2001 [DIRS 160672] Sehmel 1980 [DIRS 163178] Sehmel 1984 [DIRS 158693]	Section 4.1.2
Translocation factor, by crop type	Kennedy and Strenge 1992 [DIRS 103776] LaPlante and Poor 1997 [DIRS 101079] Leigh et al. 1993 [DIRS 100464] Mills et al. 1983 [DIRS 103781] Napier et al. 1988 [DIRS 157927] NCRP 1984 [DIRS 103784] Yu et al. 2001 [DIRS 159465]	Section 4.1.3

Table 4-1. Biosphere Model Input Parameters and Sources of Data Used to Develop Their Values and Distributions (Continued)

Biosphere Model Input Parameter	Sources of Direct Input Used to Develop Parameter Value/Distribution	Description and Justification
Weathering half-life (weathering rate constant)	Baes et al. 1984 [DIRS 103766] IAEA 2001 [DIRS 158519] LaPlante and Poor 1997 [DIRS 101079] Leigh et al. 1993 [DIRS 100464] Mills et al. 1983 [DIRS 103781] NCRP 1984 [DIRS 103784] Peterson 1983 [DIRS 167077] Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067] Smith et al. 1996 [DIRS 101085] Yu et al. 2001 [DIRS 159465]	Section 4.1.4
Animal consumption rates of water, feed, and soil, by animal type	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767] IAEA 1994 [DIRS 100458] IAEA 2001 [DIRS 158519] Kennedy and Strenge 1992 [DIRS 103776] LaPlante and Poor 1997 [DIRS 101079] Leigh et al. 1993 [DIRS 100464] Mills et al. 1983 [DIRS 103781] Napier et al. 1988 [DIRS 157927] NCRP 1984 [DIRS 103784] Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067] Smith et al. 1996 [DIRS 101085] Yu et al. 2001 [DIRS 159465]	Section 4.1.5
Transfer coefficients by animal product and element	Baes et al. 1984 [DIRS 103766] Davis et al. 1993 [DIRS 103767] IAEA 1994 [DIRS 100458] IAEA 2001 [DIRS 158519] Kennedy and Strenge 1992 [DIRS 103776] LaPlante and Poor 1997 [DIRS 101079] Mills et al. 1983 [DIRS 103781] NCRP 1984 [DIRS 103784] NCRP 1996 [DIRS 101882] Ng 1982 [DIRS 160322] Peterson 1983 [DIRS 167077] Rittmann 1993 [DIRS 107744] Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067] Smith et al. 1996 [DIRS 101085] Wang et al. 1993 [DIRS 103839] Yu et al. 2001 [DIRS 159465]	Section 4.1.6
Bioaccumulation factors for freshwater fish, by element	Davis et al. 1993 [DIRS 103767] IAEA 1994 [DIRS 100458] IAEA 2001 [DIRS 158519] Kennedy and Strenge 1992 [DIRS 103776] Mills et al. 1983 [DIRS 103781] Napier et al. 1988 [DIRS 100953] NCRP 1996 [DIRS 101882] Peterson 1983 [DIRS 167077] Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067] Wang et al. 1993 [DIRS 103839] Yu et al. 2001 [DIRS 159465]	Section 4.1.7
Water concentration modifying factor for fishpond water, by element	DTN: MO0211SPADIMEN.005 [DIRS 160653] Dimensions of Catfish Ponds in Amargosa Valley Farnsworth et al. 1982 [DIRS 160564] Mississippi State University Extension Service 2002 [DIRS 159489]	Section 4.1.8

Table 4-1. Biosphere Model Input Parameters and Sources of Data Used to Develop Their Values and Distributions (Continued)

Biosphere Model Input Parameter	Sources of Direct Input Used to Develop Parameter Value/Distribution	Description and Justification
Water evaporation rate for evaporative cooler (water use rate)	Karpiscak et al. 1998 [DIRS 160563]	Section 4.1.9.1
Airflow rate for evaporative cooler	Karpiscak and Marion 1994 [DIRS 159501] NAHB Research Center 1998 [DIRS 160428] ToolBase Services 2002 [DIRS 159507] Watt and Brown 1997 [DIRS 159497]	Section 4.1.9.2
Correlation coefficient for airflow and water use in evaporative coolers	Karpiscak and Marion 1994 [DIRS 159501] Watt and Brown 1997 [DIRS 159497]	Section 4.1.9.2
Interior wall height (ceiling height)	24 CFR 3280 [DIRS160555] NAHB Research Center 1998 [DIRS 160428]	Section 4.1.9.3
House ventilation (air exchange) rate	24 CFR 3280 [DIRS160555] HVI 2001 [DIRS 160557] Murray and Burmaster 1995 [DIRS 160554]	Section 4.1.9.4
Radon release factor (concentration ratio of ^{222}Rn in air to ^{226}Ra in surface soil)	UNSCEAR 2000 [DIRS 158644] NCRP 1999 [DIRS 155894]	Section 4.1.10.1
Ratio (conversion factor) of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil	UNSCEAR 2000 [DIRS 158644] NCRP 1999 [DIRS 155894]	Section 4.1.10.1
Fraction of ^{222}Rn flux from soil entering the house	United Nations 1988 [DIRS 159566] UNSCEAR 2000 [DIRS 158644] Landman 1982 [DIRS 160425]	Section 4.1.10.2
Equilibrium factor for ^{222}Rn decay products in indoor air	United Nations 1988 [DIRS 159566] UNSCEAR 2000 [DIRS 158644]	Section 4.1.10.3
Equilibrium factor for ^{222}Rn decay products in outdoor air	UNSCEAR 2000 [DIRS 158644] NCRP 1988 [DIRS 153691] Wasiolek and James 1998 [DIRS 163507]	Section 4.1.10.3
Carbon emission rate constant for soil	Davis et al. 1993 [DIRS 103767] Sheppard et al. 1991 [DIRS 159545] Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Mixing height of gaseous ^{14}C (CO_2)	Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Surface area of land irrigated with contaminated water	10 CFR 63 [DIRS 156605]	Section 4.1.11
Fraction of stable carbon in soil	Napier et al. 1988 [DIRS 157927] Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Concentration of stable carbon in air	IAEA 2001 [DIRS 158519] Napier et al. 1988 [DIRS 157927] Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Fraction of stable carbon in crops by crop type	Napier et al. 1988 [DIRS 157927] Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Fraction of air-derived carbon in plants	Sheppard et al. 1991 [DIRS 159545] Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Fraction of soil-derived carbon in plants	Sheppard et al. 1991 [DIRS 159545] Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Fraction of stable carbon in animal products, by animal product	Napier et al. 1988 [DIRS 157927] Yu et al. 2001 [DIRS 159465]	Section 4.1.11
Concentration of stable carbon in water	Davis et al. 1993 [DIRS 103767] Napier et al. 1988 [DIRS 157927] Yu et al. 2001 [DIRS 159465]	Section 4.1.11

The following factors were considered in the following sections to evaluate the data regarding their suitability for intended use:

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

4.1.1 Soil-to-Plant Transfer Factors

This section describes the data used to develop the values for soil-to-plant transfer factors (TFs) and correlation coefficient for TFs and partition coefficients. Parameter values were developed based on the data from the references presented in Table 4-2. This table lists the parameters, identifies specific sources of data used to develop the parameter values, and provides the section within this report where the analysis is presented. The references listed in Table 4-2 and the data within were used to determine the range of possible values of the TFs. Additional information on the use of these data is provided in Sections 6.2.1.1 and 6.2.1.2.

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values

	Biosphere Model Input Parameter	**References Used to Develop Parameter Value or Reach Conclusion**	**Section No.**
1	Chlorine soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 Kennedy and Strenge 1992 [DIRS 103776], p. 6.25 to 6.27 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
2	Selenium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
3	Strontium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
4	Technetium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
5	Tin soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 Kennedy and Strenge 1992 [DIRS 103776], pp. 25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
6	Iodine soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
7	Cesium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
8	Lead soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
9	Radium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
10	Actinium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
11	Thorium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
12	Protactinium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
13	Uranium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
14	Neptunium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
15	Plutonium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
16	Americium soil-to-plant transfer factor for leafy vegetables	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.1
17	Chlorine soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
18	Selenium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
19	Strontium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
20	Technetium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
21	Tin soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
22	Iodine soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
23	Cesium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
24	Lead soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
25	Radium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
26	Actinium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
27	Thorium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
28	Protactinium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
29	Uranium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
30	Neptunium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
31	Plutonium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
32	Americium soil-to-plant transfer factor for other vegetables	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.2
33	Chlorine soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
34	Selenium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
35	Strontium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 BIOMASS 2001 [DIRS 159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
36	Technetium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
37	Tin soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
38	Iodine soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 BIOMASS 2001 [DIRS 159468],/T3FM/WD01, pp. 82 to 92 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
39	Cesium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 BIOMASS 2001 [DIRS 159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
40	Lead soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
41	Radium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
42	Actinium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
43	Thorium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
44	Protactinium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
45	Uranium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 BIOMASS 2001 [DIRS 159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
46	Neptunium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
47	Plutonium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 BIOMASS 2001 [DIRS 159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
48	Americium soil-to-plant transfer factor for fruit	Baes et al. 1984 [DIRS 103766], p. 11 BIOMASS 2001 [DIRS 159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.3
49	Chlorine soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
50	Selenium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
51	Strontium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
52	Technetium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
53	Tin soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
54	Iodine soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
55	Cesium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
56	Lead soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
57	Radium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
58	Actinium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
59	Thorium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
60	Protactinium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
61	Uranium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
62	Neptunium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
63	Plutonium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
64	Americium soil-to-plant transfer factor for grain	Baes et al. 1984 [DIRS 103766], p. 11 IAEA 1994 [DIRS 100458], pp. 17 to 25 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.4
65	Chlorine soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
66	Selenium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
67	Strontium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1984 [DIRS 103784], p. 75 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
68	Technetium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
69	Tin soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
70	Iodine soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
71	Cesium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1984 [DIRS 103784], p. 75 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
72	Lead soil-to-plant transfer factor for forage plants, groundwater scenario, present day climate	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
73	Radium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
74	Actinium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
75	Thorium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
76	Protactinium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
77	Uranium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5

Table 4-2. Sources of Data for the Development of the Soil-to-plant Transfer Factor Values (Continued)

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
78	Neptunium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
79	Plutonium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1984 [DIRS 103784], p. 75 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
80	Americium soil-to-plant transfer factor for forage plants	Baes et al. 1984 [DIRS 103766], p. 10 IAEA 1994 [DIRS 100458], pp. 17 to 25 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Sheppard 1995 [DIRS 103789], pp. 55 to 57 Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51 Wang et al. 1993 [DIRS 103839], pp. 25 to 26	6.2.1.2.5
81	Correlation coefficient for soil-to-plant transfer factors and partition coefficients (K_ds)	Davis et al. 1993 [DIRS 103767], p. 234 Karlsson et al. 2001 [DIRS 159470], p. 37 Sheppard and Sheppard 1989 [DIRS 160644], p. 653	6.2.1.5
81	Lower and upper limits for the GSD of the transfer factor distributions	Davis et al. 1993 [DIRS 103767], p. 232 Sheppard and Evenden 1997 [DIRS 160641], Figures 2 & 3	6.2.1.1.5
82	Statistics for lognormal distribution	Lide and Frederikse 1997 [DIRS 103178], p. A-104	6.2.1.1.5

4.1.1.1 Reliability of Data Source and Qualification of the Data Originator

The documents that were used as sources of data for development of the values of TFs are mainly review reports, compendia of biosphere parameter values, and comprehensive dose assessment reports that included the descriptions of biosphere models and the selection of model input parameter values. Descriptions of the reports that were the source of the direct input are presented below. References were published by professional organizations producing technically defensible products pertinent to this analysis as indicated in the following discussion. The data from these reports are considered appropriate for the intended use (i.e., to develop the value distributions of TFs for the biosphere model). Some of the references are considered sources of established fact data.

Baes et al. 1984 [DIRS 103766]–*A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture* describes an evaluation of parameters pertaining to radionuclide transport through agricultural systems. It also provides documentation on the development of default parameters incorporated into the radionuclide food-chain-transport assessment code TERRA (p. xvii). The report was prepared by the scientific staff of the Oak Ridge National Laboratory and reviewed by several specialists in the field of environmental transport of radionuclides (p. xvii). The work was sponsored by the Office of Radiation Programs, U.S. Environmental Protection Agency. The documentation of default parameter values includes description of available literature references, as well as the protocols and assumptions used. The report also includes comparison of radionuclide concentrations in the environmental media, predicted using the model with experimentally measured concentrations. The parameters discussed in this report include element-specific transport parameters, such as soil-to-plant TFs, animal-feed–to–animal-product transfer coefficients (TCs), and other parameters. The effort reported in this review document was directed toward construction of a database of various parameters used in radiological assessments. For element-specific parameters, such as the soil-to-plant TFs and TCs for animal products, many references were reviewed. For elements for which few or no experimental data existed, systematic protocols were used to estimate parameter values (p. 1). The reported values of parameters reflect "reasonable estimates" based on unbiased approaches, parameter correlation, and theoretical models when available information was limited (p. 3). This methodology is consistent with the philosophy underlying the ERMYN biosphere model, which also uses the "reasonable estimate" approach to dose assessment.

BIOMASS 2001 [DIRS 159468]–This reference contains a collection of the working documents entitled *Biosphere Modelling and Assessment Methods* generated by the BIOMASS Program. Of these documents, *A Critical Review of Experimental, Field and Modelling Information on the Transfer of Radionuclides to Fruit* provides the results of a comprehensive effort aimed at better understanding of the transfer of radionuclides to fruit. The effort was conducted within the framework of the BIOMASS program sponsored by the International Atomic Energy Agency (IAEA) and involved participation of specialists in the area of environmental transport of radionuclides and radioecology (p. vi). The goal of the BIOMASS Project was to provide methodology for development of dose assessment models for radioactive waste disposal facilities. The subject report contains a summary of one of the tasks that was set up within the Biosphere Processes theme. The report was produced following a series of international meetings and workshops attended by researchers (p. vi and Annex A), followed by technical peer reviews occurring in the late 1990s. The report provides a review of the transfer of radionuclides to fruit and behavior in fruit-bearing plants. The intent of this review was to improve capabilities for modeling of radionuclide transfer to fruit, which was determined to be important in the overall context of the BIOMASS initiative. The report includes the most up-to-date compilation of experimental and field data on TFs for fruit.

Davis et al. 1993 [DIRS 103767]–*The Disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment* describes the biosphere model used in the performance assessment for the disposal of Canadian nuclear fuel waste. BIOTRAC is a comprehensive model used to trace radionuclide movement from the geosphere to the biosphere, to calculate environmental radionuclide concentrations, and to calculate the resulting doses. In addition to presenting the model, the report describes how the model parameter values and distributions adopted for the specific submodels were derived from the available data. The report includes a discussion of the reliability of BIOTRAC in terms of experimental validation, model and data evaluation, peer review, model intercomparisons, conservative assumptions, quality assurance procedures, and natural analogs (Chapter 11 and references within). Values for the BIOTRAC model parameters were developed based on carefully screened information and were subject to peer review (p. 334) conducted by the publishing organization.

IAEA 1994 [DIRS 100458]–IAEA Technical Reports Series No. 364, *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*, is a reference for radionuclide transfer parameter values used in biosphere assessment models. The report is based on data collected for the most part through projects of the International Union of Radioecology (IUR) and the Commission of European Communities. The report was produced through a series of consultant meetings and technical peer reviews involving numerous researchers (pp. 73 to 74). The report contains reference values for the most commonly used transfer parameters in radiological assessment models (p. 1). The parameter values are usually given as expected values and observed ranges. The expected values are best estimates of parameter values and should not be confused with the default values recommended for the generic screening models for assessing the impact of radionuclide discharges to the environment, such as those found in the IAEA document described below (2001 [DIRS 158519], p. 1).

IAEA 2001 [DIRS 158519]–IAEA Safety Reports Series No. 19, *Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment*, is the product of international efforts on generic models and parameters for assessing the environmental transfer of radionuclides from routine releases. The report provides the international community with a procedure that could be used to predict the environmental impact of future actions and decisions involving radionuclide releases to the environment. The report was developed through a series of consultant and advisory group meetings, followed by extensive technical review of the contents. The objective of the report was to provide simplified but conservative dose assessment methods. The report provides an overview of these methods and the selection of generic parameters for assessing transfers between various model components. Because of the objective of the report, the parameter values are generally conservative and not likely to lead to underestimations of the doses. The primary source of the TF information presented in this report is the IUR database compiled in the 1980s and early 1990s.

Karlsson et al. 2001 [DIRS 159470]–*Models for Dose Assessments, Models Adapted to the SFR-area, Sweden*, described the biosphere model for prediction of doses from long-term radionuclide releases from the Swedish radioactive waste repository. The report was issued by Swedish Nuclear Fuel and Waste Management Co., a company that is in charge of management and disposal of radioactive waste in Sweden. The model was developed for an existing facility for storage of low- and intermediate-level operational wastes from nuclear power plants in Sweden. Several ecosystems were modeled, including agricultural land, which is of interest for the Yucca Mountain analysis. The report includes values for model parameters. Model parameters are based on local conditions and available literature.

Kennedy and Strenge 1992 [DIRS 103776]–*Residual Radioactive Contamination from Decommissioning, Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*, is the first volume of a report that provides generic and site-specific estimates of radiation dose for exposures to residual radioactive contamination after the decommissioning of facilities licensed by the U.S. Nuclear Regulatory Commission (NRC). The document includes the description of the scenarios, models, mathematical formulations, assumption, and justification of parameter selections. The generic modeling addresses residual radioactive contamination in soil and in buildings. The information included in the report is intended to serve as the technical basis for the derivation of screening values supporting the development of NRC guidance applied to residual radioactive contamination from decommissioning (p. iii). Because of their use in development of screening guidelines, the models and the associated parameters presented in this report are inherently conservative. The report was developed by researchers from Pacific Northwest Laboratory and was sponsored by the Division of Regulatory Applications, Office of Nuclear Regulatory Research of the NRC.

LaPlante and Poor 1997 [DIRS 101079]–*Information and Analyses to Support Selection of Critical Groups and Reference Biospheres for Yucca Mountain Exposure Scenarios* is a biosphere assessment for Yucca Mountain that uses GENII-S as a supporting computer code. This assessment was done by the Center for Nuclear Waste Regulatory Analyses for the Division of Waste Management, Office of Nuclear Material Safety and Safeguards of the NRC. Because the biosphere model developed by the Yucca Mountain Repository Development Project is similar, this document provides useful insight into selection of input parameter values.

NCRP 1984 [DIRS 103784]–*Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment,* produced by the National Council on Radiation Protection and Measurements (NCRP), reviews the status of the application of radionuclide transport models from the point of discharge to the environment to the point of human intake. Models reviewed include those that describe bioaccumulation of radionuclides in food products. The report includes an in-depth analysis of the data accompanying the models in order to examine potential uncertainties inherent in the choice of model input parameters (p. iv). Where available, model validation experimental results are included. This NCRP report is written as a reference document. The NCRP reports can be considered sources of established fact data.

The NCRP is a nongovernmental, not-for-profit, public service organization and has status as an educational and scientific body. The NCRP was chartered by the U.S. Congress to collect, analyze, develop and disseminate in the public interest information and recommendations about radiation protection and radiation measurements, quantities, and units—particularly those concerned with radiation protection—and to develop basic concepts about radiation quantities, units and measurements; about the application of these concepts; and about radiation protection. The recommendations promulgated by the Council provide the scientific basis for radiation protection efforts throughout the country.

The Council publishes in the form of reports the consensus of scientific opinion on various measurement problems. The reports carry the full weight of the Council. They are reviewed by critical reviewers, usually four to eight Council members selected because of their expertise, and also by the full Council membership and collaborating organizations.

NCRP 1996 [DIRS 101882] and **NCRP 1996** [DIRS 101883]–These documents are volumes I and II of *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water and Ground*. The documents describe simple models that can be used for assessing doses from radionuclides released to the environment, and they include the recommended values of input parameters. Because the screening models are designed to be conservative (if compliance can be demonstrated using these models, it is generally understood that no further complex calculations are necessary), the selected input parameter values fall within the upper end of their respective ranges. The NCRP reports can be considered sources of established fact data.

Peterson 1983 [DIRS 167077]–This reference is a chapter in *Radiological Assessment, A Textbook on Environmental Dose Analysis*, which is a comprehensive book describing the techniques, models, and data most commonly used in radiological assessment, specifically to simulate the movement and effects of radionuclides in the environment. The preparation of the report was sponsored by the NRC. Chapter 5 of the report includes numerous tabulations of data related to radionuclide transport through terrestrial and aquatic food chains, which is of interest to the Yucca Mountain analysis. The chapters were written by scientific and technical experts, and extensive feedback was provided by professionals regarding the report.

Rittmann 1993 [DIRS 107744]–This reference, *Verification Tests for the July 1993 Revision to the GENII Radionuclide and Dose Increment Libraries*, describes a revision to some of the input data files for GENII, *The Hanford Environmental Radiation Dosimetry Software System*, and the verification tests for the July 1993 revision to the GENII input data. It also presents the most current list of default parameters for the code. GENII is a code developed to analyze the effects of environmental contamination with radionuclides. GENII-S, the stochastic implementation of GENII, was used in the biosphere modeling in support of TSPA for the Yucca Mountain Site Recommendation. GENII-S was used in performance assessment for the Waste Isolation Pilot Plant (Leigh et al. 1993 [DIRS 100464], p. 1-1).

Sheppard 1995 [DIRS 103789]–*Application of the International Union of Radioecologists Soil-to-Plant Database to Canadian Settings* presents the systematic analysis of TFs (concentration ratios) from the IUR database and development of correction factors to facilitate interpolation of TF values for ranges of soil conditions, where possible. Values of TFs are averaged for a number of crop types and species. The report provides a useful compilation of TF values based on experimental results submitted by individual contributors to the IUR database, which is the largest compilation of data on environmental transport of radionuclides. The document was published as a technical report by Atomic Energy of Canada Limited, which is an engineering company that conducted feasibility evaluations and prepared an Environmental Impact Statement for the concept of Canadian nuclear fuel waste disposal. The author of the report is one of the authors of the BIOTRAC model (Davis et al. 1993 [DIRS 103767]) described previously.

Sheppard and Evenden 1997 [DIRS 160641]–"Variation in Transfer Factors for Stochastic Models: Soil-to-Plant Transfer" presents an analysis of the uncertainties in the values of TFs from the IUR database. The article appeared in *Health Physics*, a peer-reviewed technical journal, which is an official publication of the Health Physics Society.

Sheppard and Sheppard 1989 [DIRS 160644]–"Impact of Correlations on Stochastic Estimates of Soil Contamination and Plant Uptake" is a scientific journal article that also appeared in *Health Physics*. The article discusses the impact of correlations and specifically concentrates on the values of K_ds and TFs (concentration ratios) of interest for this analysis.

Wang et al. 1993 [DIRS 103839]–*A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code* reviews TFs used in published radiological assessment reports and develops suggested default values for RESRAD, a code designed to calculate doses to human receptors from residual activity in the environment. The report contains a discussion of differences among the reported values used in different radiological assessment codes and reports. The values used in more recent reports, based on more recent experimental work, are given more weight in data comparisons for the purpose of developing default values for RESRAD. The report was produced by the research staff from Argonne National Laboratory under the sponsorship of the U.S. Department of Energy (DOE).

4.1.1.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included in the reports described in Section 4.1.1.1 were used to define, for each plant type and element, the range and the distribution of possible values of TFs. The values given in these reports differ primarily in regard to whether the approach was inherently conservative, which is the case for the screening models, or reasonable, using best estimates of parameter values. In most cases, a reference contributed only a single point value per crop type and element, and it was all the data points collectively that served as a basis for the distribution of the TF values. In this sense, neither of the references was used as a sole source of the data for a given TF value. It is believed that the combined TF data presented in these reports form a solid foundation for developing the distributions of TF values for the ERMYN biosphere model. Additional discussion of the input data and their appropriateness to represent the TFs for the biosphere model is in Sections 6.2.1.1.4 and 6.2.1.1.5.

4.1.1.3 Prior Uses of the Data

Some of the data sources listed in Section 4.1.1.1 were used in other performance assessments or other radiological assessments. For example, GENII-S model, with its input parameters reported in *Verification Tests for the July 1993 Revision to the GENII Radionuclide and Dose Increment Libraries* (Rittmann 1993 [DIRS 107744]), was used in the performance assessment for the Waste Isolation Pilot Plant. The RESRAD model has been used widely by the DOE, DOE contractors, the NRC, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [DIRS 159465], p. xi), including assessments to demonstrate compliance. The input data for the RESRAD model are reported in part in *A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code* (Wang et al. 1993 [DIRS 103839]). LaPlante and Poor (1997 [DIRS 101079]) describe the supporting biosphere analysis for the Yucca Mountain repository performance assessment conducted by the NRC staff. The NCRP is considered the established fact source, and the data within were undoubtedly used in some other radiological assessments.

4.1.1.4 Availability of Corroborating Data

The references used constitute a comprehensive set of reports describing the environmental transport of radionuclides. As noted in Section 4.1.1.2, neither of the references used to develop distributions of TF values was a sole source of input, but rather the distributions were developed based on all the applicable data from the references, as described in detail in Sections 6.2.1.1 and 6.2.1.2. This method ensured that all relevant data were included or at least considered.

Following the completion of the analysis described in Section 6 of this report, a new report was published that includes description of methods and parameter values of evaluation of radionuclide uptake by plants. This report, *Literature Review and Assessment of Plant and Animal Transfer Factors Used in Performance Assessment Modeling* (Robertson et al. 2003 [DIRS 168264]), generally confirms the TF value ranges considered in this analysis.

4.1.1.5 Additional Data Used in Development of Transfer Factors

In addition, *CRC Handbook of Chemistry and Physics* (Lide and Frederikse 1997 [DIRS 103178]) was used as a source of statistics for the lognormal distribution used in Section 6.2.1.1.5. This reference is a source of the established fact data.

In summary, the selected sources of data provide an appropriate technical basis for developing TF distributions for the ERMYN biosphere model. The combined data set can be considered qualified for intended use.

4.1.2 Parameters Pertaining to the Behavior of Particulates and Gases in Near-Surface Atmospheric Boundary Layer

The values of parameters pertaining to behavior of particulates and gases in the near-surface atmospheric boundary layer were developed based on the references listed in Table 4-3. The data from these references were used to develop the values of dry deposition velocity, annual average wind speed, and critical thickness of the surface soil layer available for resuspension (i.e., the thickness of soil, including ash or an ash–soil mixture, affected by the atmospheric processes). Table 4-3 lists the biosphere model input parameters, identifies specific sources of information used to develop the parameter values, and provides the sections within this report that contain the detailed analyses.

Parameter values are developed based on reviews of the sources listed in Table 4-3. The data referenced in Table 4-3 are suitable for the intended use, i.e., to develop distributions of the near-surface atmospheric transport input parameter values for the biosphere model. The following sections describe factors that were considered to evaluate the data regarding their suitability for the intended use.

Table 4-3. Sources of Data Used for Development of Near-Surface Atmospheric Transport Parameter Values

Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
Dry deposition velocity	DTN: MO04019SUM9397.000 [DIRS 167054] Summary of 1993-1997 Site 9 Meteorological Data Dorrian 1997 [DIRS 159476], pp. 117 and 129 NCRP 1984 [DIRS 103784], p. 48 NCRP 1999 [DIRS 155894], p. 67-68 Sehmel 1984 [DIRS 158693], pp. 547 to 551, 553, 558 to 561 Schery 2001 [DIRS 159478], p. 268	6.2.2.1
Annual average wind speed	DTN: MO04019SUM9397.000 [DIRS 167054] Summary of 1993-1997 Site 9 Meteorological Data NCRP 1984 [DIRS 103784], p. 48 Randerson 1984 [DIRS 109153], p. 169 Sehmel 1984 [DIRS 158693], p. 562 Stull 2001 [DIRS 159533], pp. 377 and 380, Figure 9.6	6.2.2.1 6.7.2
Critical thickness	Sehmel 1980 [DIRS 163178], p. 110 Sehmel 1984 [DIRS 158693], p. 574 McCartin and Lee 2001 [DIRS 160672], p. 5-4	6.8

4.1.2.1 Reliability of Data Source and Qualification of the Data Originator

Descriptions of the reports that were the source of the direct input are presented below. The references used include site-specific meteorological data as well as the reports that describe basic principles of atmospheric transport in the near-surface environment. References were either published by professional organizations, producing technically defensible products pertinent to this analysis, or are textbook-type references, as indicated in the following discussion. Some of the references are considered sources of established fact data.

The list provided below gives brief descriptions of the reports and other data that served as sources of information for the development of distributions for deposition velocity, wind speed, and critical thickness.

DTN: MO04019SUM9397.000 [DIRS 167054]–The data set *Summary of 1993–1997 Site 9 Meteorological Data* contains the summary of meteorological data collected by the Yucca Mountain Project at Meteorological Monitoring Site 9. For the ERMYN biosphere model, the average wind speed was used to develop the value of dry deposition velocity (Section 6.2.2.1) and wind speeds close to the ground surface (Section 6.7.2). The data represent meteorological conditions in the Amargosa Valley and are appropriate for the intended use.

Dorrian 1997 [DIRS 159476]–"Particle Size Distributions of Radioactive Aerosols in the Environment" was published in *Radiation Protection Dosimetry,* which is a peer-reviewed journal on the subject of radiation protection and radiation dosimetry. The article contains a comprehensive review of published measurements of activity median aerodynamic diameters of environmental aerosols to determine realistic default values for estimating doses to members of the public.

McCartin and Lee 2001 [DIRS 160672]–*Preliminary Performance-Based Analyses Relevant to Dose-Based Performance Measures for a Proposed Geologic Repository at Yucca Mountain*, prepared by the NRC staff, was published in the NUREG series. The report describes an approach for implementing a dose calculation for a defined receptor for groundwater contamination and direct disruption of the repository from volcanic activity. Some elements of this approach, especially those concerning the resuspension of contaminated ash, are adopted in this analysis.

NCRP 1984 [DIRS 103784]–See Section 4.1.1.1.

NCRP 1999 [DIRS 155894]–NCRP Report No. 129, *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies*, contains NCRP recommendations and provides screening limits that can be applied to sites where the surface soil is contaminated with radionuclides to assist with evaluating contamination levels and with making decisions regarding cleanup. The report includes a description of the methods that were used to arrive at the values of screening factors. These methods were chosen such that they are conservative under most conditions, which is consistent with a screening approach. The description of the methods and the pertinent parameters are useful for developing parameter values for the ERMYN biosphere model. The NCRP reports can be considered sources of established fact data.

Randerson 1984 [DIRS 109153]; **Sehmel 1984** [DIRS 158693]–These two authors wrote chapters in the book *Atmospheric Science and Power Production*, which is a collection of review articles written by experts on many subjects related to atmospheric science. This publication was prepared for the DOE and provides fundamentals of atmospheric transport, dispersion, chemistry, and removal processes. The book is recommended as a textbook, a handbook, and a guide for university professors and students, as well as for professionals involved in disciplines related to power production and air-quality analysis. It can be considered a reference source. Information from this book used in this analysis report concerns the behavior of aerosols in the outdoor environment with emphasis on dry deposition of particulates.

Schery 2001 [DIRS 159478]–This textbook, *Understanding Radioactive Aerosols and Their Measurement*, deals with radioactivity and aerosols in indoor and outdoor atmospheres. Although primarily intended as a textbook for college students, it is also recommended for professionals who need information on radioactive aerosols. Information used in this analysis report concerns dry deposition of particulates and is fundamental (textbook quality) in nature.

Sehmel 1980 [DIRS 163178]–"Particle Resuspension: A Review" is a journal article that appeared in *Environment International*. *Environment International* is a peer-reviewed periodical that covers the broad field of environmental research that quantifies relationships between exposure to environmental contaminants and their relationship with environmental health. Sehmel in an authority on resuspension processes.

Stull 2001 [DIRS 159533]–*An Introduction to Boundary Layer Meteorology* is a reference publication that describes the fundamentals of boundary layer meteorology. It contains a detailed treatment of the broad field of boundary layer meteorology. The book is suggested for graduate students of meteorology, as well as air chemists and aerosol physicists wanting to interpret their measured data in terms of boundary layer phenomena. It is also used as a text for many university courses in the field of atmospheric science.

4.1.2.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included in the reports described in Section 4.1.2.1 were used to define the range and the distribution of values for the parameters describing the atmospheric transport in the near-surface environment. In most cases, several references were used to develop a distribution of the parameter values. These references included the sources of the site-specific data and the references describing the general properties of atmospheric transport in the near-surface environment. The data and methods presented in these reports are appropriate for developing the input parameter values for the ERMYN biosphere model.

4.1.2.3 Prior Uses of the Data

McCartin and Lee (2001 [DIRS 160672]) describe the preliminary performance-based analysis for the Yucca Mountain repository conducted by the NRC staff. Other, prior uses of the data are not known. However, the sources of input that were selected are in large part the general descriptions of methods and parameter values that characterize the atmospheric transport processes in the near-surface environment. Since they were developed by the organizations that are well established in this field, they were undoubtedly used in other radiological assessments. The site-specific meteorological data are appropriate for the intended use.

4.1.2.4 Availability of Corroborating Data

The references used constitute a broad set of reports describing the environmental transport of radionuclides. Neither of the references used to develop distributions of TF values was a sole source of input, but rather the distributions of parameter values were developed based on the description of the atmospheric properties, the methods, and the applicable data from all the references, as described in detail in Sections 6.2.2.1, 6.7.2 and 6.8. This method ensured that the relevant information was included or at least considered. Other references were not used.

The selected sources of data provide an appropriate technical basis for developing the distributions for the biosphere model input parameters, and the data can be considered qualified for intended use. Additional discussion on the use of these data is provided in Sections 6.2.2.1, 6.7.2, and 6.8.

4.1.3 Translocation Factors

The values of crop type-dependent translocation factors were developed based on data from the references listed in Table 4-4. Table 4-4 lists the parameters, identifies specific sources of information used to develop the parameter values, and provides the section within this report that contains the analysis. Additional discussion of the use of these data is provided in Section 6.2.2.2.

Table 4-4. Sources of Data Used for Development of Translocation Factor Values

	Biosphere Model Input Parameter	References Used to Develop Parameter Value or Reach Conclusion	Section No.
1	Translocation factor for leafy vegetables, other vegetables, fruit, and grain consumed by humans	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 135 Napier et al. 1988 [DIRS 157927], p. 4.67 NCRP 1984 [DIRS 103784], p. 70 Yu et al. 2001 [DIRS 159465], p. D-12	6.2.2.2
2	Translocation factor for forage plants consumed by beef cattle and dairy cattle	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 135 Napier et al. 1988 [DIRS 157927], p. 4.67 NCRP 1984 [DIRS 103784], p. 70 Yu et al. 2001 [DIRS 159465], p. D-12	6.2.2.2
3	Translocation factor for grain consumed by poultry and laying hens	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 135 Napier et al. 1988 [DIRS 157927], p. 4.67 NCRP 1984 [DIRS 103784], p. 70 Yu et al. 2001 [DIRS 159465], p. D-12	6.2.2.2

The data referenced in Table 4-4 are suitable for the intended use, i.e., to develop distributions of the translocation factor values for the biosphere model. The following sections describe factors that were considered to evaluate the data regarding their suitability for the intended use.

4.1.3.1 Reliability of Data Source and Qualification of the Data Originator

The sources of data on translocation factors consist of reports containing recommendations regarding environmental transport models and their associated input parameters and comprehensive dose assessment reports that include selection of input parameter values. Parameter values for this analysis were developed based on reviews of these sources. References were published by professional organizations producing technically defensible products pertinent to this analysis as indicated in the following discussion. The data from these reports are considered appropriate for the intended use. Presented below are brief descriptions of the reports that were chosen as primary sources of information for the development of the translocation factors. Some of the references are considered sources of established fact data.

Kennedy and Strenge 1992 [DIRS 103776]–See Section 4.1.1.1.

LaPlante and Poor 1997 [DIRS 101079]–See Section 4.1.1.1.

Leigh et al. 1993 [DIRS 100464]–This report, *Users' Guide for GENII-S: A Code for Statistical and Deterministic Simulations of Radiation Doses to Humans from Radionuclides in the Environment*, is a user manual for the GENII-S computer program, which uses a comprehensive set of environmental pathway models used to calculate radionuclide transport in the environment and the resulting radiation doses to the human receptor. The manual includes a list of values recommended as defaults for the selected input parameters. The current biosphere model is, in part, based on GENII-S and its deterministic precursor, GENII. The default values of parameters used by GENII-S are the same as those originally developed for GENII (Napier et al. 1988 [DIRS 100953], Volume 3, Section 5.2) and subsequently updated, as documented by Rittmann (1993 [DIRS 107744]).

Mills et al. 1983 [DIRS 103781]–*Parameters and Variables Appearing in Radiological Assessment Codes* defines relevant parameters and presents typical values and ranges of values for each parameter. This report includes radionuclide source term calculations, doses to man, health effects, atmospheric transport, and environmental pathway and food chain transport parameters. The objective of the report was to compile parameters and parameter values for benchmarking and evaluating computer codes used for analyzing the performance of a high-level radioactive waste repository. Many parameters described in the report were based on PABLM, a computer code that was incorporated into GENII (Napier et al. 1988 [DIRS 100953], Volume 1, p. 1.2).

Napier et al. 1988 [DIRS 100953] and **Napier et al. 1988** [DIRS 157927]–*GENII—The Hanford Environmental Radiation Dosimetry Software System* is a three-volume report that gives a comprehensive description of the GENII model and software, including the conceptual basis, mathematical expressions, user manual, and the listing of default parameter values. GENII is an environmental pathway analysis model that was designed by the staff of Pacific Northwest Laboratory for calculating potential radiation doses resulting from routine Hanford emissions and dose calculation for purposes such as siting facilities, environmental impact statements, and safety analysis reports. The default parameter values for the code were selected based on review of the most recent pertinent information from the technical literature, with emphasis on Hanford-specific data. The GENII software package was developed in a framework for complying with the quality assurance program requirements for nuclear power plants, as described by Napier et al. (1988 [DIRS 100953], Volume 1, Section 1.2 and Volume 2, Section 5.0).

NCRP 1984 [DIRS 103784]–See Section 4.1.1.1.

Yu et al. 2001 [DIRS 159465]–*User's Manual for RESRAD Version 6* is the manual for the RESRAD code, which is used to implement DOE residual radioactive material guidelines. The manual describes the models used to derive site-specific guidelines for allowable residual concentrations in soil. It also includes description of the design and use of RESRAD and the default parameter values. The document provides useful information on selecting values of parameters of interest for the ERMYN biosphere model. As part of the RESRAD quality assurance program, the code has undergone extensive technical review, benchmarking, verification, and validation. The input parameters incorporated into RESRAD were determined to be realistic but reasonably conservative (Yu et al. 2001 [DIRS 159465], p. 1-6). The methodology for collecting RESRAD input data and the typical values and ranges of input parameters are discussed in detail in the RESRAD Data Collection Handbook (Yu et al. 1993 [DIRS 160561]) and in Yu et al. (2001 [DIRS 159465], pp. 1-6 to 1-7).

4.1.3.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included in the reports described in Section 4.1.3.1 were used to define the values and distributions of the translocation factor for each crop type included in the biosphere model. In most cases, all the relevant data from the references were used as a basis for the values and distributions of the translocation factors. Such a method ensures that the property of interest is adequately represented.

4.1.3.3 Prior Uses of the Data

Some of the data sources listed in Section 4.1.3.1 were used in other performance assessments or other radiological assessments. For example, GENII-S model (Leigh et al. 1993 [DIRS 100464]), which is based on the GENII model (Napier et al. 1988 [DIRS 100953] and Napier et al. 1988 [DIRS 157927]), was used in the performance assessment for the Waste Isolation Pilot Plant. The RESRAD model has been used widely by the DOE, DOE contractors, the NRC, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [DIRS 159465], p. xi), including assessments to demonstrate compliance. LaPlante and Poor (1997 [DIRS 101079]) describe the supporting biosphere analysis for the Yucca Mountain repository performance assessment conducted by the NRC staff. The NCRP reports are considered the established fact sources, and the data within were undoubtedly used in other radiological assessments.

4.1.3.4 Availability of Corroborating Data

The references used constitute a comprehensive set of reports describing the environmental transport of radionuclides. Neither of the references used to develop distributions of translocation factor values was a sole source of input but rather the distributions were developed based on all the applicable data from the references, as described in detail in Section 6.2.2.2. This method ensured that all relevant data were included or at least considered.

In summary, the selected sources of data provide an appropriate technical basis for developing the values and distributions of the translocation factor for the biosphere model, and the combined data set can be considered qualified for intended use.

4.1.4 Weathering Half-Life (Weathering Rate Constant)

The values of the weathering half-life (weathering rate constant) were developed based on data from the references in Table 4-5. Table 4-5 identifies specific sources of data used to develop the parameter value and provides the sections within this report that contain the analyses. Additional information on the development of this parameter is presented in Section 6.2.2.3.

Table 4-5. Sources of Data Used for Development of Weathering Half Life

Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
Weathering half-life (weathering rate constant)	Baes et al. 1984 [DIRS 103766], p. 124 IAEA 2001 [DIRS 158519], pp. 63 to 64 LaPlante and Poor 1997 [DIRS 101079], p. B-7 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 137 NCRP 1984 [DIRS 103784], p. 70 Peterson 1983 [DIRS 167077], pp. 5-36 to 5-37 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-69 Smith et al. 1996 [DIRS 101085], p. 5-30 Yu et al. 2001 [DIRS 159465], p. D-12	6.2.2.3

The data referenced in Table 4-5 are suitable for the intended use, i.e., to develop distributions of the weathering half-life for the biosphere model. The following sections describe factors that were considered to evaluate the data regarding their suitability for the intended use.

4.1.4.1 Reliability of Data Source and Qualification of the Data Originator

The sources of data related to weathering consist of reports providing summaries of measurements of weathering half-life (weathering rate constant), reports containing recommendations of the environmental transport models and their associated input parameters, and comprehensive dose assessment reports that include selection of input parameter values. In this analysis, parameter values are developed based on reviews of these sources. These references were published by professional organizations, producing technically defensible products pertinent to this analysis, as indicated in the following discussion. The information from these reports is appropriate for the intended use. Presented below are descriptions of reports that were chosen as primary sources of information for developing the distribution of the weathering half-life for the biosphere model. Some of the references are considered sources of established fact data.

Baes et al. 1984 [DIRS 103766]–See Section 4.1.1.1

IAEA 2001 [DIRS 158519]–See Section 4.1.1.1

LaPlante and Poor 1997 [DIRS 101079]–See Section 4.1.1.1

Leigh et al. 1993 [DIRS 100464]–See Section 4.1.3.1

Mills et al. 1983 [DIRS 103781]–See Section 4.1.3.1

NCRP 1984 [DIRS 103784]–See Section 4.1.1.1

Peterson 1983 [DIRS 167077]–See Section 4.1.1.1

Regulatory Guide 1.109 1977 [DIRS 100067]–*Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I*, an NRC Regulatory Guide, provides guidance regarding methods acceptable to the NRC for calculating radiation doses from nuclear power reactor effluent releases to the environment. The document specifies the methods for calculating annual external exposure, inhalation, and ingestion doses due to liquid, noble gas, and particulate matter releases. Numerical data supporting the equations presented in the publication are those routinely used by the NRC staff (Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-36). The data include environmental, human, dose factors, and other parameters. Of interest for the ERMYN biosphere analysis are the environmental data provided in Appendix E. The methods and parameters represent general approaches developed by the NRC staff for use in lieu of specific parameters for individual sites.

Smith et al. 1996 [DIRS 101085]–*Biosphere Modeling and Dose Assessment for Yucca Mountain* was prepared by the Electric Power Research Institute. The report documents the development of a biosphere model for Yucca Mountain and includes an extensive review of biosphere model parameter values with emphasis on radionuclides identified as important in previous TSPA calculations. Best estimates and appropriate ranges are provided with a comparison of data values considered in the review (Smith et al. 1996 [DIRS 101085]). This model constitutes an alternative approach to biosphere modeling that is based on the BIOMASS (2001 [DIRS 159468]) methodology.

Yu et al. 2001 [DIRS 159465]–See Section 4.1.3.1

4.1.4.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included in the reports described in Section 4.1.4.1 were used to define the distribution of the weathering half-life values for the biosphere model. All the relevant data from the references were used as a basis for the distribution of the weathering half-life. Such a method ensures that the property of interest is adequately represented.

4.1.4.3 Prior Uses of the Data

Some of the data sources listed in Section 4.1.4.1 were used in other performance assessments or other radiological assessments. For example, the GENII-S model (Leigh et al. 1993 [DIRS 100464]) was used in the performance assessment for the Waste Isolation Pilot Plant. The RESRAD model has been used widely by the DOE, DOE contractors, the NRC, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [DIRS 159465], p. xi), including assessments to demonstrate compliance. LaPlante and Poor (1997 [DIRS 101079]) describe the supporting biosphere analysis for the Yucca Mountain repository performance assessment conducted by the NRC staff. Similarly, Smith et al. (1996 [DIRS 101085]) present the biosphere model, including its input parameters, for the repository at Yucca Mountain. NCRP reports are considered established fact sources, and the data within were undoubtedly used in other radiological assessments.

4.1.4.4 Availability of Corroborating Data

The references used constitute a comprehensive set of reports describing the environmental transport of radionuclides. Neither of the references used to develop the distribution of the weathering half life was a sole source of input, but rather the distribution was developed based on all the applicable data from the references, as described in detail in Sections 6.2.2.3. This method ensured that all relevant data were included or at least considered.

The selected sources of data provide an appropriate technical basis for developing the distribution of the weathering half-life for the biosphere model, and the combined data set can be considered qualified for intended use.

4.1.5 Animal Consumption Rates for Water, Feed, and Soil

The values of animal consumption rates for water, feed, and soil were developed based on external-source information from the references listed in Table 4-6. Table 4-6 lists the parameters, identifies specific sources of information used to develop the parameter values, and provides the sections within this report that contain the analyses. Additional information on the development of these parameters can be found in Section 6.3.2.

Table 4-6. Sources of Data Used for Development of Animal Consumption Rates

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Beef cattle consumption rate of feed	BIOMASS 2003 [DIRS 168563], p. 449 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 IAEA 2001 [DIRS 158519], p. 70 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 143 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], pp. 70 to 71 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-38 Smith et al. 1996 [DIRS 101085], p. 5-24 Yu et al. 2001 [DIRS 159465], p. D-15	6.3.2
2	Beef cattle consumption rate of water	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 IAEA 2001 [DIRS 158519], p. 70 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 143 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], p. 70-71 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-38 Smith et al. 1996 [DIRS 101085], p. 5-24 Yu et al. 2001 [DIRS 159465], p. D-15	6.3.2

Table 4-6. Sources of Data Used for Development of Animal Consumption Rates (Continued)

	Biosphere Model Input Parameter	**References used to Develop Parameter Value or Reach Conclusion**	**Section No.**
3	Beef cattle consumption rate of soil	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 Smith et al. 1996 [DIRS 101085], p. 5-24 Yu et al. 2001 [DIRS 159465], p. D-15	6.3.2
4	Diary cow consumption rate of feed	BIOMASS 2003 [DIRS 168563], p. 449 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], pp. 15 and 33 IAEA 2001 [DIRS 158519], p. 70 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 143 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], p. 70-71 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-38 Smith et al. 1996 [DIRS 101085], p. 5-24 Yu et al. 2001 [DIRS 159465], p. D-15	6.3.2
5	Diary cow consumption rate of water	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 IAEA 2001 [DIRS 158519], p. 70 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 143 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], p. 70-71 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-38 Smith et al. 1996 [DIRS 101085], p. 5-24 Yu et al. 2001 [DIRS 159465], p. D-15	6.3.2
6	Diary cow consumption rate of soil	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 Smith et al. 1996 [DIRS 101085], p. 5-24 Yu et al. 2001 [DIRS 159465], p. D-15	6.3.2
7	Poultry consumption rate of feed	BIOMASS 2003 [DIRS 168563], p. 449 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Mills et al. 1983 [DIRS 103781], p. 143 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], p. 70-71 Smith et al. 1996 [DIRS 101085], p. 5-24	6.3.2

Table 4-6. Sources of Data Used for Development of Animal Consumption Rates (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
8	Poultry consumption rate of water	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], p. 70-71 Smith et al. 1996 [DIRS 101085], p. 5-24	6.3.2
9	Poultry consumption rate of soil	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 Smith et al. 1996 [DIRS 101085], p. 5-24	6.3.2
10	Laying hen consumption rate of feed	BIOMASS 2003 [DIRS 168563], p. 449 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], p. 70-71 Smith et al. 1996 [DIRS 101085], p. 5-24	6.3.2
11	Laying hen consumption rate of water	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 IAEA 1994 [DIRS 100458], p. 33 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 LaPlante and Poor 1997 [DIRS 101079], p. B-8 Leigh et al. 1993 [DIRS 100464], p. 5-63 Napier et al. 1988 [DIRS 157927], p. 4-72 NCRP 1984 [DIRS 103784], p. 70-71 Smith et al. 1996 [DIRS 101085], p. 5-24	6.3.2
12	Laying hen consumption rate of soil	BIOMASS 2003 [DIRS 168563], p. 450 Davis et al. 1993 [DIRS 103767], p. 253 Kennedy and Strenge 1992 [DIRS 103776], p. 6.19 Smith et al. 1996 [DIRS 101085], p. 5-24	6.3.2

The data referenced in Table 4-6 are suitable for the intended use, i.e., to develop distributions of the animal consumption rates for the biosphere model. The following sections describe factors that were considered to evaluate the data regarding their suitability for the intended use.

4.1.5.1 Reliability of Data Source and Qualification of the Data Originator

The sources of data on animal consumption rates of water, feed, and soil consist of reports that provide the summary of the measurements of animal consumption rates, reports containing recommendations regarding environmental transport models and their associated input parameters, and the comprehensive dose assessment reports that include selection of input parameter values. In this analysis, the parameter values are developed based on review of these sources. References were published by professional organizations, producing technically defensible products pertinent to this analysis, as indicated in the following discussion. The data from these reports are appropriate for the intended use. The following reports were chosen as primary sources of data for the development of animal consumption rates of water, feed, and soil. These reports were described in the previous sections of this analysis, as indicated below.

BIOMASS 2003 [DIRS 168563]–*"Reference Biospheres" for Solid Radioactive Waste Disposal* is the final report of the international program and is described in more detail in Section 4.1.1.1.

Davis et al. 1993 [DIRS 103767]–See Section 4.1.1.1

IAEA 1994 [DIRS 100458]–See Section 4.1.1.1

IAEA 2001 [DIRS 158519]–See Section 4.1.1.1

Kennedy and Strenge 1992 [DIRS 103776]–See Section 4.1.1.1

LaPlante and Poor 1997 [DIRS 101079]–See Section 4.1.1.1

Leigh et al. 1993 [DIRS 100464]–See Section 4.1.3.1

Mills et al. 1983 [DIRS 103781]–See Section 4.1.3.1

Napier et al. 1988 [DIRS 157927]–See Section 4.1.3.1

NCRP 1984 [DIRS 103784]–See Section 4.1.1.1

Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067]–See Section 4.1.4.1

Smith et al. 1996 [DIRS 101085]–See Section 4.1.4.1

Yu et al. 2001 [DIRS 159465]–See Section 4.1.3.1

4.1.5.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included in the reports listed in Section 4.1.5.1 were used to define animal food, water, and soil consumption rates for each type of animal product included in the biosphere model. In most cases, all the relevant data from the references were used as a basis for the values and distributions of the animal consumption rates. Such a method ensures that the property of interest is adequately represented.

4.1.5.3 Prior Uses of the Data

Some of the data sources listed in Section 4.1.5.1 were used in other performance assessments or other radiological assessments. For example, the GENII-S model (Leigh et al. 1993 [DIRS 100464]), which is based on the GENII model (Napier et al. 1988 [DIRS 100953] and Napier et al. 1988 [DIRS 157927]), was used in the performance assessment for the Waste Isolation Pilot Plant. The RESRAD model has been used widely by the DOE, DOE contractors, the NRC, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [DIRS 159465], p. xi), including assessments to demonstrate compliance. The input data for the RESRAD model are reported in part in Wang et al. (1993 [DIRS 103839]). LaPlante and Poor

(1997 [DIRS 101079]) describe the supporting biosphere analysis for the Yucca Mountain repository performance assessment conducted by the NRC staff. Similarly, Smith et al. (1996 [DIRS 101085]) present the biosphere model, including its input parameters, for the repository at Yucca Mountain. The NCRP reports are considered the established fact source, and the data within were undoubtedly used in some other radiological assessments.

4.1.5.4 Availability of Corroborating Data

The references used constitute a comprehensive set of reports describing the environmental transport of radionuclides. Neither of the references used to develop the values and distributions of animal consumption rates was a sole source of input, but rather the distribution was developed based on all the applicable data from the references, as described in detail in Section 6.3.2. This method ensured that all relevant data were included or at least considered.

The selected sources of data provide an appropriate technical basis for developing the values and distributions of the animal consumption rates of feed, water, and soil for the biosphere model, and the combined data set can be considered qualified for intended use.

4.1.6 Transfer Coefficients for Animal Products

Values of TCs for animal products were developed based of the data from references in Table 4-7, which lists the parameters, identifies specific sources of information used to develop the parameter values, and provides the sections within this report that contain the analyses. Additional information is presented in Section 6.3.3.

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Chlorine transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 IAEA 1994 [DIRS 100458], p. 37 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
2	Selenium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
3	Strontium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 85 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Regulatory Guide 1.109, Rev. 1 1997 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
4	Technetium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 85 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-87 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
5	Tin transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
6	Iodine transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 85 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
7	Cesium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 85 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
8	Lead transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
9	Radium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 85 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
10	Actinium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
11	Thorium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
12	Protactinium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
13	Uranium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
14	Neptunium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-87 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
15	Plutonium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1
16	Americium transfer coefficient for meat	Baes et al. 1984 [DIRS 103766], p. 51 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 37 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.1

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
17	Chlorine transfer coefficient for poultry	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Rittmann 1993 [DIRS 107744], pp. 35 to 36	6.3.3.2
18	Selenium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
19	Strontium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36	6.3.3.2
20	Technetium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
21	Tin transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36	6.3.3.2
22	Iodine transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
23	Cesium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982, p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
24	Lead transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
25	Radium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
26	Actinium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
27	Thorium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
28	Protactinium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
29	Uranium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
30	Neptunium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
31	Plutonium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
32	Americium transfer coefficient for poultry	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 40 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.2
33	Chlorine transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 IAEA 1994 [DIRS 100458], p. 35 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
34	Selenium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
35	Strontium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 82 to 83 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
36	Technetium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-86 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
37	Tin transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
38	Iodine transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 82 to 83 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
39	Cesium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 82 to 83 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
40	Lead transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
41	Radium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 82 to 83 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
42	Actinium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
43	Thorium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
44	Protactinium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	**References used to Develop Parameter Value or Reach Conclusion**	**Section No.**
45	Uranium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 82 to 83 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
46	Neptunium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Peterson 1983 [DIRS 167077], p. 5-86 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
47	Plutonium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1984 [DIRS 103784], pp. 82 to 83 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982 [DIRS 160322], p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
48	Americium transfer coefficient for milk	Baes et al. 1984 [DIRS 103766], p. 50 Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 35 IAEA 2001 [DIRS 158519], pp. 67 to 68 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 NCRP 1996 [DIRS 101882], pp. 52 to 54 Ng 1982, p. 62 Peterson 1983 [DIRS 167077], p. 5-86 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-27 Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	6.3.3.3
49	Chlorine transfer coefficient for eggs	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 Rittmann 1993 [DIRS 107744], pp. 35 to 36	6.3.3.4
50	Selenium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
51	Strontium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36	6.3.3.4
52	Technetium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
53	Tin transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36	6.3.3.4
54	Iodine transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
55	Cesium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Peterson 1983 [DIRS 167077], p. 5-87 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-28	6.3.3.4
56	Lead transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
57	Radium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
58	Actinium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
59	Thorium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
60	Protactinium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
61	Uranium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
62	Neptunium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4

Table 4-7. Sources of Data Used for Development of Transfer Coefficients for Animal Products (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
63	Plutonium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4
64	Americium transfer coefficient for eggs	Davis et al. 1993 [DIRS 103767], p. 233 to 234 IAEA 1994 [DIRS 100458], p. 41 Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [DIRS 101079], p. 2-13 Mills et al. 1983 [DIRS 103781], pp. 145 to 146 Ng 1982 [DIRS 160322], p. 63 Rittmann 1993 [DIRS 107744], pp. 35 to 36 Smith et al. 1996 [DIRS 101085], p. 5-29	6.3.3.4

The data referenced in Table 4-7 are suitable for the intended use, i.e., to develop distributions of TCs for the animal product types included in the biosphere model. The following sections describe factors that were considered to evaluate the data regarding their suitability for the intended use.

4.1.6.1 Reliability of Data Source and Qualification of the Data Originator

The sources of data on TCs for animal products consist of reports that summarize measurements of TCs, reports containing recommendations on the environmental transport models and their associated input parameters, and comprehensive dose assessment reports that include selection of input parameter values. In this analysis, parameter values are developed based on a review of these sources. These references were published by professional organizations, producing technically defensible products pertinent to this analysis, as indicated in the following discussion. The following publications were used to develop the distributions of TCs for animal products.

Baes et al. 1984 [DIRS 103766]–See Section 4.1.1.1

Davis et al. 1993 [DIRS 103767]–See Section 4.1.1.1

IAEA 1994 [DIRS 100458]–See Section 4.1.1.1

IAEA 2001 [DIRS 158519]–See Section 4.1.1.1

Kennedy and Strenge 1992 [DIRS 103776]–See Section 4.1.1.1

LaPlante and Poor 1997 [DIRS 101079]–See Section 4.1.1.1

Mills et al. 1983 [DIRS 103781]–See Section 4.1.3.1

NCRP 1984 [DIRS 103784]–See Section 4.1.1.1

NCRP 1996 [DIRS 101882]–See Section 4.1.1.1

Ng 1982 [DIRS 160322]–*A Review of Transfer Factors for Assessing the Dose from Radionuclides in Agricultural Products* presents a summary of literature reviews and a derivation of updated TFs for the prediction of radionuclide concentration in terrestrial foods using equilibrium models. Dr. Ng was one of the leading experts in the area of environmental transport of radionuclides and the uptake of radionuclides by biota.

Peterson 1983 [DIRS 167077]–See Section 4.1.1.1

Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067]–See Section 4.1.4.1

Rittmann 1993 [DIRS 107744]–See Section 4.1.1.1

Smith et al. 1996 [DIRS 101085]–See Section 4.1.4.1

Wang et al. 1993 [DIRS 103839]–See Section 4.1.1.1

Yu et al. 2001 [DIRS 159465]–See Section 4.1.3.1

Additional information is presented in Section 6.3.3.

4.1.6.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included in the reports listed in Section 4.1.6.1 were used to define TCs for the animal products included in the biosphere model. In most cases, all the relevant data from the references were used as a basis for the distributions of the parameter values. Such a method ensures that the property of interest is adequately represented.

4.1.6.3 Prior Uses of the Data

Some of the data sources listed in Section 4.1.6.1 were used in other performance assessments or other radiological assessments. For example, the GENII-S model, including its input parameters (Rittmann 1993 [DIRS 107744]), was used in the performance assessment for the Waste Isolation Pilot Plant. The RESRAD model (Wang et al. 1993 [DIRS 103839] and Yu et al. 2001 [DIRS 159465]) has been used widely by the DOE, DOE contractors, the NRC, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [DIRS 159465], p. xi), including assessments to demonstrate compliance. LaPlante and Poor (1997 [DIRS 101079]) describe the supporting biosphere analysis for the Yucca Mountain repository performance assessment conducted by the NRC staff. Similarly, Smith et al. (1996 [DIRS 101085]) present the biosphere model, including its input parameters, for the repository at Yucca Mountain. The NCRP reports are considered established fact sources, and the data within were undoubtedly used in some other radiological assessments.

4.1.6.4 Availability of Corroborating Data

The references used constitute a comprehensive set of reports describing the environmental transport of radionuclides. Neither of the references used to develop the distributions of animal product TCs was a sole source of input, but rather the distribution was developed based on all the applicable data from the references, as described in detail in Section 6.3.3. This method ensured that all relevant data were included or at least considered.

Following the completion of the analysis described in Section 6 of this report, a new report was published that includes description of methods and parameter values of evaluation of radionuclide uptake by animals. This report, *Literature Review and Assessment of Plant and Animal Transfer Factors Used in Performance Assessment Modeling* (Robertson et al. 2003 [DIRS 168264]), generally confirms the TC value ranges considered in this analysis.

The selected sources of data provide an appropriate technical basis for developing the distributions of the transfer coefficient for animal products for the biosphere model, and the combined data set can be considered qualified for intended use.

4.1.7 Bioaccumulation Factors for Freshwater Fish

The bioaccumulation factors for freshwater fish were developed based on external-source information from the references listed in Table 4-8, which lists the parameters, identifies specific sources of information used to develop the parameter values, and provides the sections within this report that contain the analyses.

Table 4-8. Sources of Data Used for Development of Bioaccumulation Factors for Freshwater Fish

	Biosphere Model Input Parameter	**References used to Develop Parameter Value or Reach Conclusion**	**Section No.**
1	Carbon bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-13 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3 and 6.4.4
2	Chlorine bioaccumulation factor for freshwater fish	Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
3	Selenium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3

Table 4-8. Sources of Data Used for Development of Bioaccumulation Factors for Freshwater Fish (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
4	Strontium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-13 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
5	Technetium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-13 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
6	Tin bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
7	Iodine bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-13 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
8	Cesium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-13 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3

Table 4-8. Sources of Data Used for Development of Bioaccumulation Factors for Freshwater Fish (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
9	Lead bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
10	Radium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
11	Actinium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
12	Thorium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
13	Protactinium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3

Table 4-8. Sources of Data Used for Development of Bioaccumulation Factors for Freshwater Fish (Continued)

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
14	Uranium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
15	Neptunium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-13 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
16	Plutonium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Peterson 1983 [DIRS 167077], pp. 5-98 to 5-103 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3
17	Americium bioaccumulation factor for freshwater fish	Davis et al. 1993 [DIRS 103767], pp. 233 to 234 IAEA 1994 [DIRS 100458], p. 45 IAEA 2001 [DIRS 158519], p. 73 Kennedy and Strenge 1992 [DIRS 103776], p. 6.32 Mills et al. 1983 [DIRS 103781], pp. 148 to 149 Napier et al. 1988 [DIRS 100953], pp. 5.769 to 5.770 NCRP 1996 [DIRS 101882], pp. 58 to 60 Wang et al. 1993 [DIRS 103839], pp. 33 to 35 Yu et al. 2001 [DIRS 159465], p. D-19	6.4.3

The data referenced in Table 4-8 are suitable for the intended use, that is, to develop distributions of bioaccumulation factors for the biosphere model. The following sections describe factors that were considered to evaluate the data regarding their suitability for the intended use.

4.1.7.1 Reliability of Data Source and Qualification of the Data Originator

Sources of data on bioaccumulation factors for freshwater fish consist of reports that summarize measurements of bioaccumulation factors, reports containing recommendations of the environmental transport models and their associated input parameters, and comprehensive dose assessment reports that include selection of input parameter values. In this analysis, parameter values were based on a review of these sources. These references were published by professional organizations, producing technically defensible products pertinent to this analysis, as indicated in the following discussion. The following documents were used to develop distributions of bioaccumulation factor values for the freshwater fish.

Davis et al. 1993 [DIRS 103767]–See Section 4.1.1.1.

IAEA 1994 [DIRS 100458]–See Section 4.1.1.1.

IAEA 2001 [DIRS 158519]–See Section 4.1.1.1.

Kennedy and Strenge 1992 [DIRS 103776]–See Section 4.1.1.1.

Mills et al. 1983 [DIRS 103781]–See Section 4.1.3.1.

Napier et al. 1988 [DIRS 100953]–See Section 4.1.3.1.

NCRP 1996 [DIRS 101882]–See Section 4.1.1.1.

Peterson 1983 [DIRS 167077]–See Section 4.1.1.1.

Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067]–See Section 4.1.4.1.

Wang et al. 1993 [DIRS 103839]–See Section 4.1.1.1.

Yu et al. 2001 [DIRS 159465]–See Section 4.1.3.1.

Additional information regarding the reliability of the data sources can be found in Sections 6.4.3 and 6.4.4.

4.1.7.2 Extent to Which the Data Demonstrate the Properties of Interest

The data included in the reports listed in Section 4.1.7.1 were used to define distributions of bioaccumulation factors for freshwater fish for the biosphere model. In most cases, all the relevant data from the references were used as a basis for the distributions of the parameter values. Such a method ensures that the property of interest is adequately represented.

4.1.7.3 Prior Uses of the Data

Some of the data sources listed in Section 4.1.7.1 were used in other performance assessments or other radiological assessments. For example, the GENII-S model (Leigh et al. 1993 [DIRS 100464]), which is based on the GENII model (Napier et al. 1988 [DIRS 100953] and Napier et al. 1988 [DIRS 157927]), was used in the performance assessment for the Waste Isolation Pilot Plant. The RESRAD model (Wang et al. 1993 [DIRS 103839] and Yu et al. 2001 [DIRS 159465]) has been used widely by the DOE, DOE contractors, the NRC, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [DIRS 159465], p. xi), including assessments to demonstrate compliance. NCRP reports are considered established fact sources, and the data within the cited NCRP report were undoubtedly used in some other radiological assessments.

4.1.7.4 Availability of Corroborating Data

The references used constitute a comprehensive set of reports describing the environmental transport of radionuclides. Neither of the references used to develop the distributions of bioaccumulation factors for freshwater fish was a sole source of input, but rather the distribution was developed based on all the applicable data from the references, as described in detail in Sections 6.4.3 and 6.4.4. This method ensured that all relevant data were included or at least considered.

The selected sources of data provide an appropriate technical basis for developing the distributions of the bioaccumulation factor for the biosphere model, and the combined data set can be considered qualified for intended use.

4.1.8 Water Concentration Modifying Factor

This section describes the parameters that were used to develop the distribution of the water concentration modifying factor values for the fishponds. The factors that were considered to evaluate the data regarding their suitability for the intended use are described below.

4.1.8.1 Dimensions of Catfish Ponds in Amargosa Valley

The data set Dimensions of Catfish Ponds in Amargosa Valley (DTN: MO0211SPADIMEN.005 [DIRS 160653]) contains results from regional investigations of fish farming practices in Amargosa Valley concerning the dimensions of ponds used for catfish production. These data are used in Section 6.4.3 to support the development of the water concentration modifying factor for the fishpond water. Data on fish farming in Amargosa Valley are qualified, were collected to support this analysis, and are appropriate for the intended use.

4.1.8.2 Annual Free Water Surface Evaporation

Average annual free water surface evaporation was used to determine the water loss from catfish ponds due to evaporation. Isopleth maps of average annual free water surface evaporation (shallow lake) are shown in the National Oceanic and Atmospheric Administration Technical Report NWS 33, *Evaporation Atlas for the Contiguous 48 United States* (Farnsworth et al. 1982 [DIRS 160564], Map 3). The National Oceanic and Atmospheric Administration is considered a source of established fact data. The annual average evaporation rate for a shallow lake is used in Sections 6.4.3 and 6.4.5 to develop values for the water concentration modifying factors for fishpond water for the present day and future climates. The data on shallow lake evaporation is an appropriate surrogate for estimating evaporation from fishponds and is appropriate for the intended use.

4.1.8.3 Time Required to Raise Catfish

4.1.8.3.1 Reliability of Data Source and Qualification of the Data Originator

The Mississippi State University Extension Service (2002 [DIRS 159489]) was the source of data on catfish farming and time required to raise a full-grown catfish. The Mississippi State University Extension Service provides research-based information, educational programs, and technology transfer. Agriculture and natural resources belong to the Extension's ongoing priorities. Mississippi State University is also the lead institution for the project, a part of the family of national cooperative projects supported by the U.S. Department of Agriculture Cooperative State Research, Education and Extension Service. A national catfish information database will be developed through nationwide cooperation among the colleges and universities in the land grant system, and will direct the best expertise in the nation toward the knowledge, educational and decision-support needs of the farm-raised catfish industry.

4.1.8.3.2 Extent to Which the Data Demonstrate the Properties of Interest

The data on catfish farming obtained from the Mississippi State University Extension Service represent the state-of-the-art knowledge on catfish farming and are appropriate for the intended use. It is not expected that the time needed to raise catfish would differ for the area of interest from the data obtained from this source.

4.1.8.3.3 Prior Uses of the Data

There are no known prior uses of these data.

4.1.8.3.4 Availability of Corroborating Data

The information on catfish farming is consistent with the results of the investigation conducted at the Amargosa Valley fish farm (Roe 2002 [DIRS 160674]) and with the overall production profile at the time of the regional food consumption survey (DOE 1997 [DIRS 100332]).

The data can be considered qualified for intended use.

4.1.9 Characteristics of Homes and Indoor Air Exchange

Parameter values pertaining to characteristics of residential homes and indoor air exchange were developed based on the references listed in Table 4-9, which presents the parameters and identifies specific sources of information used to develop the parameter values. The table also provides the sections within this report that contain the analyses and the sources of additional information on the parameter use in the analysis.

Table 4-9. Sources of Data Used for Developing Characteristics of Homes and Indoor Air Exchange

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Water use rate for evaporative coolers	Karpiscak et al. 1998 [DIRS 160563], pp. 122 to 130	6.5.2
2	Airflow rate for evaporative coolers	Karpiscak and Marion 1994 [DIRS 159501], p. 3 NAHB Research Center 1998 [DIRS 160428], p. 35 ToolBase Services 2002 [DIRS 159507] Watt and Brown 1997 [DIRS 159497], Chapters VII and VIII	6.5.2
5	Correlation between airflow and water use for evaporative coolers	Karpiscak and Marion 1994 [DIRS 159501], p. 3-4 Watt and Brown1997 [DIRS 159497], p. 103	6.5.2
3	Ceiling height of a home	24 CFR 3280.104 [DIRS 160555] NAHB Research Center 1998 [DIRS 160428], p. 38	6.6.2
4	Air exchange (ventilation) rate	24 CFR 3280.103(b) [DIRS 160555] HVI 2001 [DIRS 160557], p. 24 Murray and Burmaster 1995 [DIRS 160554], pp. 462 to 464	6.6.2

Sources of data on the characteristics of residential homes and indoor air exchange consist of reports that summarize related measurements and building industry recommendations. In this analysis, the parameter values are based on reviews of these sources. Information in these reports is considered appropriate for the intended use. The following sections describe factors that were considered to evaluate the data regarding their suitability for the intended use.

4.1.9.1 Water Use Rate for Evaporative Coolers

4.1.9.1.1 Reliability of Data Source and Qualification of the Data Originator

Karpiscak and Marion 1994 [DIRS 159501] and **Karpiscak et al. 1998** [DIRS 160563]–These references present the results of a study conducted by the University of Arizona, College of Agriculture, on water use by evaporative coolers in the city of Phoenix. The results were published by the University of Arizona (Karpiscak and Marion 1994 [DIRS 159501]) in a publication entitled *Evaporative Cooler Water Use* and as an article (Karpiscak et al. 1998 [DIRS 160563]) entitled "Evaporative Cooler Water Use" in Phoenix in the *Journal of American Water Works Association*. Founded in 1881, the American Water Works Association is an international nonprofit scientific and educational society dedicated to improving drinking water quality and supply, and it is the largest organization of water supply professionals in the world. This study is the only large-scale, long-term investigation of water use by residential evaporative coolers in the southwestern United States. The results of this study are considered applicable for developing parameters for the biosphere model.

4.1.9.1.2 Extent to Which the Data Demonstrate the Properties of Interest

The references used to develop the distribution for the evaporative cooler water use rate values for the biosphere model present the results of the actual large-scale study of the evaporative cooler performance in residential houses in the Southwest. These references provide a good representation of the range of parameter values for use in the biosphere model.

4.1.9.1.3 Prior Uses of the Data

There are no known prior uses of these data.

4.1.9.1.4 Availability of Corroborating Data

The references used provide an appropriate range of parameter values for developing the distribution of the water use rate for evaporative coolers. Neither of the references was a sole source of input, but rather the distribution was developed based on all the applicable data from the references, as described in detail in Sections 6.5.2. This method ensured that all relevant data were included or considered.

The selected sources of data provide an appropriate technical basis for developing the distributions of the water use rate for evaporative coolers for the biosphere model, and the data can be considered qualified for intended use.

4.1.9.2 Airflow Rate for Evaporative Coolers and Correlation between the Water Use Rate and Air Flow Rate

4.1.9.2.1 Reliability of Data Source and Qualification of the Data Originator

Karpiscak and Marion 1994 [DIRS 159501]–See Section 4.1.9.1.1.

NAHB Research Center 1998 [DIRS 160428] and **ToolBase Services 2002** [DIRS 159507]-*Factory and Site-Built Housing, a Comparison for the 21st Century*, and *Evaporative Coolers*, respectively, were published by the National Association of Home Builders (NAHB), a trade association representing more than 205,000 residential home-building and remodeling industry members. The NAHB Research Center is the research and development leader in the home building industry. Government agencies, manufacturers, builders, and remodelers rely on the expertise and objectivity of the Research Center. The Research Center is dedicated to advancing housing technology and enhancing housing affordability. ToolBase (ToolBase 2002 [DIRS 159507]) is a resource for the home-building industry. It is a service of the NAHB Research Center, funded by private industry and the U.S. Department of Housing and Urban Development through the Partnership for Advancing Technology in Housing program. These articles are considered appropriate sources for information on buildings and building technologies.

Watt and Brown 1997 [DIRS 159497]–*Evaporative Air Conditioning Handbook* is a guide on energy-efficient evaporative air conditioning technologies and their application. This book addresses technical aspects of evaporative cooling and a broad range of specific commercial and industrial applications. Topics include cost analysis, technology and equipment options, application guidelines, and operational and performance characteristics. Data from this book are used to determine operational characteristics of evaporative coolers and are considered appropriate for the intended use.

4.1.9.2.2 Extent to Which the Data Demonstrate the Properties of Interest

The references used to develop the distribution of the evaporative cooler airflow rate values and correlation between the water use and airflow rates for the biosphere model represent approaches from the theoretical perspective (Watt and Brown 1997 [DIRS 159497]) and from the application perspective based on the actual large-scale study of the evaporative cooler performance in residential houses (Karpiscak and Marion 1994 [DIRS 159501]) and from the industry perspective (ToolBase Services 2002 [DIRS 159507]). These references provide a good representation of the range of parameter values for use in the biosphere model.

4.1.9.2.3 Prior Uses of the Data

There are no known prior uses of these data.

4.1.9.2.4 Availability of Corroborating Data

The references used provide an appropriate range of parameter values for developing the distribution of the evaporative cooler airflow rate for the biosphere model. Neither of the references was a sole source of input, but rather the distribution was developed based on all the applicable data from the references, as described in detail in Section 6.5.2. This method ensured that all relevant data were included or considered.

The selected sources of data provide an appropriate technical basis for developing the parameters related to evaporative cooler operation for the biosphere model, and the data can be considered qualified for intended use.

4.1.9.3 Ceiling Height

The distribution of the ceiling height values for the biosphere model was developed from the data included in 24 CFR 3280 [DIRS 160555] and the industry data included in NAHB Research Center (1998 [DIRS 160428]). This input parameter is described in detail in Section 6.6.2.

The factors that were considered to evaluate the data from NAHB Research Center (1998 [DIRS 160428]) regarding their suitability for intended use are described below.

4.1.9.3.1 Reliability of Data Source and Qualification of the Data Originator

24 CFR 3280.104 [DIRS 160555]–Title 24 of the Code of Federal Regulations (CFR), Housing and Urban Development, contains rules promulgated by the Department of Housing and Urban Development. Code of Federal Regulations can be considered a source of established fact data. This reference was used to define the minimum ceiling height for the habitable part of a house.

NAHB Research Center 1998 [DIRS 160428]–See Section 4.1.9.2.1.

4.1.9.3.2 Extent to Which the Data Demonstrate the Properties of Interest

The data on the interior wall (ceiling) height obtained from NAHB Research Center (1998 [DIRS 160428]) are for manufactured homes. Since over 90 percent of the Amargosa Valley population lives in manufactured homes (Bureau of the Census 2002 [DIRS 159728], Table H33), the data for such homes appropriately represent local conditions.

4.1.9.3.3 Prior Uses of the Data

There are no known prior uses of these data.

4.1.9.3.4 Availability of Corroborating Data

The data considered for the development of the distribution of the ceiling height values encompass the range of possible, reasonable values for manufactured homes. It is unlikely that additional information would significantly alter this range.

The selected sources of data provide an appropriate technical basis for developing the distribution of the ceiling height for the biosphere model, and the data can be considered qualified for intended use.

4.1.9.4 Ventilation Rate

The distribution of the ventilation rate values was developed based on the data from 24 CFR 3280 as well as the industry standards and the results of the large-scale survey of the residential air exchange rates. This input parameter is described in detail in Section 6.6.2.

The factors considered in evaluation of suitability of the other data sources for intended use are described below.

4.1.9.4.1 Reliability of Data Source and Qualification of the Data Originator

24 CFR 3280.104 [DIRS 160555]–See Section 4.1.9.3.1. The minimum ventilation rate recommended for manufactured homes was taken from this source.

HVI 2001 [DIRS 160557]–“Home Ventilation & Indoor Air Quality” is a special supplement to *Contracting Business Magazine*, which is published by the Home Ventilating Institute, a trade organization representing manufacturers from the United States, Canada, Asia, and Europe who produce most of the residential ventilation products sold in North America. The Institute was established to serve consumers and members by advancing residential ventilation. The activities of the Institute include providing certification of product performance (accepted and recognized as the method of performance assurance by the U.S. Department of Housing and Urban Development and the DOE) and providing consumer information. The publication used in this analysis provides consumers with recommendations regarding home ventilation, and therefore it is considered appropriate for use in this analysis.

Murray and Burmaster 1995 [DIRS 160554]–“Residential Air Exchange Rates in the United States: Empirical and Estimated Parametric Distributions by Season and Climatic Region,” published in the journal *Risk Analysis*, contains results of statistical analysis to specify empirical distributions of air exchange rates for residential structures in the United States. Experimental data for 2,844 households were compiled by the Brookhaven National Laboratory and are considered to be the best available. *Risk Analysis* is an international journal of the Society for Risk Analysis. All scientific articles in *Risk Analysis* are peer-reviewed. This source is considered appropriate for the intended use.

4.1.9.4.2 Extent to Which the Data Demonstrate the Properties of Interest

The references used to develop the distribution of the ventilation rate values for the biosphere model represent approaches from the regulator's perspective (24 CFR 3280.103(b) [DIRS 160555]), from the functional perspective based on the actual large-scale study of the ventilation rates in residential houses (Murray and Burmaster 1995 [DIRS 160554]), and from the industry perspective (HVI 2001 [DIRS 160557]). These references provide a good representation of the range of parameter values for use in the biosphere model.

4.1.9.4.3 Prior Uses of the Data

There are no known prior uses of these data.

4.1.9.4.4 Availability of Corroborating Data

The data considered for the development of the distribution of the parameter values encompass the range of possible, reasonable values for residential homes. It is unlikely that additional information would significantly alter this range.

The selected sources of data provide an appropriate technical basis for developing the distribution of the home ventilation rate for the biosphere model, and the data can be considered qualified for intended use.

4.1.10 Parameters Related to Radon in Indoor and Outdoor Air

Parameter values pertaining to radon in indoor and outdoor air were developed based on the references listed in Table 4-10, which presents the parameters and identifies specific sources of data used to develop the parameter values. The table also provides the sections within this report that contain the analyses and the sources of additional information on the parameter use in the analysis. More detailed description of the data sources used to develop values of parameters related to radon level in indoor and outdoor air is presented in the following sections.

Table 4-10. Sources of Data Used for Developing Parameters Related to Radon in Indoor and Outdoor Air

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Radon release factor (concentration ratio of ^{222}Rn in air to ^{226}Ra in surface soil)	UNSCEAR 2000 [DIRS 158644], pp. 103 and 115 NCRP 1999 [DIRS 155894], pp. 87 to 88	Section 6.6.1
2	Ratio (conversion factor) of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil	UNSCEAR 2000 [DIRS 158644], p. 99 and 103 NCRP 1999 [DIRS 155894], pp. 87 to 88	Section 6.6.1
3	Fraction of ^{222}Rn flux from soil entering the house	United Nations 1988 [DIRS 159566], pp. 63 to 70 UNSCEAR 2000 [DIRS 158644], pp. 99 to 102 Landman 1982 [DIRS 160425], p. 71	Section 6.6.2
4	Equilibrium factor for ^{222}Rn decay products in indoor air	United Nations 1988 [DIRS 159566], pp. 75 and 105 UNSCEAR 2000 [DIRS 158644], p. 104	Section 6.6.3
5	Equilibrium factor for ^{222}Rn decay products in outdoor air	UNSCEAR 2000 [DIRS 158644], p. 103 NCRP 1988 [DIRS 153691], p. 24 Wasiolek and James 1998 [DIRS 163507], Table 2	Section 6.6.3

4.1.10.1 Radon Release Factor and Ratio of Radon Flux from Soil to Radon Concentration in Air

Conversion factors for radium concentration in the soil to radon concentration in the air, as well as radon flux density from the soil to radon concentration in the air, were based on data from reports published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the NCRP. The data from the UNSCEAR and NCRP reports are technically defensible and can be considered established fact data. UNSCEAR was established by the General Assembly of the United Nations in 1955. Its mandate in the United Nations system is to assess and report levels and effects of exposure to ionizing radiation. Governments and organizations throughout the world rely on the Committee's estimates as the scientific basis for evaluating radiation risk, establishing radiation protection and safety standards, and regulating radiation sources. The mission and the publications of the NCRP were described in Section 4.1.1.1.

The conversion factors for radon were developed based on the data from the UNSCEAR report *Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes* (UNSCEAR 2000 [DIRS 158644]) and the NCRP report *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies* (NCRP 1999 [DIRS 155894]). The data from UNSCEAR and NCRP are appropriate for the intended use and can be used to represent site-specific conditions. The reason is that conversion factors for radon can be developed because there is a strong correlation between radon flux from soil and radium concentration in the soil from which radon is released (Schery and Wasiolek 1998

[DIRS 160686], p. 210). This fundamental dependence is valid regardless of the site-specific conditions.

4.1.10.2 Fraction of Radon Flux from Soil Entering the House

The distribution of the fraction of radon exhaled from the soil that enters the house was developed based on data from the UNSCEAR reports and a journal article. UNSCEAR reports are considered sources of established fact data, as discussed in Section 4.1.10.1. The data from UNSCEAR reports are appropriate for the intended use. The justification for the appropriateness of the data from the journal article for intended use is presented below.

4.1.10.2.1 Reliability of Data Source and Qualification of the Data Originator

A journal article, "Diffusion of Radon Through Cracks in a Concrete Slab" (Landman 1982 [DIRS 160425]), was used for developing the fraction of radon flux density from soil beneath the house entering the indoor space. This article appeared in *Health Physics*, a peer-reviewed technical journal, which is an official publication of the Health Physics Society. The journal adheres to high standards for published articles, which are subject to review by experts in the field.

4.1.10.2.2 Extent to Which the Data Demonstrate the Properties of Interest

The references used to develop a distribution of the fraction of radon flux entering the indoor space provide a reasonable range of parameter values. The source data include evaluation of experimental results by UNSCEAR and predictions of expected values of the parameter under different circumstances regarding the condition of the concrete slab under the house. The references provide a good representation of the range of parameter values for use in the biosphere model, although it may lead to some degree of conservatism in the assessment, as further explained in Section 6.6.2.

4.1.10.2.3 Prior Uses of the Data

There are no known prior uses of these data.

4.1.10.2.4 Availability of Corroborating Data

The data considered for the development of the distribution of the fraction of radon flux entering the indoor space encompass the range of possible, reasonable values for residential homes. Additional arguments are presented in Section 6.6.2, pointing to the fact that the parameter value distribution is unlikely to underestimate the radon inhalation exposure due to the types of prevalent residential housing in Amargosa Valley.

The selected sources of data provide an appropriate technical basis for developing the value of fraction of radon flux from soil entering the house for the biosphere model, and the data can be considered qualified for intended use.

4.1.10.3 Equilibrium Factors for Radon Decay Products in Outdoor and Indoor Air

Distributions of equilibrium factor values for radon decay products in outdoor and indoor air were developed based on the data from the UNSCEAR and NCRP reports (UNSCEAR 2000 [DIRS 158644]; United Nations 1988 [DIRS 159566]; NCRP 1988 [DIRS 153691]). UNSCEAR and NCRP are considered sources of established fact data. Data from these reports concern the basic properties of radon behavior in the environment and are appropriate for the intended use.

In addition, a journal article, described below, was used in support of the outdoor equilibrium factor value.

4.1.10.3.1 Reliability of Data Source and Qualification of the Data Originator

A journal article, "Outdoor Radon Dose Conversion Coefficient in South-Western and South-Eastern United States" (Wasiolek and James 1998 [DIRS 163507]), was used to develop the value of equilibrium factor for radon decay products outdoors. This journal article presents the results of outdoor radon measurements from the southwestern region of the United States. The article was published in *Radiation Protection Dosimetry*, which is a peer-reviewed professional journal covering all aspects of personal and environmental dosimetry and monitoring and maintaining high scientific and technical standards.

4.1.10.3.2 Extent to Which the Data Demonstrate the Properties of Interest

The data on the radon equilibrium factor outdoors presented in the article represents experimental results of the parameter measurements in the Southwest region of the United States. These locations could be considered an analogue to Amargosa Valley, considering the type of environment. These data complement more generic data reported in the UNSCEAR, and NCRP publications and were used to develop a distribution of the parameter values.

4.1.10.3.3 Prior Uses of the Data

There are no known prior uses of these data.

4.1.10.3.4 Availability of Corroborating Data

The data considered for the development of the indoor and outdoor equilibrium factors for the radon decay products encompass the range of typical values and are based on the results of many experimental measurements. It is unlikely that additional information would significantly alter this range.

The selected sources of data provide an appropriate technical basis for developing the distributions of the radon equilibrium factor for the biosphere model, and the data can be considered qualified for intended use.

4.1.11 Parameters Pertaining to Carbon-14 Transport in the Environment

The data pertaining to ^{14}C transport in the environment were obtained from the references listed in Table 4-11. The data were used in Sections 6.7.1 through 6.7.4 to develop values for the carbon emission rate constant for soil, mixing height of gaseous ^{14}C, fraction of stable carbon in crops, fraction of stable carbon in animal products, fraction of stable carbon in soil, fraction of air-derived carbon in plants, fraction of soil-derived carbon in plants, concentration of stable carbon in air, concentration of stable carbon in water, and surface area of land irrigated with contaminated water. Table 4-11 lists the parameters, identifies specific sources of information used to develop the parameter values, and provides the sections within this report where the analyses are presented.

Table 4-11. Sources of Data Used for Development of Parameters Pertaining to Carbon Transport in the Environment

	Biosphere Model Input Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Carbon emission rate constant for soil	Davis et al. 1993 [DIRS 103767], p. 156 Sheppard et al. 1991 [DIRS 159545], pp. 491 Yu et al. 2001 [DIRS 159465], p. L-16	6.7.1
2	Mixing height of gaseous ^{14}C	Yu et al. 2001 [DIRS 159465], p. L-16	6.7.2
3	Surface area of land irrigated with contaminated water	10 CFR 63.312(c) [DIRS 156605]	6.7.2
4	Fraction of stable carbon in soil	Napier et al. 1988 [DIRS 157927], p. 4.88 Yu et al. 2001 [DIRS 159465], p. L-17	6.7.3
5	Concentration of stable carbon in air	IAEA 2001 [DIRS 158519], p. 144 Napier et al. 1988 [DIRS 157927], p. 4.88 Yu et al. 2001 [DIRS 159465], p. L-17	6.7.3
6	Fraction of stable carbon in crops	Napier et al. 1988 [DIRS 157927], p. 4.88 Yu et al. 2001 [DIRS 159465], p. L-20	6.7.3
7	Fraction of air-derived carbon in plants	Sheppard et al. 1991 [DIRS 159545], pp. 490 to 491 Yu et al. 2001 [DIRS 159465], p. L-20	6.7.3
8	Fraction of soil-derived carbon in plants	Sheppard et al. 1991 [DIRS 159545], pp. 490 to 491 Yu et al. 2001 [DIRS 159465], p. L-20	6.7.3
9	Fraction of stable carbon in animal products	Napier et al. 1988 [DIRS 157927], p. 4.88 Yu et al. 2001 [DIRS 159465], p. L-22	6.7.4
10	Concentration of stable carbon in water	Davis et al. 1993 [DIRS 103767], p. 262 Napier et al. 1988 [DIRS 157927], p. 4.88 Yu et al. 2001 [DIRS 159465], p. L-21	6.7.4

The sources of data on transport of carbon in the environment consist of the journal article, the reports containing descriptions of the environmental transport models and their associated input parameters, and the comprehensive dose assessment reports that include selection of input parameter values. In this analysis, parameter values are based on reviews of these sources. These references were published by professional organizations, producing technically defensible products pertinent to this analysis, as indicated in the following discussion. The information from these reports is considered appropriate for the intended use.

4.1.11.1 Reliability of Data Source and Qualification of the Data Originator

Most of the data concerning the levels and fractions of stable carbon in the environmental media were taken from the same few reports (Napier et al. 1988 [DIRS 157927]; Yu et al. 2001 [DIRS 159465]; Davis et al. 1993 [DIRS 103767]). All of these reports use special models for carbon transport in the environment, generally based on the ratios of ^{14}C and stable carbon in environmental media, proportions of carbon uptake from these media by plants and animals, and carbon content of the media. A similar approach to ^{14}C transport modeling is also used in the biosphere model, so the parameter values presented in the relevant references are appropriate.

The description of these reports and the appropriateness of the data for the intended use was presented in Sections 4.1.1.1 for *The Disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment* (Davis et al. 1993 [DIRS 103767]) and *Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment* (IAEA 2001 [DIRS 158519]) and in Section 4.1.3.1 for *Conceptual Representation.* Volume 1 of *GENII -The Hanford Environmental Radiation Dosimetry Software System* (Napier et al. 1988 [DIRS 157927]) and *User's Manual for RESRAD Version 6* (Yu et al. 2001 [DIRS 159465]).The additional data on carbon emission from soils and fraction of carbon in plant derived from air and soil were obtained from Sheppard et al. (1991 [DIRS 159545]).

Sheppard et al. 1991 [DIRS 159545]–"Mobility and Plant Uptake of Inorganic ^{14}C and ^{14}C-Labelled PCB in Soils of High and Low Retention" is a journal article that appeared in *Health Physics*, a peer-reviewed periodical of the Health Physics Society. The article describes an experiment in which the plant uptake of carbon from soil was studied with different soils and different chemical forms of carbon. The methods are sufficiently described to determine the applicability of the measurements to biosphere modeling. The data from this article are considered appropriate for intended use.

In addition, the rule in 10 CFR Part 63 ([DIRS 156605]), *Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada*, was used to define the value of the annual water demand, which was used in Section 6.7.2 to develop the value of area of irrigated land for calculation of ^{14}C concentration in the air.

4.1.11.2 Extent to Which the Data Demonstrate the Properties of Interest

The model of carbon transport in the environment used in the biosphere model is based on the basic principles regarding carbon concentration in the environmental media. Therefore, the data that were used in other models using a similar approach are appropriate for use in the biosphere model.

4.1.11.3 Prior Uses of the Data

The GENII-S model (Leigh et al. 1993 [DIRS 100464]), which is based on the GENII model (Napier et al. 1988 [DIRS 100953]; Napier et al. 1988 [DIRS 157927]), was used in the performance assessment for the Waste Isolation Pilot Plant. The RESRAD model (Wang et al. 1993 [DIRS 103839]; Yu et al. 2001 [DIRS 159465]) has been used widely by the DOE, DOE contractors, the NRC, the U.S. Environmental Protection Agency, the U.S. Army Corps of

Engineers, industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [DIRS 159465], p. xi), including assessments to demonstrate compliance.

4.1.11.4 Availability of Corroborating Data

The references used provide an appropriate technical basis for selection of parameter values related to ^{14}C transport in the environment for the biosphere model. Generally, more than one reference was used to develop a parameter value. In many cases, a distribution was developed based on all the applicable data from the references, as described in detail in Sections 6.7.1 to 6.7.4. This method ensured that all relevant data were included or considered.

The selected sources of data provide an appropriate technical basis for developing the values of parameters describing carbon transport in the environment for the biosphere model, and the data can be considered qualified for intended use.

4.2 CRITERIA

Applicable requirements from the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 2-3) are presented in Table 4-12. These requirements are for compliance with applicable portions of 10 CFR Part 63.

Table 4-12. 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 4-12, 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 the acceptance criteria from the Biosphere Characteristics section of the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.3.14), based on meeting the requirements of 10 CFR 63.114, 10 CFR 63.305, and 10 CFR 63.312 [DIRS 156605] that relate in whole or in part to this analysis.

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 assumption in other total system performance assessment abstractions.

Acceptance Criterion 2: Data are Sufficient for Model Justification

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

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

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

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

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

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

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulations, other than those identified in the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 2-3) and determined to be applicable (Table 4-12), were used in this analysis.

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5. ASSUMPTIONS

Four assumptions are used in the analysis. There are no upstream assumptions in the references cited in this section.

5.1 DISTRIBUTION OF TRANSLOCATION FACTORS

Assumption 1–The translocation factor for other vegetables (see Section 6.2.1.1.2), fruit, grain, and stored feed for laying hens and other poultry is represented by a piece-wise linear cumulative probability distribution represented by the pairs (0.05, 0 percent), (0.1, 50 percent), and (0.3, 100 percent).

Rationale–The translocation factor quantifies the fraction of contaminant that is translocated from the site of deposition to the edible part of a plant. The literature review indicated that the translocation factor for crops (other than leafy vegetables and fresh forage) is a parameter with the fixed value of 0.1 (Table 6-36). It was anticipated that this parameter might be important for the biosphere model because of the importance of foliar deposition of contaminants in arid environments. Therefore, it was prudent to develop the capability of testing the sensitivity of the model outcome to this parameter and to represent this parameter by the probability distribution function. Although the literature review did not provide an indication of the possible distribution function, a piece-wise linear cumulative probability distribution, represented by (0.05, 0 percent), (0.1, 50 percent), and (0.3, 100 percent), is reasonable, considering the value used in the reviewed reports (Table 6-36).

Confirmation Status–This assumption does not need further confirmation because it is based on the realistic representation of the process.

Use in the Analysis–This assumption is used in Section 6.2.2.2.

5.2 REMOVAL OF RADIONUCLIDES FROM FISHPONDS

Assumption 2–The entire amount of radioactivity added to fishponds during a fish raising cycle remains within the system, but it is not transferred to the next fish raising cycle.

Rationale–Losses of activity during the fish-raising cycle could arise if water were lost from the system. Because of the history of fish farming in Amargosa Valley, radionuclide transfer to fish, and the resulting exposure pathway, are included in the biosphere model. An interview conducted at the fish farm revealed that there were no known mechanisms of water (and thus activity) loss from the fishponds other than evaporation (Roe 2002 [DIRS 160674]). Because activity could be transferred between the fish-raising cycles, potential activity gains could arise. Because the ponds are drained after harvest (Roe 2002 [DIRS 160674]), it is assumed that there is no activity transfer from the previous fish-raising cycle to the next. Activity losses from the system were not taken into account to maintain conservatism in the analysis. This assumption does not apply to the concentration of carbon in fishpond water, which is considered separately (Section 6.4.4).

Confirmation Status–This assumption does not require further confirmation because it is consistent with observed fish farming practices.

Use in the Analysis–This assumption is used in Section 6.4.3.

5.3 DISTRIBUTION OF CARBON-14 BIOACCUMULATION FACTOR

Assumption 3–The uncertainty distribution for the bioaccumulation factor for carbon is lognormal with a confidence interval that spans one order of magnitude on each side of the mean at the 95-percent confidence level.

Rationale–For the biosphere model, the mean value of the bioaccumulation factor for carbon is equal to the lowest value reported in the reviewed publications (Section 6.4.4), but an assumption is made that the uncertainty distribution is lognormal with a 95-percent confidence interval spanning one order of magnitude on each side of the mean. This assumed distribution is consistent with the range of uncertainty in reported values of the bioaccumulation factor for carbon (Table 6-64) and will cover the range of possible values when water is the only contaminated medium, without underestimating the concentration of ^{14}C in fish, as discussed in Section 6.4.4.

Confirmation Status–This assumption does not require further confirmation because it is unlikely to underestimate ^{14}C transfer to fish and because the approach is consistent with that used to develop bioaccumulation factor distributions for the other elements.

Use in the Analysis–This assumption is used in Section 6.4.4.

5.4 EVAPORATIVE COOLER CONTAMINANT TRANSFER

Assumption 4–A fraction of the contaminants will be transferred from the evaporative cooler inlet water to the outlet air, and the probability distribution function for the fraction of contaminant carried-over is uniform, with a range of 0 to 1.

Rationale–For evaporative coolers, the outlet air can become contaminated by water carry-over or by the air pulling small particles of previously deposited minerals off the pads. Although no information was found in the literature for this parameter, the fraction must range from 0 to 1. The dissolved solids brought into the evaporative cooler do not evaporate. Eventually, the water becomes saturated with minerals, and the minerals precipitate out (Otterbein 1996 [DIRS 159495]). In an evaporative cooler that operates correctly, most of the minerals in the water do not contaminate the indoor air. However, there is a possibility of some contaminant carry-over, especially if the pads fail to function efficiently. The uniform distribution of the possible parameter values allows evaluation of the biosphere model sensitivity to this parameter to determine whether any additional work is warranted to develop a more realistic distribution of the parameter values.

Confirmation Status–This assumption does not require further confirmation because it is unlikely to result in underestimation of the receptor’s exposure.

Use in the Analysis–This assumption is used in Section 6.5.2.

6. ANALYSIS

The function of the ERMYN biosphere model that is relevant to this analysis is to represent, conceptually and mathematically, radionuclide transport and accumulation in the environment. The mathematical representation of environmental transport involves many parameters. The values for some of these parameters are developed in this analysis. After presenting general considerations applicable to parameter value selection for the biosphere model (Section 6.1), the subsequent sections address development of parameter values related to specific environmental transport pathways. Section 6.2 contains information on how parameters related to radionuclide transport to crops were developed. Section 6.3 is focused on parameters used in submodels of radionuclide transport to animal products. Parameters related to radionuclide transport to aquatic food, evaporative coolers, ^{222}Rn, and ^{14}C are addressed in Sections 6.4, 6.5, 6.6, and 6.7, respectively. Equations representing the environmental transport processes were taken from the *Biosphere Model Report* (BSC 2004 [DIRS 169460]).

6.1 GENERAL CONSIDERATIONS

This section presents a discussion of the methods used in parameter value development, sources of information, application of generic information to the site-specific conditions, and elements of interest for this analysis.

Environmental transport parameters support mathematical representations of the environmental transport pathways that describe radionuclide migration from the source of contamination to the environmental media (e.g., crops for human and animal consumption, animal products, ambient air, and soil). Environmental transport pathways form the basis of the model representation of radionuclide transport through terrestrial and aquatic food chains, as well as radionuclide transport in the soil and atmosphere.

Modeling the environmental transport of radionuclides results in estimates of radionuclide concentrations in environmental media. These media concentrations, when coupled with the attributes of human behavior, allow calculations of internal and external radiation exposure levels associated with individual human exposure pathways and the resulting doses.

The mathematical treatment of radionuclide migration through the environment in the biosphere model is based on the rate of a process or on the equilibrium between participating environmental media, depending on the process. Because the biosphere model uses both of these approaches, some environmental transport parameters represent the rate of change in the amount of a radionuclide in a specific medium (e.g., weathering rate and emission rate constant) while others represent equilibrium concentration ratios of radionuclides in the environmental media (e.g., TFs and bioaccumulation factors).

The following 13 environmental transport processes are included in the ERMYN biosphere model (BSC 2004 [DIRS 169460], Section 6.3):

- Radionuclide accumulation in soil as a result of contaminated ashfall or long-term irrigation with contaminated water
- Resuspension of contaminated soil

- Radionuclide deposition on crop surfaces by dry processes (resuspension of contaminated soil and subsequent adhesion of soil particles onto vegetation surfaces)
- Radionuclide deposition on crop surfaces by wet processes resulting from the use of contaminated irrigation water
- Initial interception and retention of deposited activity by vegetation surfaces
- Translocation of contaminants from the deposition site to the edible tissues of vegetation
- Postdeposition retention by vegetation (consideration of weathering processes)
- Root uptake of radionuclides by plants
- Release of gaseous radionuclides from the soil
- Absorption of $^{14}CO_2$ by crops from the atmosphere
- Transfer of radionuclides from soil, vegetation, and water to the milk and meat of grazing animals
- Radionuclide transfer from water to air via evaporative coolers
- Radionuclide transfer from water to fish (aquatic food).

6.1.1 Sources of Information

Parameter values for the biosphere model primarily were developed through a literature review, but site-specific information was used when available. Literature reviews are commonly used in scientific investigations and technical analyses and are considered appropriate for the intended use. This analysis focused on review articles and comprehensive dose assessment reports that included selection of input parameter values rather than on publications reporting individual experimental results. Documents reporting specific experimental results were used if they provided additional information.

These review articles and other publications evaluated and used a broad range of published information to provide recommendations on the parameter values. In many cases, authors of two or more reviews used the same or overlapping information sources to develop a representative value for a given parameter, but they obtained somewhat different results. This indicates that there is inherent uncertainty associated with the experimental data and their interpretation. In this analysis, the use of results from multiple reviews incorporated this uncertainty into the developed distributions. The uncertainty distributions of parameter values developed using data from outside the Yucca Mountain region represent the ranges of values expected to occur in the environment and thus encompass or bound the site-specific values.

6.1.2 Parameter Value Development Methods

The values of parameters for the biosphere model were based on multiple sources of data, so it was important to apply a consistent method to develop parameter values. The arithmetic mean is justified if data come from a consistent set of observations. To estimate the expected value of a parameter, the geometric mean (GM) is recommended in the literature as a way to properly average data over space and time (BIOMASS 2001 [DIRS 159468], T1/WD04, p. 12; IAEA 1994 [DIRS 100458], p. 3). For this approach to be valid, the data sources should be qualitatively similar (e.g., a compilation of experimental data only or a set of values obtained from literature reviews). If this condition is not met (e.g., if data averages from one source were mixed with individual data points from another), the averaging would be difficult to control and justify.

The GM is considered the best representation of parameters for which reported values span more than an order of magnitude. This was the case with the soil-to-plant TFs (Section 6.2.1.2) and animal intake–to–animal product TCs (Section 6.3.3), where the range of values often spanned several orders of magnitude (Baes et al. 1984 [DIRS 103766], p. 7).

Technical judgment was often necessary in cases where data were sparse or were obtained from experiments that were incompatible with the reference biosphere. When judgments were used to determine expected values, the minimum and maximum values were considered to establish a confidence interval representing uncertainty due to incomplete knowledge about the actual range of data (IAEA 1994 [DIRS 100458], p. 3-4). Specific methods for developing parameter values are addressed in greater detail in the appropriate sections of this report.

6.1.3 Site Specificity

Environmental transport parameters used in the biosphere model may be influenced to some degree by local conditions such as the climate and soil types, and parameter values would ideally be obtained through site-specific studies. However, the values of many parameters would not expect to be unique for the Yucca Mountain region, but rather they are representative of a process or an event that is governed by the same environmental transport principles, regardless of the location.

The development of parameter values for the biosphere model relied to a large degree on published information, especially when site-specific data were lacking. However, the distributions developed from these data are consistent with conditions in the Yucca Mountain region. This is because in many cases it was not expected that the parameter values would depend on a specific environment, and it was reasonable to assume that the literature values that are not necessarily site-specific would be appropriate for use in the biosphere model. It usually was possible to evaluate the basis for applying the literature-derived parameter value to Yucca Mountain conditions. Also, the FEPs describing the reference biosphere that are supported by parameters addressed in this analysis were consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain site.

The pathway analysis indicated that some environmental transport and receptor exposure pathways contribute a small percentage to the BDCFs (BSC 2004 [DIRS 169674], Tables 6.2-10 and 6.2-11; BSC 2004 [DIRS 167287], Table 6.2-7). Parameters that support such pathways can be adequately represented by generic values, as long as it can be demonstrated that such values do not underestimate the risk to the receptor.

6.1.4 Radionuclides and Elements Included in Analysis

The following 28 radionuclides were included in the biosphere model: 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 6.3.5). This list includes radionuclides that are of importance during the compliance period of 10,000 years (10 CFR 63.305(c) [DIRS 156605]) for the groundwater and volcanic ash release of radionuclides to the environment as well as those that should be considered for the period out to 1,000,000 years (BSC 2004 [DIRS 169460], Section 6.1.3). The TSPA-LA will be conducted for the postclosure period of 20,000 years (BSC 2003 [DIRS 166296], Section 1.3). Some of the radionuclides of interest for the TSPA-LA are accompanied by decay products, which are not individually tracked in the TSPA-LA model. Because the biosphere model must account for potential exposures to these radionuclides, decay products of radionuclides of interest to TSPA-LA were included in the biosphere model. Short-lived decay products (those with half-lives of less than 180 days) were assumed to be in secular equilibrium with the parent radionuclides, and the contribution of short-lived decay products to BDCFs was added to that of a parent radionuclide. Two decay product radionuclides, ^{228}Ra and ^{228}Th, have half-lives longer than 180 days and were considered separately in the biosphere model, at par with primary radionuclides, as explained in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Section 6.3.5). The resulting set of radionuclides considered in the biosphere model (Table 6-1) consists of the 30 primary radionuclides; also listed are the decay products of primary radionuclides with half-lives less than 180 days. (^{235}U has been added to the table to complete the decay chain, although ^{235}U is not considered a primary radionuclide.) The set of primary radionuclides includes 17 elements. Table 6-1 includes the half-lives of radionuclides under consideration.

Table 6-1. Primary Radionuclides and Their Decay Products Included in the Biosphere Model

Primary Radionuclide	Short-lived Decay Product	Branching Fraction, % [a]	Half-life [a]
Carbon-14 (^{14}C)		100	5.730E+3 yr
Chlorine-36 (^{36}Cl)		100	3.01E+05 yr
Selenium-79 (^{79}Se)		100	6.50E+04 yr
Strontium-90 (^{90}Sr)		100	2.912E+01 yr
	Yttrium-90 (^{90}Y)	100	6.40E+01 hr
Technetium-99 (^{99}Tc)		100	2.13E+05 yr
Tin-126 (^{126}Sn)		100	1.0E+05 yr
	Antimony-126m (^{126m}Sb)	100	1.90E+01 min

Table 6-1. Primary Radionuclides and Their Decay Products Included in the Biosphere Model (Continued)

Primary Radionuclide	Short-lived Decay Product	Branching Fraction, %[a]	Half-life[a]
	Antimony-126 (^{126}Sb)	14	1.24E+01 d
Iodine-129 (^{129}I)		100	1.57E+07 yr
Cesium-135 (^{135}Cs)		100	2.3E+06 yr
Cesium-137 (^{137}Cs)		100	3.00E+01 yr
	Barium-137m (^{137m}Ba)	94.60	2.552E+00 min
Thorium Series (4n)			
Plutonium-240 (^{240}Pu)		100	6.537E+03 yr
Uranium-236 (^{236}U)		100	2.3415E+07 yr
Thorium-232 (^{232}Th)		100	1.405E+10 yr
Radium-228 (^{228}Ra)		100	5.75E+00 yr
	Actinium-228 (^{228}Ac)	100	6.13E+00 hr
Uranium-232 (^{232}U)		100	7.2E+00 yr
Thorium-228 (^{228}Th)		100	1.913E+001 yr
	Radium-224 (^{224}Ra)	100	3.66E+00 d
	Radon-220 (^{220}Rn)	100	5.56E+01 s
	Polonium-216 (^{216}Po)	100	1.5 E-01 s
	Lead-212 (^{212}Pb)	100	1.064E+01 hr
	Bismuth-212 (^{212}Bi)	100	6.055 E+01 min
	Polonium-212 (^{212}Po)	64.07	3.05 E-07 s
	Thallium-208 (^{208}Tl)	35.93	3.07E+00 min
Neptunium Series (4n+1)			
Americium-241 (^{241}Am)		100	4.322E+02 yr
Neptunium-237 (^{237}Np)		100	2.14E+06 yr
	Protactinium-233 (^{233}Pa)	100	2.70 E+01 d
Uranium-233 (^{233}U)		100	1.585E+05 yr
Thorium-229 (^{229}Th)		100	7.340E+03 yr
	Radium-225 (^{225}Ra)	100	1.48E+01 d
	Actinium-225 (^{225}Ac)	100	1.00E+01 d
	Francium-221 (^{221}Fr)	100	4.8E+00 min
	Astatine-217 (^{217}At)	100	3.23E-02 s
	Bismuth-213 (^{213}Bi)	100	4.565E+01 min
	Polonium-213 (^{213}Po)	97.84	4.2E-06 s
	Thallium-209 (^{209}Tl)	2.16	2.20 E+00 min
	Lead-209 (^{209}Pb)	–	3.253E+00 hr
Uranium Series (4n+2)			
Plutonium-242 (^{242}Pu)		100	3.763E+05 yr
Uranium-238 (^{238}U)		100	4.468E+09 yr
	Thorium-234 (^{234}Th)	100	2.410E+01 d
	Protactinium-234m (^{234m}Pa)	99.80	1.17E+00 min
	Protactinium-234 (^{234}Pa)	0.33	6.70E+00 hr
Plutonium-238 (^{238}Pu)		100	8.774E+01 yr

Table 6-1. Primary Radionuclides and Their Decay Products Included in the Biosphere Model (Continued)

Primary Radionuclide	Short-lived Decay Product	Branching Fraction, %[a]	Half-life[a]
Uranium-234 (^{234}U)		100	2.445E+05 yr
Thorium-230 (^{230}Th)		100	7.7E+04 yr
Radium-226 (^{226}Ra)		100	1.600E+03 yr
	Radon-222 (^{222}Rn)	100	3.8235E+00 d
	Polonium-218 (^{218}Po)	100	3.05E+00 min
	Lead-214 (^{214}Pb)	99.98	2.68 E+01 min
	Astatine-218 (^{218}At)	0.02	2.E+00 s
	Bismuth-214 (^{214}Bi)	100	1.99E+01 min
	Polonium-214 (^{214}Po)	99.98	1.643E-04 s
	Thallium-210 (^{210}Tl)	0.02	1.3E+00 min[b]
Lead-210 (^{210}Pb)		100	2.23 E+01 yr
	Bismuth-210 (^{210}Bi)	100	5.012E+00 d
	Polonium-210 (^{210}Po)	100	1.3838 E+02 d
Actinium Series (4n + 3)			
Americium-243 (^{243}Am)		100	7.380E+03 yr
	Neptunium-239 (^{239}Np)	100	2.355E+00 d
Plutonium-239 (^{239}Pu)		100	2.4065E+04 yr
Uranium-235 (^{235}U)		100	7.038E+08 yr
	Thorium-231 (^{231}Th)	100	2.552E+01 hr
Protactinium-231 (^{231}Pa)		100	3.276E+04 yr
Actinium-227 (^{227}Ac)		100	2.1773E+01 yr
	Thorium-227 (^{227}Th)	98.62	1.8718E+01 d
	Francium-223 (^{223}Fr)	1.38	2.18E+01 min
	Radium-223 (^{223}Ra)	100	1.1434E+01 d
	Radon-219 (^{219}Rn)	100	3.96 E+00 s
	Polonium-215 (^{215}Po)	100	1.78 E-03 s
	Lead-211 (^{211}Pb)	100	3.61 E+01 min
	Bismuth-211 (^{211}Bi)	100	2.14 E+00 min
	Thallium-207 (^{207}Tl)	99.72	4.77 E+00 min
	Polonium-211 (^{211}Po)	0.28	5.16E-01 s

[a] Eckerman and Ryman (1993 [DIRS 107684], Table A.1).
[b] Lide and Frederikse (1997 [DIRS 103178], p. 11-125).

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

Environmental transport parameters can be element-specific, radionuclide-specific, or independent of the contaminant species. Examples of parameters that do not depend on chemical species include animal consumption rates of feed, water, and soil; dry deposition velocity; and parameters related to evaporative coolers. Element-specific parameters in this analysis are:

- Soil-to-plant TFs
- Animal intake-to-animal product TCs
- Bioaccumulation factors for aquatic food

- Modifying factors for radionuclide concentration in fishpond water
- Parameters related to radon transport in the environment
- Parameters related to carbon transport in the environment.

The results of the TSPA for the Supplemental Science and Performance Analysis indicated that ^{14}C, ^{99}Tc, ^{129}I, and ^{237}Np were the most important dose contributors for nominal performance (CRWMS M&O 2000 [DIRS 153246], Figure 4.1-6), and that ^{241}Am, ^{239}Pu, and ^{240}Pu were the most important dose contributors for the igneous disruption scenario (CRWMS M&O 2000 [DIRS 153246], Figures 4.2-3 and 4.2-4). The ^{14}C dose for the nominal performance scenario resulted primarily from the aquatic food pathway (BSC 2003 [DIRS 169674], Tables 6.2-10 and 6.2-11). These radionuclides were the main concern for developing element-dependent parameters such as TFs and TCs. The analysis also included a more detailed treatment of carbon accumulation in aquatic food.

6.1.5 Consideration of Exposure Scenarios and Climate Change

Biosphere modeling is performed for the release of radionuclides to the biosphere under two exposure scenarios: groundwater and volcanic ash. For the groundwater exposure scenario, radionuclides enter the biosphere from a well that extracts contaminated groundwater from an aquifer. Human exposure arises from using the contaminated water for domestic and agricultural purposes. The groundwater scenario applies 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 may result in the release of radionuclides to groundwater (BSC 2003 [DIRS 166296], pp. 51 to 52).

For the volcanic ash scenario, the mode of radionuclide release into the biosphere is a volcanic eruption through the repository with the resulting entrainment of contaminated waste in the tephra and the subsequent atmospheric transport and dispersion of contaminated material in the biosphere. This scenario applies to the volcanic eruption modeling case of the igneous scenario class (BSC 2003 [DIRS 166296], pp. 51 to 52), which is one of the TSPA-LA disruptive scenario classes.

The biosphere model for the volcanic ash release scenario is, in many aspects, similar to that for the groundwater scenario. Most exposure pathways are the same for both scenarios, except for the pathways, where water is the direct source of contamination. This analysis provides recommendations for environmental transport parameter values for the biosphere model, supporting both release scenarios.

The model realizations for both scenarios, done using the GoldSim software program, involve consideration of climate change. In the TSPA-LA, the climate will be assumed to shift in a series of step changes between three climate states in the first 10,000 years: present day (present-day) interglacial climate, monsoon climate (with about twice the precipitation of the present-day climate), and glacial transition (intermediate glacial) climate (colder than monsoon but similar in amount of precipitation) (BSC 2003 [DIRS 166296], p. 79). Within the GoldSim program, these shifts require coordination among the coupled submodels because they must all simultaneously change to the appropriate climate state. The climates and their predicted occurrence at Yucca Mountain are described in the *Future Climate Analysis* (2004 [DIRS 170002]).

The values of some environmental transport parameters are different for the present-day and future climates. The present-day conditions, referred to as the present day climate, are characteristic of the interglacial climate (BSC 2004 [DIRS 170002], Section 6.2). The future climate states are represented in this analysis by the upper bound of the glacial transition climate. The glacial transition climate is predicted to persist for the majority of the 10,000-year compliance period (BSC 2004 [DIRS 170002], Table 6-1). The glacial transition climate, referred to as the future climate, is predicted to have cooler, wetter winters and to have warm-to-cool, dry summers relative to current conditions (BSC 2004 [DIRS 170002], Section 6.6.2). Recommended analogue weather stations for the upper bound of this climate are Spokane, St. John, and Rosalia, Washington (BSC 2004 [DIRS 170002], Table 6-1). Data from these weather stations and agricultural practices in east central Washington were used in biosphere modeling to characterize conditions for the future climate.

6.2 RADIONUCLIDE TRANSPORT TO CROPS

Radionuclide uptake by crops can occur by several processes. The biosphere model considers directly deposited contamination intercepted by and retained on crops as well as contamination taken up by crops through the root system. Direct deposition results from irrigation with contaminated water and from deposition of resuspended contaminated soil or ash. The total activity concentration in the crops is the sum of the contributions from these processes (BSC 2004 [DIRS 169460], Equation 6.4.3-1):

$$Cp_{i,j} = Cp_{root,\ i,j} + Cp_{water,i,j} + Cp_{dust,i,j} \qquad \text{(Eq. 6-1)}$$

where

$Cp_{i,j}$ = activity concentration of radionuclide *i* in crop type *j* (Bq/kg $_{wet}$)

j = crop type index; j = 1 for leafy vegetables, 2 for other vegetables, 3 for fruit, 4 for grain (used for humans and poultry), and 5 for fresh forage feed (used for beef cattle and dairy cows)

$Cp_{root,\ i,\ j}$ = activity concentration of radionuclide *i* in crop type *j* contributed from plant root uptake (Bq/kg $_{wet}$)

$Cp_{water,\ i\ ,j}$ = activity concentration of radionuclide *i* in crop type *j* contributed from direct deposition on crop leaves due to interception of contaminated irrigation water (Bq/kg $_{wet}$)

$Cp_{dust,\ i,\ j}$ = activity concentration of radionuclide *i* in crop type *j* contributed from direct deposition on crop leaves due to interception of resuspended particles from contaminated soil (Bq/kg $_{wet}$).

The fraction of activity concentration in a crop, attributable to any of these processes, is element- and plant-dependent. For soluble species, which remain relatively available in the soil solution, root absorption processes are usually more effective than foliar deposition processes (Cataldo and Vaughan 1976 [DIRS 160551], p. 341). In contrast, root uptake of actinides, such as plutonium and americium, tends to be less important than the contamination of external plant surfaces in terms of food chain transfers (Romney et al. 1977 [DIRS 160558], p. 54). The type of environment is also important. The results of studies at the Nevada Test Site (NTS) demonstrate that radionuclide contamination of vegetation in an arid and dusty environment occurs primarily by resuspension rather than by root uptake (Gilbert et al. 1988 [DIRS 160552], p. 876).

The mobility, solubility, and accumulation of radionuclides in the environment are governed to a large degree by their chemical forms (BIOMASS 2001 [DIRS 159468], T3FM/WD01, p. 30). Information on the chemical form of radionuclides in the biosphere resulting from repository releases is not available, and speciation considerations were not included in the parameter selection for the biosphere model. For parameters such as TFs and TCs, for which the value may depend on the chemical form of a radionuclide, the developed probability distribution functions account for the related uncertainty.

This section describes the development of values for parameters involved in modeling radionuclide transport to crops for human and animal consumption. These parameters include element-specific and plant-type–specific soil-to-plant TFs (Section 6.2.1), deposition velocity (Section 6.2.2.1), translocation factor (Section 6.2.2.2), and weathering rate (Section 6.2.2.3). The effects of climate change and postvolcanic conditions on parameter values are also discussed.

6.2.1 Radionuclide Transfer to Crops by Root Uptake

One of the environmental transport processes leading to contamination of crops is radionuclide uptake through the roots. Only radionuclides dissolved in water can be transferred to crops via this pathway. This section discusses root uptake of contaminants and documents the development of soil-to-plant TFs.

6.2.1.1 Background Information

Background information on modeling radionuclide transfer to crops via roots is summarized below.

6.2.1.1.1 Root Uptake Model and Related Parameters

Activity concentration in crops resulting from radionuclide uptake through roots is estimated in the biosphere model (BSC 2004 [DIRS 169460], Equation 6.4.3-2) as

$$Cp_{root,i,j} = Cs_{m,i}\ F_{s\rightarrow p\ i,j}\ DW_j \qquad \text{(Eq. 6-2)}$$

where

$Cp_{root,i,j}$ = activity concentration of radionuclide i in crop type j contributed from root uptake (Bq/kg wet weight of edible portions of the plant)

$Cs_{m,i}$ = activity concentration of radionuclide i in surface soil (Bq/kg $_{\text{dry soil}}$)

$F_{s\rightarrow p\ i,j}$ = soil-to-plant TF for radionuclide i and crop type j (Bq/kg $_{\text{dry plant}}$ per Bq/kg $_{\text{dry soil}}$)

DW_j = dry-to-wet weight ratio for edible part of crop type j (kg $_{\text{dry plant}}$ per kg $_{\text{wet plant}}$).

This analysis develops the values of radionuclide- and crop-type–specific soil-to-plant TFs used in Equation 6-2. The TFs, also called the concentration factors (ICRU 2001 [DIRS 160339], p. 13), relate the dry- or wet-weight activity concentration in the edible parts of plants (Bq/kg) to the dry-weight activity concentration in soil (Bq/kg), assuming equilibrium between the two media. In this analysis, TFs are based on a dry weight of the plant, following the format used in the biosphere model (BSC 2004 [DIRS 169460], Section 6.4.3.1). The conversion between the dry-weight–based and wet-weight–based TFs can be accomplished using dry-to-wet weight ratios. The dry-to-wet weight ratio values range from a few percent for fruit to over 90 percent for grain (BSC 2004 [DIRS 169673], Section 7). The TFs are dimensionless, crop-type– and element-dependent parameters. Observed values of TFs differ mainly as a result of soil characteristics, vegetation types, and environmental conditions. Crop uptake through roots is also affected by soil management practices (e.g., plowing, fertilizing, and irrigation). There are also differences between the TFs for various parts of the plants, for example, the whole plant vs. the grain (UNSCEAR 2000 [DIRS 158644], p. 39).

6.2.1.1.2 Crop Types Used in the Model

Soil-to-plant TFs were developed for each crop type included in the biosphere model. Crop types are composed of crops with similar characteristics (e.g., crops of which the leafy parts consumed or crops of which the fruit is consumed). Combining crops into categories helps to model radionuclide transport with enough detail to capture differences in radionuclide accumulation by plants with different morphologies without being overly specific when specificity is not warranted by the precision of the models and the availability of supporting information. Although the TF values may differ among species within a crop type, the approach of combining and averaging TFs for a certain crop type is useful when few data are available for a given radionuclide or for a crop category. The ERMYN model uses four crop types for human consumption and one additional crop type for animal consumption:

- Leafy vegetables
- Other vegetables (including root vegetables and legumes)
- Fruit
- Grain for human consumption as well as for chicken and for laying hen feed
- Forage for beef cattle and diary cows.

The leafy vegetable category includes crops like cabbage, lettuce, broccoli, and spinach. The other-vegetable category includes crops like beans, carrots, cucumbers, potatoes, and peppers. The fruit category is the most diversified and includes fruits of woody trees, (e.g., apples, apricots, and grapevines), shrubs (e.g., currants and gooseberries), and herbaceous plants (e.g., strawberries and watermelons). The grain category is composed of different types of cereals, such as barley, oats, wheat, and corn. Crops for animal consumption include fresh pasture (alfalfa and clover) for diary cows and beef cattle, and grain for chicken and laying hens.

The crop types used in the biosphere model are consistent with the crop types grown in Amargosa Valley and identified in a food consumption survey (DOE 1997 [DIRS 100332]).

6.2.1.1.3 Properties of Soils in Amargosa Valley

The TF values partially depend on the characteristics of the soils from which they were derived. Soils in Amargosa Valley have one or more characteristics that make them unsuitable or potentially unsuitable for residential or sustainable farming (e.g., high pH, shallow bedrock, or high salt content). Nevertheless, people farm these soils, possibly using careful selection of crops and special management practices (CRWMS M&O 1999 [DIRS 107736], p. 7).

Information on soils in the Amargosa Valley region is based on the analysis of soil samples collected in the region (CRWMS M&O 1999 [DIRS 107736], p. 4). Mean pH within the A-horizon of cultivated and uncultivated soil for the four soil mapping units sampled was within the range of pH = 7.8 to 8.4 (CRWMS M&O 1999 [DIRS 107736], p. 8), which represents highly alkaline soils.

The analysis of soil texture indicated high sand content. The mean sand, silt, and clay contents were 82.5, 12.0, and 5.6 percent, respectively (these percentages apply to the soil portion of the samples, which was obtained by separating it by sieving out coarse fragments greater than 2 mm). The organic matter content was low, and only 18 percent of the soil samples were more than 1 percent organic matter. The highest level of organic matter was 1.65 percent (CRWMS M&O 1999 [DIRS 107736], pp. D-4 to D-6). Therefore, the soils in Amargosa Valley can be classified as mineral soils (as opposed to organic soils), which may have implications regarding the potential accumulation of radionuclides in the surface soil.

6.2.1.1.4 Sources of Information on Transfer Factors

TFs were developed based on reports listed in Section 4.1.1. Other sources of information were used to further support or corroborate the selection of the parameter values, especially from the perspective of site-specificity.

A potential source of information on TFs is the RADFLUX Database, which is sponsored by the IUR. The database (as of the writing of this report) has not yet been completed. The RADFLUX Database contains rates for various environmental transport processes and updated information on TFs, including the most recent experimental results. The TF part of the database includes the previous IUR TF database and information that became available in the 1990s (many publications used in this analysis were based on the older IUR database). This new database was not considered in this report for developing parameter values.

6.2.1.1.5 Methods Used for Development of Transfer Factors for the Biosphere Model

To develop values for TFs, many publications containing the reviews of the TFs or their applications in biosphere modeling for performance assessment have been evaluated. If a report provided a choice of values corresponding more closely to the environmental conditions of the Yucca Mountain region, such values were used. The process of selecting information is described below. In many cases, a relatively broad range of TF values was recommended for the biosphere model because of the inherent uncertainty associated with the future environmental conditions and the use of soil amendments, which may influence radionuclide uptake from soil by the crops.

Selection of Literature Data–TFs are typically given in units of Bq/kg dry-weight of plant per Bq/kg dry-weight of soil, but sometimes the TFs are reported on a wet-weight (fresh) basis. The biosphere model uses the dry-weight ratios for the TFs because such an approach minimizes differences in the parameter values due to environmental conditions or crop types. The conversion from the wet-weight to the dry weight can be done with the dry-to-wet weight ratio. This approach is not straightforward if the data do not refer to a single crop but rather to a crop type, such as the leafy vegetables. If a TF based on the wet weight for a single crop and the dry-to-wet weight ratio was known, the TF values were converted to dry-weight TFs, and the dry-weight TFs were used in the analysis. TFs based on wet weights were not used in the analysis.

Most of the sources listed in Section 4.1.1 derive information on soil-to-plant TFs from experiments performed on soils typical of temperate climates, and the generic TF values (i.e., values that are recommended if site-specific data are lacking) reflect such conditions. The soils of Amargosa Valley region are characterized by a high pH, high mineral concentrations, and higher sand content (lower clay content) than typical soils (Section 6.2.1.1.3). Relying on generic TF information to develop the parameter values for soils in Amargosa Valley may introduce parametric uncertainty into the model. In all instances where there was detailed soil information, a value corresponding most closely to the properties of soils in Amargosa Valley was used. For example, if a distinction was made between soil types in a reference, values for sandy soils or low–clay content soils were used. Regarding soil pH, higher pH values result in decreased uptake of elements, while lower values produce increased uptakes (IAEA 1994 [DIRS 100458], p. 16). Thus, if a TF value for higher pH soils was available, it was used in the analysis. TF selection also considered the mineral content of the soils (i.e., the concentration of specific minerals in different soils) and the organic matter content (i.e., mineral soils versus organic soils). The instances of using specific TF values are noted in the comment column of the TF tables that follow later in this section. In addition, TFs for plant species not known to be grown in Amargosa Valley were not used in the calculations. Specifically, the TFs for tropical plants were eliminated.

Aggregation of Selected Values–TF values, selected using the criteria above, were aggregated in the following manner. First, the GM was calculated using TF values from all relevant references. The GM is preferred over the arithmetic mean whenever large variability in the data is expected (Section 6.1.2), which is the case for the TFs (BIOMASS 2001 [DIRS 159468], T1/WD04, p. 12). The GM is also a better statistic for TFs than the arithmetic mean because TFs for many elements are lognormally distributed (Baes et al. 1984 [DIRS 103766], p. 7; Davis et al. 1993 [DIRS 103767], p. 232; Sheppard 1995 [DIRS 103789], p. 2).

Observed TF values differ, mainly as a result of different soils, vegetation types, and environmental conditions. However, even field-scale measurements are subject to variability. Measurements of soil partition coefficients (K_ds) on a 100-m^2–by–150-m^2 study plot produced values differing by a factor of four for some radionuclides (BIOMASS 2001 [DIRS 159468], T1/WD04, p. 9-11). Because K_ds are inversely correlated with TFs (BIOMASS 2001 [DIRS 159468], T1/WD04, pp. 27 to 31; Karlsson et al. 2001 [DIRS 159470], p. 37; Davis et al. 1993 [DIRS 103767], p. 234), the degree of variability in the TF values is expected to be at least on the same order. Differences among TF values reported in the literature reviews are usually even higher. Such differences mainly appear to be a function of the number of samples and the range of conditions under which the TFs were measured, rather than characteristics of the system studied (Davis et al. 1993 [DIRS 103767], p. 232).

The TFs used in the biosphere model not only represent composite values for many crop species within a crop type but also capture potential temporal changes. Because temporal changes may cause a wider distribution of parameter values, the geometric standard deviation (GSD) of the values reported in the literature was used as a measure of uncertainty in the TF value for a given element and crop type.

As noted previously, the sources of information on TFs were summary reviews and reports containing recommendations of generic TF values or reports describing biosphere models that include selections of input parameters. In either case, the values of TFs are the authors' best estimates for a given radionuclide, pathway, and application. When the GM of such data is calculated, as is done in this analysis, the result represents the estimate of the parameter value based on the best estimates of other authors. The scatter of values, characterized by the GSD, indicates the level of agreement among the authors. Usually there is good agreement between the TF values from different reports, which, in most cases, differ by less than two orders of magnitude (Tables 6-2 to 6-31). In a few instances, TF values reported by different authors differed by several orders of magnitude. For such cases, the calculated GSD is large.

To determine the realistic representation of the TF values, the upper and lower limits for the GSD were set. The limits were based on an analysis of the TFs from the IUR database by Sheppard and Evenden (1997 [DIRS 160641], p. 727). The analysis concerned the expected uncertainty in TF values for a range of possible conditions ranging from fully generic to site-specific situations. It was concluded that the most site-specific data (single-site, single-crop) have a GSD of about 1.5. When data are fully generic, the GSD is generally above 3, with a typical value of about 6. NCRP (1984 [DIRS 103784]) reported the GSD of 3.8 and 4.1 for strontium and cesium TFs for food crops, respectively. The corresponding values for the forage plants were 3.8 and 3.5. The GSD of 10 was chosen for all elements in support of biosphere modeling for the Canadian nuclear fuel waste assessment (Davis et al. 1993 [DIRS 103767], p. 232). Compared to the IUR data (Sheppard and Evenden 1997 [DIRS 160641], p. 730), this value is an upper limit for GSD values. Because higher values of GSDs are not supported by the existing data (Sheppard and Evenden 1997 [DIRS 160641], Figures 2 and 3), the GSD of 10 was chosen as an upper limit for the TFs for the biosphere model.

The TFs used in the biosphere model represent the composite mean values for the crop species within the crop type. Variability in the value of a composite parameter is expected to be lower than that among the TFs for individual crop species. The lower limit for the GSD was set at 2 because the typical site- and crop-specific TF GSD was about 1.5 (Sheppard and Evenden 1997 [DIRS 160641], Table 1). Because TFs in the biosphere model represent values for crop types, rather than individual crops, it is unlikely that the corresponding GSD would be lower than the site- and crop-specific value. The value of 1.5 was rounded up to the nearest integer (i.e., 2) and used as the lower limit of the GSD. In practice, when the GSD of the published values was less than 2, it was set at 2, and if it was greater than 10, it was set at 10. Such an approach is appropriate because the distributions of TF values do not represent variability in the expected values of the TFs for different individual crops but rather uncertainty in the generic value of the parameter.

The biosphere model uses many parameters. This report develops the values for about 200 parameters that will be sampled in the biosphere model for each radionuclide. To obtain statistically sound results, the number of biosphere model realizations may need to be large. In such a case, if the TFs are represented by unlimited probability distribution functions, the sampling will include the extremely low and extremely high values, which in some cases may be unrealistic. As noted, the TFs in the biosphere model are composite values for the number of crops within a crop type and are considered the best representation of the generic mean value of the parameter, with some consideration of the site-specific conditions. Therefore, truncation limits are specified for the biosphere model. The truncation limits are set such that the truncated distributions encompass 99 percent of the values of the unlimited distribution. For the lognormal distribution, the lower and upper bounds of the 99-percent confidence interval for the GM can be expressed, based on LaPlante and Poor ([DIRS 101079], p. 3-12), as the point where the number of standard deviations is 2.576 (Lide and Frederikse 1997 [DIRS 103178], p. A-104), such that the 99-percent confidence interval is

$$\begin{aligned} lower\ truncation &= \frac{GM}{GSD^{2.576}} \\ upper\ truncation &= GM \times GSD^{2.576} \end{aligned} \qquad \text{(Eq. 6-3)}$$

where

GM = geometric mean

GSD = geometric standard deviation.

6.2.1.2 Transfer Factors for the Groundwater Exposure Scenario

This section describes the development of TFs for the biosphere model for the groundwater exposure scenario and present day climate. Recommendations regarding TF values for the volcanic ash exposure scenario are given in Section 6.2.1.3, and those for the future climate groundwater exposure scenario in Section 6.2.1.4. The primary references used for information on TFs are listed in Section 4.1.1.

6.2.1.2.1 Leafy Vegetables

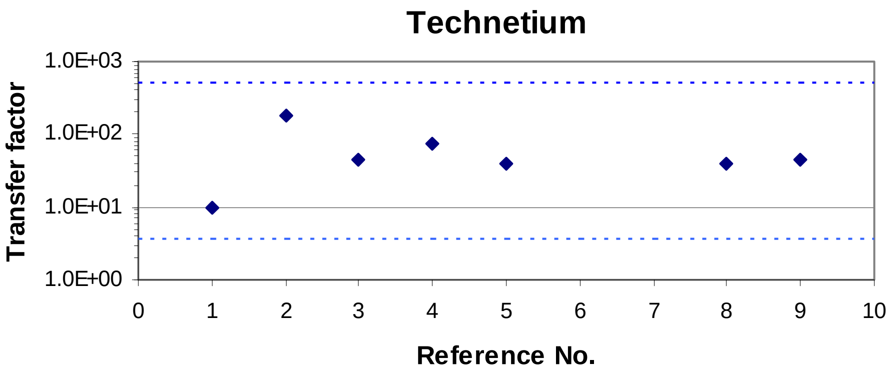
The soil-to-plant TFs for leafy vegetables, and the reports used to develop the values, are listed in Tables 6-2 through 6-7. Calculation of GMs, standard deviations, and truncation limits for the TFs were preformed using Microsoft Excel 2000, as described in Appendix A. Some TFs listed in the references were not included in the analysis if information on the soils and crops was detailed enough to determine that the environmental conditions under which they were collected were inappropriate for the Yucca Mountain area. Several references from the list (Section 4.1.1) used wet- weight–based (fresh) TFs and were not used.

The values listed by the IAEA (1994 [DIRS 100458], pp. 17 to 25), based on IUR data, were combined using the GM of the values for selected crops (see Tables 6-2 to 6-7 for more detail). Other authors (Kennedy and Strenge 1992 [DIRS 103776], p. 6.27) used weighted GMs, with the weights being the number of observations for each data value. Such an approach biases the result toward plant species for which more data were collected, misrepresenting those most frequently grown or consumed. Unweighted means better represent the contribution of individual species into the TFs for leafy vegetables.

The TFs for organic soils with low pH (peat) provided by Peterson (1983 [DIRS 167077], pp. 5-50 to 5-51) were not included in the calculation; TFs for soils with potassium content less than 80 mg/kg, as well as TFs for soils with low calcium and low pH values, were excluded. This was based on the laboratory analyses of the soil samples collected in Amargosa Valley, which indicated that Amargosa Valley soils have higher concentrations of these elements and higher pH values (CRWMS M&O 1999 [DIRS 107736], pp. D-4 to D-6). The aerial values of TFs (Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51), representing the gross plant-to-soil concentration ratio, including external contamination, were not used. External crop contamination is especially important for crops in which root uptake is low or in the case of radionuclides that are not easily taken up through the roots, such as the transuranics. The adhesion of soil particles can be important, as the amounts of radionuclides present in the adhering soil can exceed the amounts taken up via the roots (IAEA 1994 [DIRS 100458], p. 27), and thus, even minute external activity can result in an elevated "apparent" TF. This effect is important for plant-element TF values of less than 0.1 (IAEA 1994 [DIRS 100458], p. 27). However, it is usually noticeable only for the individual experimental results rather than for the averaged values, as is the case for the references used in this analysis.

Table 6-2. Technetium Soil-to-Plant Transfer Factors for Leafy Vegetables

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 10	9.5E+00 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	1.8E+02 [b]	1.0E+01 – 7.8E+03 (95-% confidence range)
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	4.4E+01	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	7.6E+01 [c]	lognormal, GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E+01 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	–	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	4.0E+01 [e]	–
9	This analysis - recommendation	–	lognormal, GM = 4.6E+01[f], GSD = 2.6 truncation: low = 3.8E+00; high = 5.5E+02



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to leafy vegetables but rather it was developed for plant parts usually associated with vegetative functions (leaves, stems, straw)

[b] Best estimate is the GM of the values for cabbage, lettuce, and spinach.

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

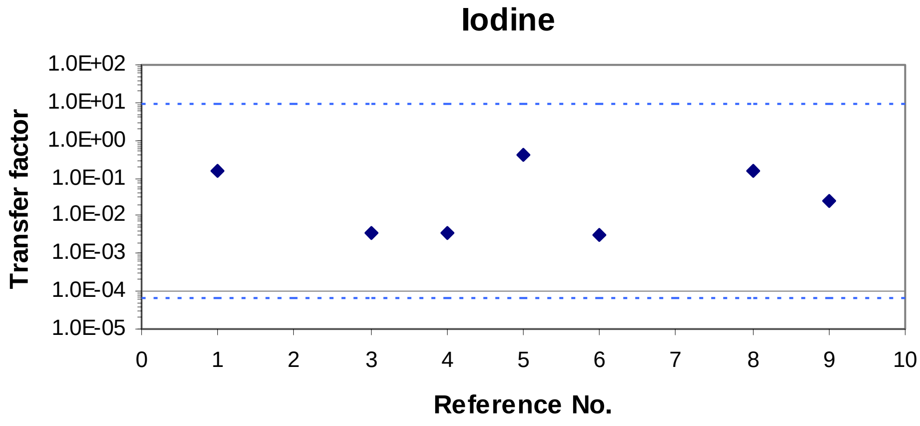
[d] GENII-S default

[e] RESRAD default value

[f] For the references listed in this table, GM = 4.6E+01; GSD = 2.6

Table 6-3. Iodine Soil-to-Plant Transfer Factors for Leafy Vegetables

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 10	1.5E−01 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	3.4E−03	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	3.4E−03 [b]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E−01 [c]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	3.2E−03 [d]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.5E−01 [e]	–
9	This analysis - recommendation	–	lognormal; GM = 2.6E−02 [f]; GSD = 9.9 truncation: low = 7.2E−05; high = 9.7E+00



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to leafy vegetables but rather it was developed for plant parts usually associated with vegetative functions (leaves, stems, straw)

[b] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[c] GENII-S default

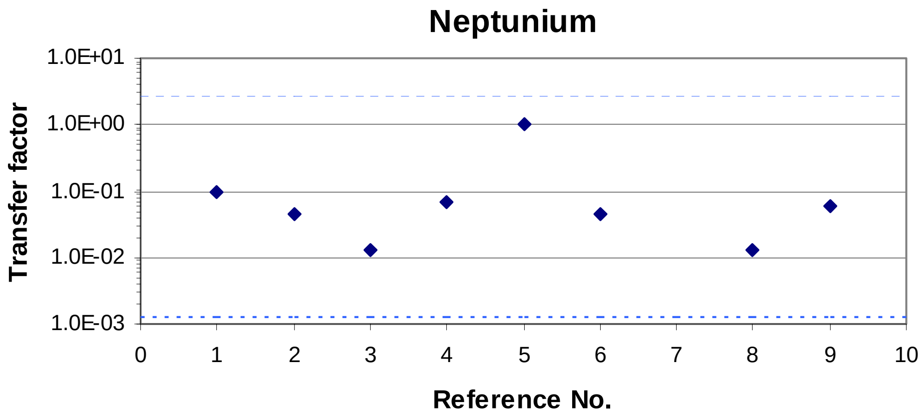
[d] Value for 5 percent clay content in soil

[e] RESRAD default value

[f] For the references listed in this table, GM = 2.6E−02; GSD = 9.9

Table 6-4. Neptunium Soil-to-Plant Transfer Factors for Leafy Vegetables

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 10	1.0E−01 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	4.6E−02 [b]	2.4E−02 to 1.1E-01(expected values)
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	1.3E−02	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	6.9E−02 [c]	Lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E+00 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	4.6E−02 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.3E−02 [f]	–
9	This analysis - recommendation	–	lognormal; GM = 5.9E-02 [g]; GSD = 4.4 truncation: low = 1.3E-03; high = 2.6E+00



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to leafy vegetables but rather it was developed for plant parts usually associated with vegetative functions (leaves, stems, straw)

[b] Best estimate is the GM of the values for cabbage, leeks and mixed green vegetables

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

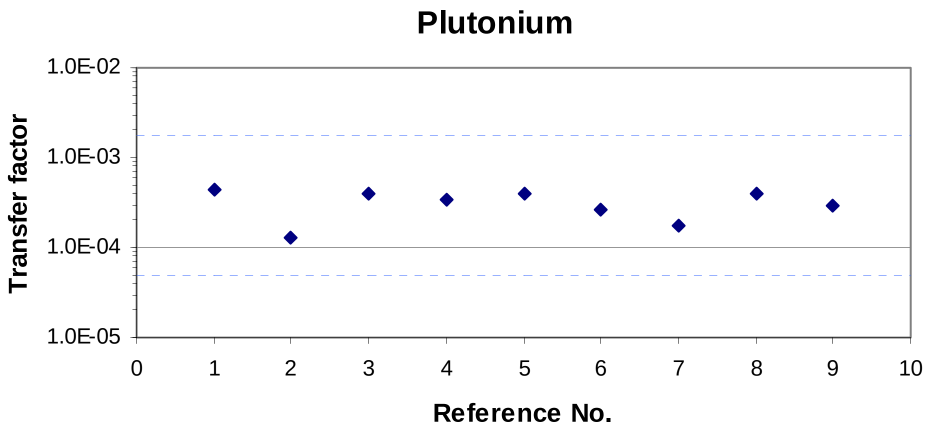
[e] Value for 5 percent clay content in soil

[f] RESRAD default value

[g] For the references listed in this table, GM = 5.9E-02; GSD = 4.4

Table 6-5. Plutonium Soil-to-Plant Transfer Factors for Leafy Vegetables

No.	Reference	Transfer Factor, dimensionless Best Estimate	Transfer Factor, dimensionless Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 10	4.5E-04 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	1.2E-4 [b]	4.1E-05 to 6.4E-04
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	3.9E-04	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	3.4E-4 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-04 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	2.6E-4 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	1.75E-4	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	3.9E-04 [f]	–
9	This analysis - recommendation	–	lognormal; GM = 2.9E-04 [g]; GSD = 2.0 truncation: low = 4.9E-05; high = 1.7E-03



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to leafy vegetables but rather it was developed for plant parts usually associated with vegetative functions (leaves, stems, straw)

[b] Best estimate is the GM of the values for cabbage, leeks and mixed green vegetables

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

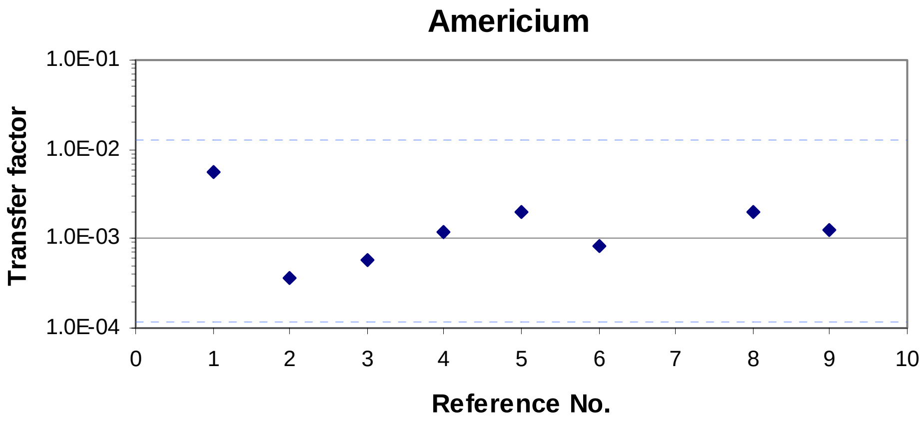
[e] Value for 5 percent clay content in soil

[f] RESRAD default value

[g] For the references listed in this table, GM = 2.9E-04; GSD = 1.6. The GSD = 2 was used (see text for details).

Table 6-6. Americium Soil-to-Plant Transfer Factors for Leafy Vegetables

		Transfer Factor, dimensionless Comments	
No.	**Reference**	**Best Estimate**	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 10	5.5E-03 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	3.6E-04 [b]	2.0E-04 to 6.6E-04
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	5.8E-04	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.2E-03 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-03 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	8.2E-04 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	2.0E-03 [f]	–
9	This analysis - recommendation	–	lognormal; GM = 1.2E-03 [g] , GSD = 2.5 truncation: low = 1.2E-04; high = 1.3E-02



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to leafy vegetables but rather it was developed for plant parts usually associated with vegetative functions (leaves, stems, straw)

[b] Best estimate is the GM of the values for cabbage and mixed green vegetables

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

[e] Value for 5 percent clay content in soil

[f] RESRAD default value

[g] For the references listed in this table, GM = 1.2E-03; GSD = 2.5

Table 6-7. Soil-to-Plant Transfer Factors for Leafy Vegetables for Other Elements

	Reference	Transfer Factor, dimensionless (Bq/kg dry-weight crop per Bq/kg dry-weight soil)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Baes et al. 1984 [DIRS 103766], p. 10	7.0E+01	2.5E-02	2.5E+00	3.0E-02	8.0E-02	4.5E-02	1.5E-02	3.5E-03	8.5E-04	2.5E-03	8.5E-03
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–	1.3E+00	–	2.8E-01	1.0E-02	7.0E-02	–	1.8E-03	–	8.3E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	7.0E+01	2.5E-02	1.6E+00	3.0E-02	1.3E-01	5.8E-03	7.5E-02	3.5E-03	6.6E-03	2.5E-03	1.7E-02
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	2.5E-02	1.1E+00	3.0E-02	1.1E-01	1.1E-03	8.0E-02	3.5E-03	1.1E-02	2.5E-03	2.3E-02
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	5.0E+01	5.0E-01	2.0E+00	1.0E-01	2.0E-02	1.0E-01	1.0E-01	1.0E-02	4.0E-03	5.0E-02	4.0E-03
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	–	–	2.2E+00	–	1.5E-01	1.5E-02	2.3E-02	–	1.6E-02	–	2.1E-02
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–	2.2E+00	–	2.2E-02	–	4.4E-01	–	–	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	7.0E+01	2.5E-02	1.6E+00	3.0E-02	1.3E-01	4.5E-02	7.5E-02	3.5E-03	4.0E-03	2.5E-03	8.5E-03
	GM	6.4E+01	4.6E-02	1.7E+00	3.8E-02	8.5E-02	1.5E-02	6.8E-02	4.3E-03	4.3E-03	4.6E-03	1.1E-02
	GSD	1.2	3.8	1.3	1.7	2.5	4.6	2.7	1.6	2.8	3.8	1.9
	Recommended GSD	2.0 [a]	3.8	2.0 [a]	2.0 [a]	2.5	4.6	2.7	2.0 [a]	2.8	3.8	2.0 [a]
	Truncation, lower limit	1.1E+01	1.4E-03	2.9E-01	6.4E-03	7.7E-03	3.0E-04	5.1E-03	7.2E-04	3.2E-04	1.4E-04	1.8E-03
	Truncation, upper limit	3.8E+02	1.4E+00	1.0E+01	2.3E-01	9.4E-01	7.7E-01	9.2E-01	2.6E-02	5.9E-02	1.4E-01	6.6E-02

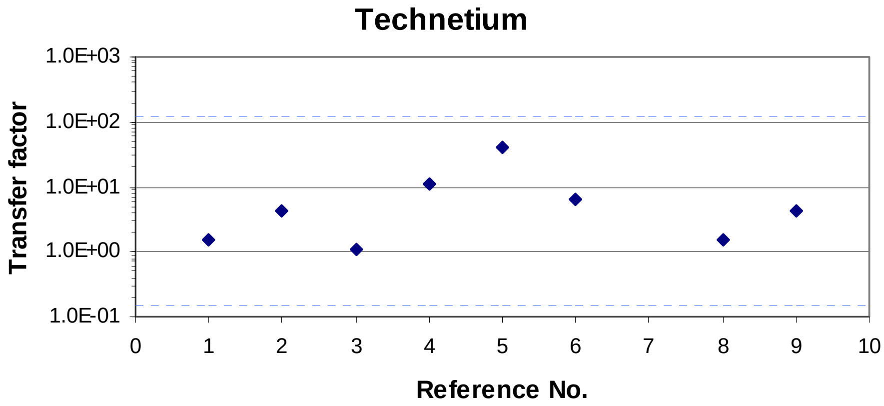
[a] The lower bound of the value of the GSD was used.

6.2.1.2.2 Other Vegetables

To derive TFs for other vegetables, the same references and the same methods were used as those for leafy vegetables. TFs for other vegetables are listed in Tables 6-8 through 6-13. Calculation of GMs, standard deviations, and truncation limits for the TFs were preformed using Microsoft Excel 2000, as described in Appendix A.

Table 6-8. Technetium Soil-to-Plant Transfer Factors for Other Vegetables

No.	Reference	Transfer Factor, dimensionless Best Estimate	 Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	1.5E+00 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	4.3E+00 [b]	2.4E-01 to 7.9E+01
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	1.1E+00	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.1E+01 [c]	lognormal, GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E+01 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	6.6E+00 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.5E+00 [f]	–
9	This analysis - recommendation	–	lognormal; GM = 4.4E+00 [g]; GSD = 3.7 truncation: low = 1.5E-01; high = 1.2E+02



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to other vegetables but rather it was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Best estimate is the GM of the values for individual crops (potato, pea, bean, and turnip)

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

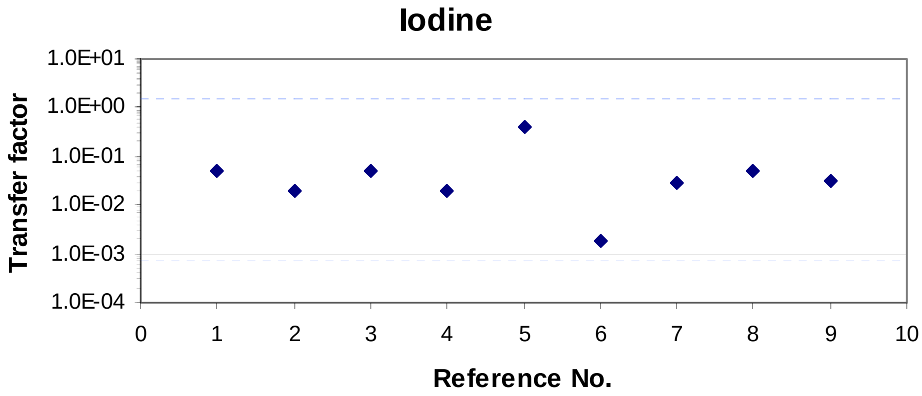
[e] Value for 5 percent clay content in soil

[f] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[g] For the references listed in this table, GM = 4.4E+00; GSD = 3.7

Table 6-9. Iodine Soil-to-Plant Transfer Factors for Other Vegetables

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	5.0E-02 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	2.0E-02 [b]	–
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	5.0E-02	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.0E-02 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-01 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	1.9E-03 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	3.0E-02	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	5.0E-02 [f]	–
9	This analysis - recommendation	–	lognormal; GM = 3.2E-02 [g]; GSD = 4.4 truncation: low = 7.0E-04; high = 1.5E+00



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to other vegetables but rather it was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Composite of unspecified crop types.

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

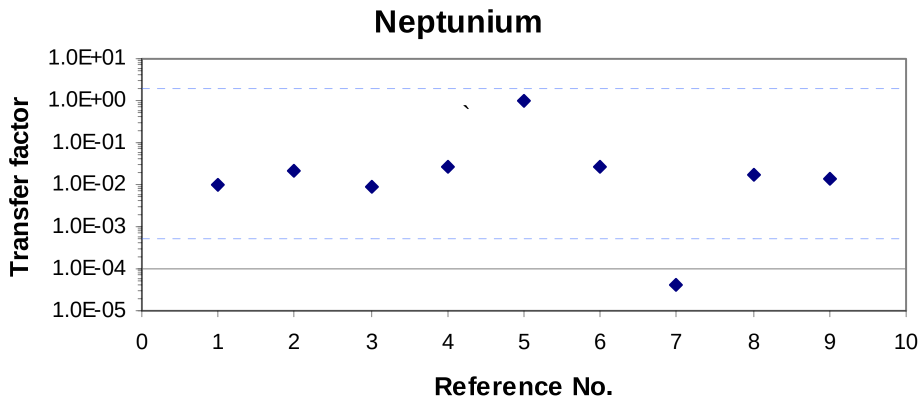
[e] Value for root vegetables, 5 percent clay content in soil.

[f] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[g] For the references listed in this table, GM = 3.2E-02; GSD = 4.4

Table 6-10. Neptunium Soil-to-Plant Transfer Factors for Other Vegetables

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 11	1.0E-02 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	2.1E-02 [b]	6.7E-03 to 3.5E-02
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	9.4E-03	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.7E-02 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E+00 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	2.8E-02 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	4.0E-5 [f]	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.7E-02 [g]	–
9	This analysis - recommendation	–	lognormal; GM = 3.1E-02 [h]; GSD = 4.9 truncation: low = 5.0E-04; high = 1.9E+00



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to other vegetables but rather it was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Best estimate is the GM of the values for individual crops (potato, onion, radish, carrot, and bean)

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

[e] Value for root vegetables, 5 percent clay content in soil.

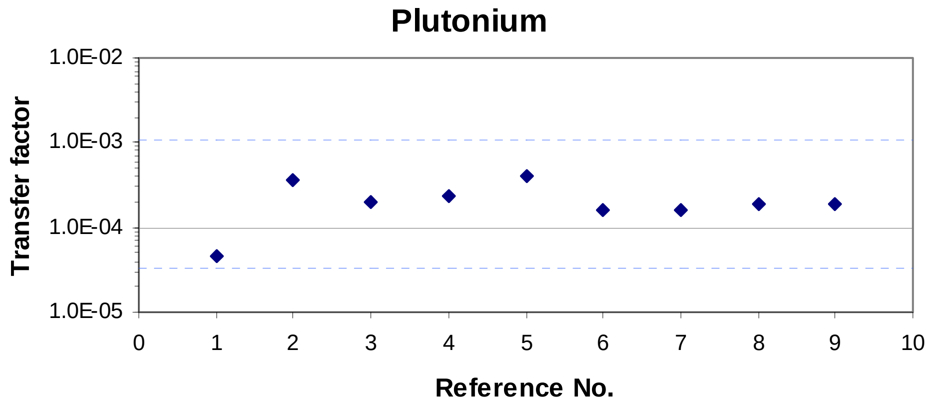
[f] Value for legumes for pH greater than 7—not included in the calculations because it was over two orders of magnitude less than the remaining values.

[g] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[h] For all references listed in this table, GM = 1.3E-02; GSD = 16.0.

Table 6-11. Plutonium Soil-to-Plant Transfer Factors for Other Vegetables

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	4.5E-05 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	3.7E-04 [b]	6.1E-05 to 4.4E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	2.0E-04	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.3E-04 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-04 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	1.6E-04 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	1.6E-04 [f]	8.1E-06 to 1.4E-03
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.9E-04 [g]	–
9	This analysis - recommendation	–	lognormal; GM = 1.9E-04 [h]; GSD = 2.0 truncation: low = 3.3E-05; high = 1.1E-03



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to other vegetables but rather it was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Best estimate is the GM of the values for individual crops (bean, carrot, radish, onion, mixed root vegetables, and potato)

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

[e] Value for root vegetables, 5 percent clay content in soil

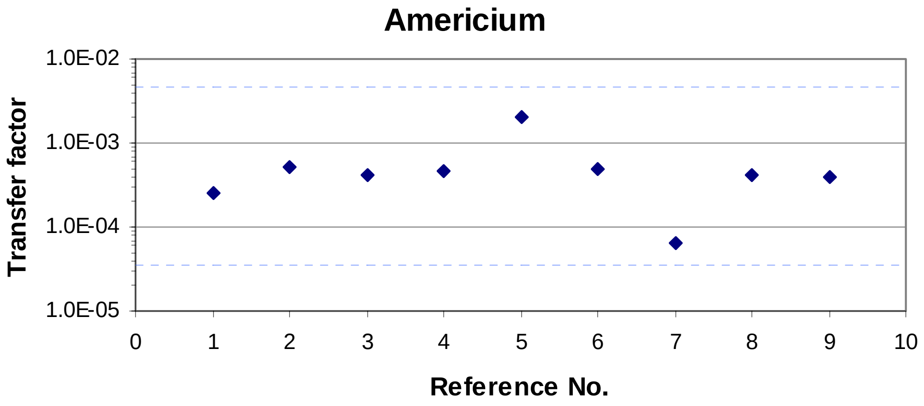
[f] Best estimate is the GM of the values for individual crops in this category reported in the reference.

[g] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[h] For the references listed in this table, GM = 1.9E-04; GSD = 2.0

Table 6-12. Americium Soil-to-Plant Transfer Factors for Other Vegetables

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	2.5E-04 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	5.2E-04 [b]	1.6E-04 to 2.2E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	4.1E-04	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	4.7E-04 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-03 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	5.0E-04 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	6.4E-05 [f]	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	4.1E-04 [g]	–
9	This analysis - recommendation	–	lognormal; GM = 4.0E-04 [h]; GSD = 2.6 truncation: low = 3.5E-05; high = 4.6E-03



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to other vegetables but rather it was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)
[b] Best estimate is the GM of the values for individual crops (potato, onion, radish, carrot, and bean)
[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.
[d] GENII-S default
[e] Value for root vegetables, 5 percent clay content in soil
[f] Value for legumes
[g] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.
[h] For the references listed in this table, GM = 4.0E-04; GSD = 2.6

Table 6-13. Soil-to-Plant Transfer Factors for Other Vegetables for Other Elements

	Reference	Transfer Factor, dimensionless (Bq/kg dry-weight crop per Bq/kg dry-weight soil)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Baes et al. 1984 [DIRS 103766], p. 11	7.0E+01	2.5E-02	2.5E-01	6.0E-03	3.0E-02	9.0E-03	1.5E-03	3.5E-04	8.5E-05	2.5E-04	4.0E-03
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–	7.5E-01	–	5.1E-02	5.1E-03	6.5E-03	–	2.3E-04	–	1.2E-02
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	7.0E+01	2.5E-02	8.1E-01	6.0E-03	4.9E-02	3.2E-03	3.2E-03	3.5E-04	1.2E-04	2.5E-04	1.4E-02
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	2.5E-02	8.6E-01	3.0E-02	7.2E-02	6.4E-03	1.3E-02	3.5E-03	3.1E-04	2.5E-03	1.1E-02
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	5.0E+01	5.0E-01	2.0E+00	1.0E-01	2.0E-02	1.0E-01	1.0E-01	1.0E-02	4.0E-03	5.0E-02	4.0E-03
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	–	–	1.3E+00	–	9.1E-02	9.2E-03	1.4E-02	–	1.0E-02	–	1.3E-02
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–	1.2E+00	–	4.2E-02	–	1.7E-01	–	2.2E-04	–	6.5E-04
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	7.0E+01	2.5E-02	3.7E-01	6.0E-03	9.8E-02	5.6E-03	3.5E-03	3.5E-04	2.1E-04	2.5E-04	6.4E-03
	GM	6.4E+01	4.6E-02	7.9E-01	1.5E-02	5.0E-02	9.0E-03	1.2E-02	1.1E-03	4.4E-04	1.1E-03	6.0E-03
	GSD	1.2	3.8	2.0	3.6	1.7	3.1	5.3	4.9	5.6	10.3	2.8
	Recommended GSD	2.0 [a]	3.8	2.0	3.6	2.0 [a]	3.1	5.3	4.9	5.6	10.0 [b]	2.8
	Truncation, lower limit	1.1E+01	1.4E-03	1.4E-01	5.3E-04	8.4E-03	5.0E-04	1.6E-04	1.8E-05	5.3E-06	3.0E-06	4.2E-04
	Truncation, upper limit	3.8E+02	1.4E+00	4.5E+00	4.0E-01	3.0E-01	1.6E-01	8.6E-01	6.6E-02	3.6E-02	4.3E-01	8.5E-02

[a] The lower bound of the value of the GSD was used.
[b] The upper bound of the value of the GSD was used.

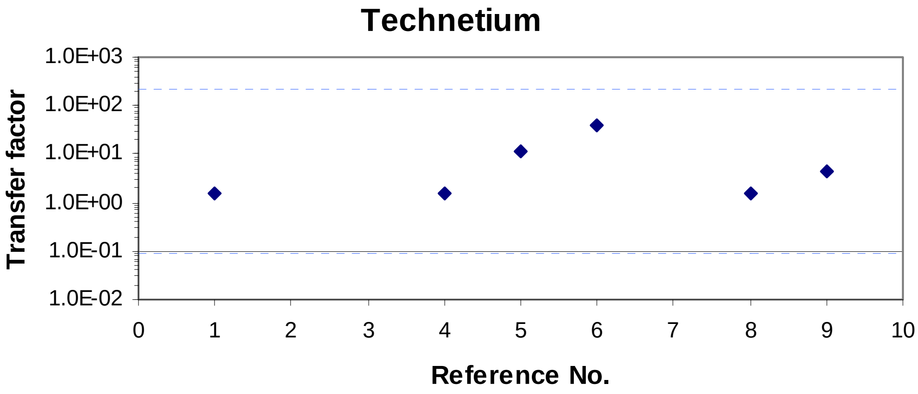
6.2.1.2.3 Fruit

The TF data for fruit are scarce. To improve capabilities for modeling of radionuclides transfer to fruit, the BIOMASS Theme 3 Fruits Working Group reviewed the available experimental, field, and modeling information and then summarized the element-specific soil-to-fruit TFs for individual fruit species for many elements (BIOMASS 2001 [DIRS 159468], T3FM/WD01). TFs were given based on the fresh weight of the fruit. However, a table with percent water content of individual fruit species was included in the publication making the conversion to dry-weight possible. The fresh weight values of TFs for individual fruits were converted to a dry-weight basis, and then a GM was calculated using TFs for fruits that are grown in Amargosa Valley. TFs for tropical fruits and TFs for organic soils (peat) were not included in the calculations.

Most of the references used to derive TFs for vegetables, except Sheppard's *Application of the International Union of Radioecologists Soil-to-Plant Database to Canadian Settings* (1995 [DIRS 103789]), also contained some fruit-related TF data. TFs for fruit are summarized in Tables 6-14 through 6-19. Calculation of GMs, standard deviations, and truncation limits for the TFs were preformed using Microsoft Excel 2000, as described in Appendix A.

Table 6-14. Technetium Soil-to-Plant Transfer Factors for Fruit

No.	Reference	Transfer Factor, dimensionless Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	1.5E+00 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–
3	BIOMASS 2001 [DIRS 159468], T3FM/WD01, pp. 82 to 92	–	–
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	1.5E+00	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.1E+01 [b]	lognormal; GSD = 2
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E+01 [c]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.5E+00 [d]	–
9	This analysis - recommendation	–	lognormal; GM = 4.3E+00 [e]; GSD = 4.6 truncation: low = 8.7E-02; high = 2.1E+02



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

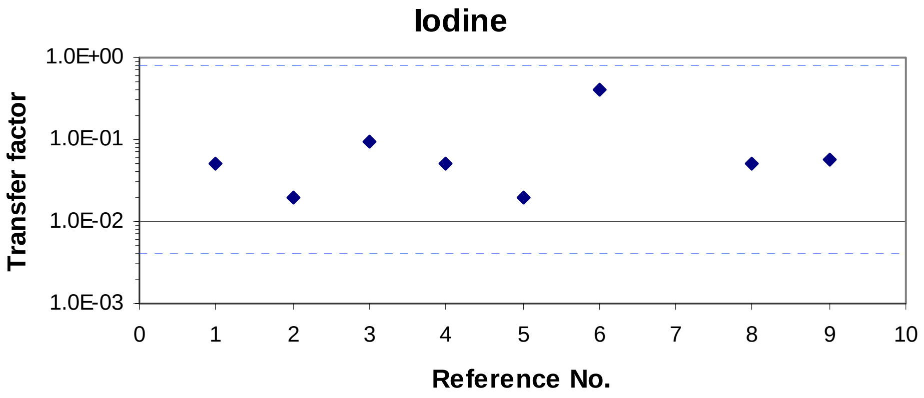
[c] GENII-S default

[d] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[e] For the references listed in this table, GM = 4.3E+00; GSD = 4.6

Table 6-15. Iodine Soil-to-Plant Transfer Factors for Fruit

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	5.0E-02 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	2.0E-02 [b]	–
3	BIOMASS 2001 [DIRS 159468], T3FM/WD01, pp. 82 to 92	9.3E-02 [c]	GSD = 1.8
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	5.0E-02	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.0E-02 [d]	lognormal; GSD = 2
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-01 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	5.0E-02 [f]	–
9	This analysis - recommendation	–	lognormal; GM = 5.7E-02 [g]; GSD = 2.8 truncation: low = 4.1E-03; high = 7.9E-01



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Composite of unspecified crop types

[c] Best estimate is the GM of the TFs for individual crops (apple, apricot, and watermelon) that could be grown in Amargosa Valley. Subtropical fruits were not included; also, TFs for fruit grown in peat soil were not included because of incompatibility with Amargosa Valley soils.

[d] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

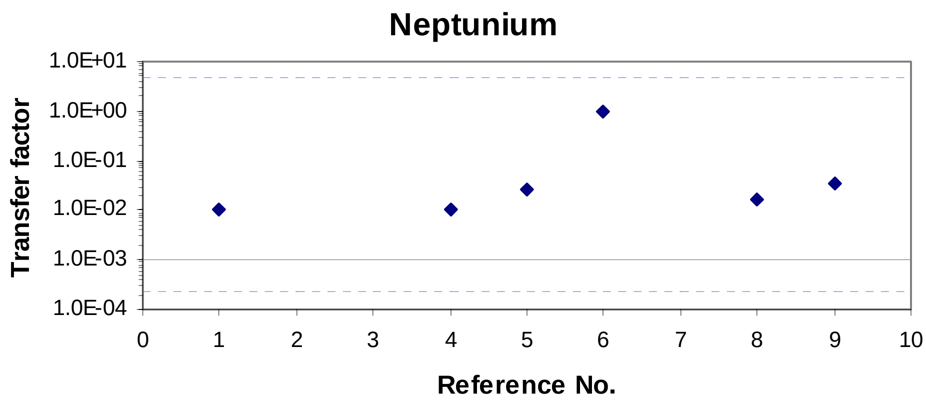
[e] GENII-S default

[f] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[g] For the references listed in this table, GM = 5.7E-02; GSD = 2.8

Table 6-16. Neptunium Soil-to-Plant Transfer Factors for Fruit

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 11	1.0E-02 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–
3	BIOMASS 2001 [DIRS 159468], T3FM/WD01, pp. 82 to 92	–	–
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	1.0E-02	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.7E-02 [b]	lognormal; GSD = 2
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E+00 [c]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.7E-02 [d]	–
9	This analysis - recommendation	–	lognormal; GM = 3.4E-02 [e]; GSD = 6.9 truncation: low = 2.3E-04; high = 5.0E+00



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

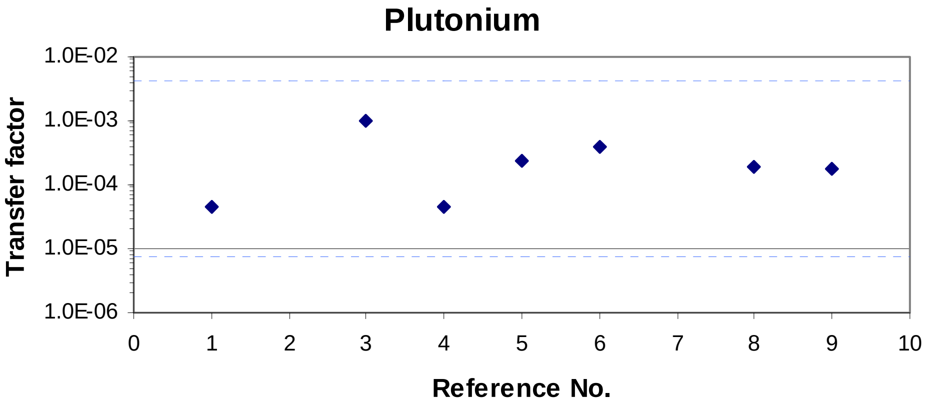
[c] GENII-S default

[d] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[e] For the references listed in this table, GM = 3.4E-02; GSD = 6.9

Table 6-17. Plutonium Soil-to-Plant Transfer Factors for Fruit

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	4.5E-05 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–
3	BIOMASS 2001 [DIRS 159468], T3FM/WD01, pp. 82 to 92	1.0E-03 [b]	GSD = 2.7
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	4.5E-05	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.3E-04 [c]	lognormal; GSD = 2
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-04 [d]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.9E-04 [e]	–
9	This analysis - recommendation	–	lognormal; GM = 1.8E-04 [f]; GSD = 3.4 truncation: low = 7.8E-06; high = 4.2E-03



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Best estimate is the GM of the TFs for individual crops (apple, peach, gooseberry, blackcurrant, strawberry, melon, rhubarb) that could be grown in Amargosa Valley. Subtropical fruits were not included; also, TFs for fruit grown in peat soil were not included because of incompatibility with Amargosa Valley soils.

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

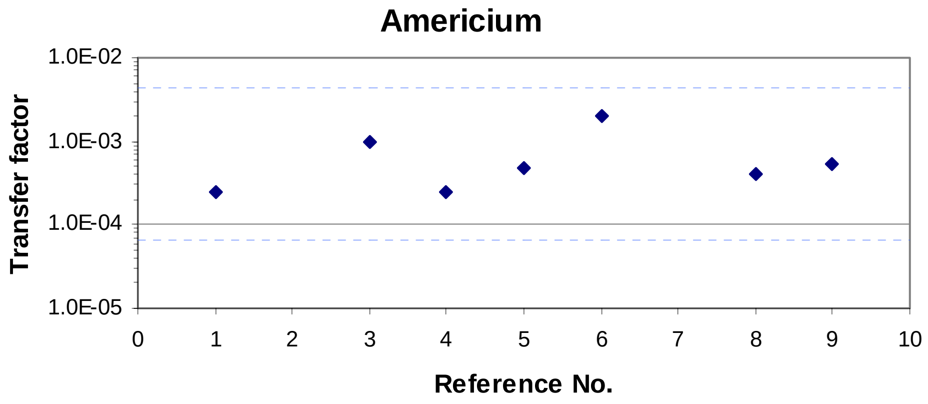
[d] GENII-S default

[e] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit and grain.

[f] For the references listed in this table, GM = 1.8E-04; GSD = 3.4

Table 6-18. Americium Soil-to-Plant Transfer Factors for Fruit

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	2.5E-04 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–
3	BIOMASS 2001 [DIRS 159468], T3FM/WD01, pp. 82 to 92	1.0E-03 [b]	GSD = 3.4
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	2.5E-04	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	4.7E-04 [c]	lognormal; GSD = 2
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-03 [d]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	4.1E-04 [e]	–
9	This analysis - recommendation	–	lognormal; GM = 5.4E-04 [f]; GSD = 2.3 truncation: low = 6.5E-05; high = 4.5E-03



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Best estimate is the GM of the TFs for individual crops (apple, peach, gooseberry, blackcurrant, strawberry, melon, rhubarb) that could be grown in Amargosa Valley. Subtropical fruits were not included; also, TFs for fruit grown in peat soil were not included because of incompatibility with Amargosa Valley soils.

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

[e] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[f] For the references listed in this table, GM = 5.4E-04; GSD = 2.3

Table 6-19. Soil-to-Plant Transfer Factors for Fruit for Other Elements

	Reference	Transfer Factor, dimensionless (Bq/kg dry-weight crop per Bq/kg dry-weight soil)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Baes et al. 1984 [DIRS 103766], p. 11	7.0E+01	2.5E-02	2.5E-01	6.0E-03	3.0E-02	9.0E-03	1.5E-03	3.5E-04	8.5E-05	2.5E-04	4.0E-03
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–	2.0E-01	–	2.2E-01	–	–	–	–	–	–
3	BIOMASS 2001 [DIRS 159468], T3FM/WD01, pp. 82 to 92	–	–	1.8E-01	–	1.7E-02	–	–	–	–	–	5.0E-2
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	7.0E+01	2.5E-02	1.7E-01	6.0E-03	2.2E-01	9.0E-03	6.1E-03	3.5E-04	8.5E-05	2.5E-04	4.0E-03
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	2.5E-02	2.0E-01	3.0E-02	7.2E-02	6.4E-03	1.3E-02	3.5E-03	3.1E-04	2.5E-03	1.1E-02
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	5.0E+01	5.0E-01	2.0E+00	1.0E-01	2.0E-02	1.0E-01	1.0E-01	3.0E-3	4.0E-03	5.0E-02	4.0E-03
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–	2.4E-01	–	2.6E-02	–	3.5E-03	–	–	–	1.7E-03
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	7.0E+01	2.5E-02	3.7E-01	6.0E-03	9.8E-02	5.6E-03	3.5E-03	3.5E-04	2.1E-04	2.5E-04	6.4E-03
	GM	6.4E+01	4.6E-02	2.9E-01	1.5E-02	5.6E-02	1.2E-02	7.3E-03	8.5E-04	2.9E-04	1.1E-03	6.3E-03
	GSD	1.2	3.8	2.3	3.6	2.8	3.3	4.3	3.4	4.9	10.3	2.9
	Recommended GSD	2.0 [a]	3.8	2.3	3.6	2.8	3.3	4.3	3.4	4.9	10.0 [b]	2.9
	Truncation, lower limit	1.1E+01	1.4E-03	3.6E-02	5.3E-04	3.8E-03	5.8E-04	1.6E-04	3.7E-05	4.8E-06	3.0E-06	3.9E-04
	Truncation, upper limit	3.8E+02	1.4E+00	2.4E+00	4.0E-01	8.1E-01	2.6E-01	3.2E-01	2.0E-02	1.7E-02	4.3E-01	1.0E-01

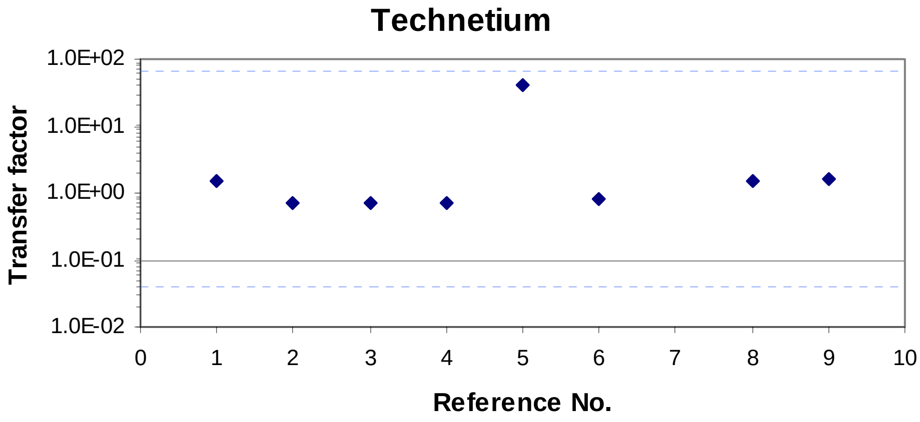
[a] The lower bound of the value of the GSD was used.
[b] The upper bound of the value of the GSD was used.

6.2.1.2.4 Grain

The TFs for grain are listed in Tables 6-20 through 6-25. The references used were the same as those used to develop TFs for vegetables. Calculation of GMs, standard deviations, and truncation limits for the TFs were preformed using Microsoft Excel 2000, as described in Appendix A.

Table 6-20. Technetium Soil-to-Plant Transfer Factors for Grain

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 11	1.5E+00 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	7.3E-01	7.3E-02 to 3.7E+00 [b]
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	7.3E-01	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	7.3E-01 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E+01 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	8.3E-01[e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.5E+00 [f]	–
9	This analysis - recommendation	–	lognormal; GM = 1.6E+00 [g]; GSD = 4.3 truncation: low = 3.8E-02; high = 6.8E+01



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Range given as 95-percent confidence range.

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

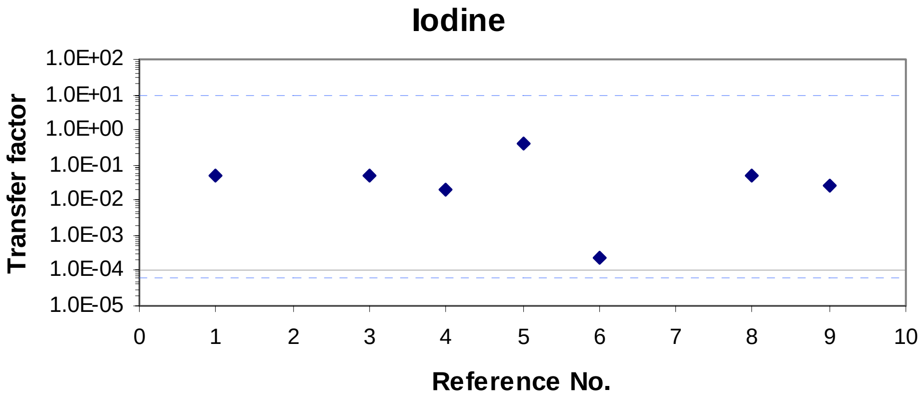
[e] Value for 5 percent clay content in soil

[f] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[g] For the references listed in this table, GM = 1.6E+00; GSD = 4.3

Table 6-21. Iodine Soil-to-Plant Transfer Factors for Grain

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	5.0E-02 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	5.0E-02	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.0E-02 [b]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-01 [c]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	2.4E-04 [d]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	5.0E-02 [e]	–
9	This analysis - recommendation	–	lognormal; GM = 2.5E-02 [f]; GSD = 10.0 truncation: low = 6.6E-05; high = 9.4E+00



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[c] GENII-S default

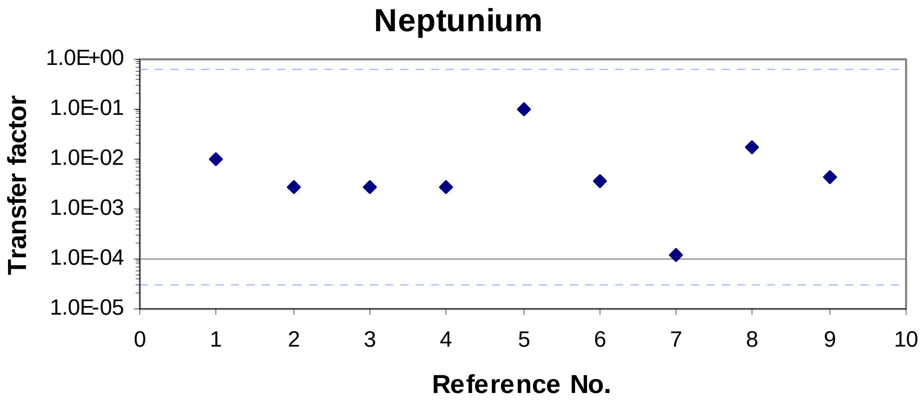
[d] Value for 5 percent clay content in soil

[e] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[f] For the references listed in this table, GM = 2.5E-02; GSD = 11.9. The GSD = 10 was used (see text for details).

Table 6-22. Neptunium Soil-to-Plant Transfer Factors for Grain

No.	Reference	Transfer Factor, dimensionless Best Estimate	 Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	1.0E-02 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	2.7E-03	2.3E-05 – 8.3E-02 [b]
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	2.7E-03	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.7E-03 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E-01 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	3.5E-03 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	1.2E-04 [f]	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.7E-02 [g]	–
9	This analysis - recommendation	–	lognormal; GM = 4.4E-03 [h]; GSD = 6.9 truncation: low = 3.1E-05; high = 6.3E-01

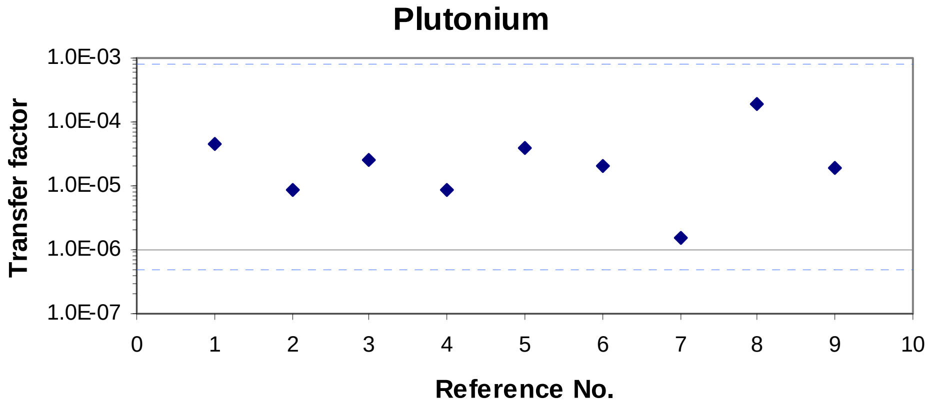


NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)
[b] Range given as 95-percent confidence range
[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.
[d] GENII-S default
[e] Value for 5 percent clay content in soil
[f] Value for soils with pH greater than 7
[g] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.
[h] For the references listed in this table, GM = 4.4E-03; GSD = 6.9

Table 6-23. Plutonium Soil-to-Plant Transfer Factors for Grain

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 11	4.5E-05 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	8.6E-06	3.5E-07 – 4.2E-01 [b]
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	2.6E-05	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	8.6E-06 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-05 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	2.0E-05 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	1.5E-06 [f]	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.9E-04 [g]	–
9	This analysis - recommendation	–	lognormal; GM = 1.9E-05 [h]; GSD = 4.2 truncation: low = 4.8E-07; high = 7.8E-04



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Range given as 95-percent confidence range

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENII-S default

[e] Value for 5 percent clay content in soil

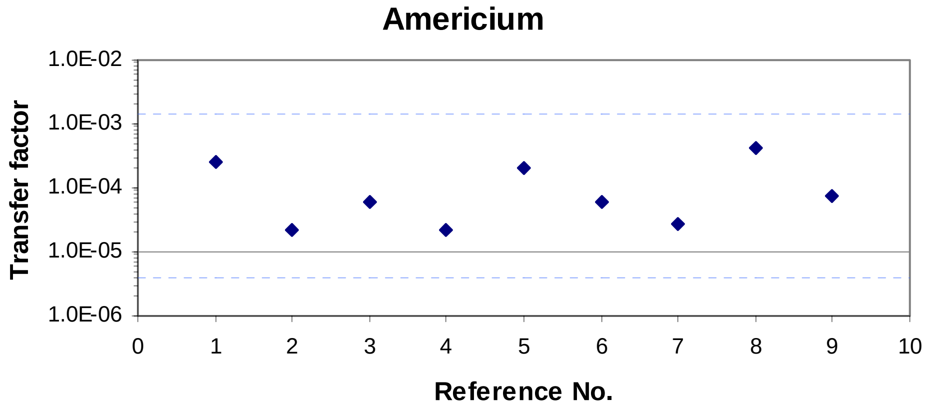
[f] Value for wheat, oat, and barley

[g] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[h] For the references listed in this table, GM = 1.9E-05; GSD = 4.2

Table 6-24. Americium Soil-to-Plant Transfer Factors for Grain

No.	Reference	Transfer Factor, dimensionless Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 11	2.5E-04 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	2.2E-05	1.5E-07 to 7.7E-01 [b]
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	5.9E-05	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.2E-05 [c]	lognormal; GSD = 2
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-04 [d]	–
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	6.0E-05 [e]	–
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	2.8E-05 [f]	–
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	4.1E-04 [g]	–
9	This analysis - recommendation	–	lognormal; GM = 7.5E-05 [h]; GSD = 3.2 truncation: low = 3.8E-06; high = 1.5E-03



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value was developed for plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers)

[b] Range given as 95-percent confidence range

[c] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain.

[d] GENIIS default

[e] Value for 5 percent clay content in soil

[f] Value for wheat, oat, and barley

[g] RESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

[h] For the references listed in this table, GM = 7.5E-05; GSD = 3.2

Table 6-25. Soil-to-Plant Transfer Factors for Grain for Other Elements

	Reference	Transfer Factor, dimensionless (Bq/kg dry-weight crop per Bq/kg dry-weight soil)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Baes et al. 1984 [DIRS 103766], p. 11	7.0E+01	2.5E-02	2.5E-01	6.0E-03	3.0E-02	9.0E-03	1.5E-03	3.5E-04	8.5E-05	2.5E-04	4.0E-03
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–	1.7E-01	–	2.8E-02	4.7E-03	1.2E-03	–	3.4E-05	–	1.3E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	7.0E+01	2.5E-02	1.3E-01	6.0E-03	2.6E-02	4.7E-03	1.2E-03	3.5E-04	3.4E-05	2.5E-04	1.3E-03
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	2.5E-02	1.2E-01	3.0E-02	1.0E-02	4.7E-03	1.2E-03	3.5E-03	3.4E-05	2.5E-03	1.3E-03
5	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E+00	5.0E-02	2.0E-01	1.0E-02	1.0E-02	1.0E-02	1.0E-02	3.0E-04	4.0E-04	2.0E-02	2.0E-04
6	Sheppard 1995 [DIRS 103789], pp. 55 to 57	–	–	1.7E-01	–	1.2E-02	1.2E-03	1.8E-03	–	1.3E-03	–	1.6E-03
7	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–	7.7E-02	–	1.2E-02	1.4E-02	5.8E-02	–	2.0E-03	–	1.6E-04
8	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	7.0E+01	2.5E-02	3.7E-01	6.0E-03	9.8E-02	5.6E-03	3.5E-03	3.5E-04	2.1E-04	2.5E-04	6.4E-03
9	GM	2.4E+01	2.9E-02	1.7E-01	9.2E-03	2.0E-02	5.5E-03	3.1E-03	5.4E-04	1.7E-04	9.5E-04	1.1E-03
	GSD	8.4	1.4	1.6	2.0	2.2	2.1	4.0	2.9	5.2	7.2	3.6
	Recommended GSD	8.4	2.0 [a]	2.0 [a]	2.0	2.2	2.1	4.0	2.9	5.2	7.2	3.6
	Truncation, lower limit	1.0E-01	4.8E-03	2.8E-02	1.5E-03	2.7E-03	8.2E-04	8.8E-05	3.6E-05	2.4E-06	5.9E-06	4.1E-05
	Truncation, upper limit	5.8E+03	1.7E-01	1.0E+00	5.5E-02	1.6E-01	3.8E-02	1.1E-01	8.0E-03	1.2E-02	1.5E-01	3.1E-02

[a] The lower bound of the value of the GSD was used.

6.2.1.2.5 Forage Plants

The TFs for forage plants were based on TF values from the references listed in Tables 6-26 to 6-31. If there was a choice of TFs for a specific plant species used as forage, the TFs for leguminous plants were selected. Leguminous plants (e.g., peas, soybeans, snap beans, alfalfa, and clover) have a symbiotic relationship with nitrogen-fixing bacteria in their roots and often exhibit higher radionuclide uptake than non-legumes (Peterson 1983 [DIRS 167077], p. 5-52). The TFs for actinide uptake by plants sometimes are an order of magnitude higher for legumes and for other species, such as grasses (Peterson 1983 [DIRS 167077], p. 5-52). Alfalfa, a leguminous plant, is the major crop grown in the Amargosa Valley (CRWMS M&O 1997 [DIRS 101090], pp. 3-18 to 3-19; YMP 1999 [DIRS 158212], pp. 17 to 18). Therefore, a preference was given to TFs for leguminous plants in developing TF values for pasture crops (e.g., alfalfa and clover). TFs for other forage crops (e.g., grasses) were only used if TFs for leguminous plants were not available or if the reference did not specify the plant species. The TFs for forage plants are listed in Tables 6-26 to 6-31. Calculation of GMs, standard deviations, and truncation limits for the TFs were preformed using Microsoft Excel 2000, as described in Appendix A.

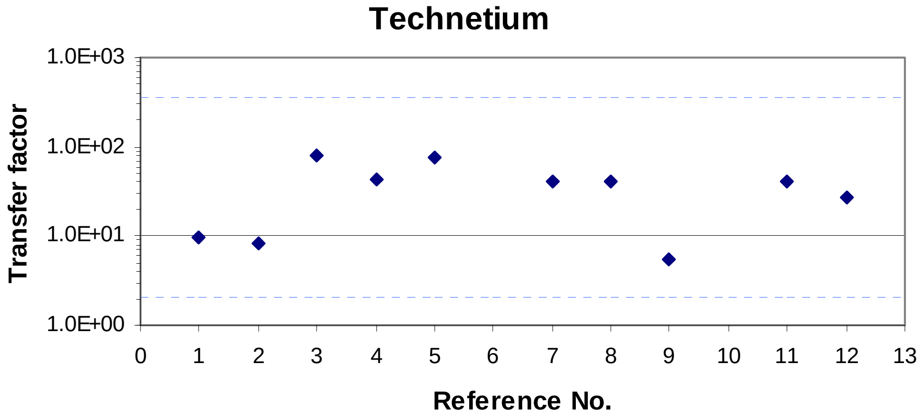
6.2.1.2.6 Site-specific Studies

This section compares selected TF values developed for the biosphere model with the results of site-specific measurements involving plutonium and americium uptake by plants. These measurement have been conducted on the NTS and also under greenhouse conditions using soil collected from aged fallout areas on the NTS (Romney and Wallace 1976 [DIRS 160549], pp. 287 to 302; Romney et al. 1977 [DIRS 160558], pp. 53 to 64). For plants grown under field conditions, the majority of the contamination was from resuspended material deposited on the plant surfaces. Root uptake of plutonium was a minor contributor to the overall activity concentration in the plants (Romney and Wallace 1976 [DIRS 160549], p. 295). The greenhouse experiments involved several species of plants grown in pots. For these experiments, TFs were in the range of 10^{-6} to 10^{-3}, while the TFs calculated for plutonium in the field, where the majority of contamination was external, ranged from 10^{-3} to 10^{0} (Romney and Wallace 1976 [DIRS 160549], p. 295). The experiments also indicated that the uptake of americium from soils is greater than the uptake of plutonium. Americium uptake by plants is also influenced by soil pH (Au et al. 1977 [DIRS 160560], p. 4). A summary of the results of these experiments is shown in Tables 6-32 and 6-33 for plutonium and americium, respectively.

The experiments involving NTS soils were also designed to test the influence of soil amendments on plant uptake of plutonium and americium through the root system. The results showed that addition of nitrogen fertilizer and organic matter amendments did not alter the uptake of plutonium and americium through roots of barley and alfalfa plants. However, acidulation of soils considerably increased root uptake, especially when applied with a chelating agent.

Table 6-26. Technetium Soil-to-Plant Transfer Factors for Forage Plants

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 10	9.5E+00 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	8.1E+00 [b]	8.1E-01 to 8.1E+01 [b]
3	IAEA 2001 [DIRS 158519], pp. 67 to 68	8.0E+01 [c]	–
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	4.4E+01 [d]	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	7.6E+01 [e]	lognormal; GSD = 2
6	NCRP 1984 [DIRS 103784], p. 75	–	–
7	NCRP 1996 [DIRS 101882], pp. 52 to 54	4.0E+01 [f]	–
8	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E+01 [g]	–
9	Sheppard 1995 [DIRS 103789], pp. 55 to 57	5.6E+00 [h]	–
10	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–
11	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	4.0E+01 [i]	–
12	This analysis - recommendation	–	lognormal; GM = 2.7E+01 [j]; GSD = 2.7 truncation: low = 2.1E+00; high = 3.5E+02



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to forage plants but rather it was developed for vegetative portions of crops (leaves and stems)

[b] Value for fodder. Range given as 95-percent confidence range.

[c] Value recommended for screening models

[d] Value for leafy vegetables (human crop types and animal crop types were combined)

[e] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain. Same value as that for leafy vegetables (GENII-S does not distinguish between TFs for the leafy vegetables and forage plants).

[f] Value recommended for screening models.

[g] GENII-S default

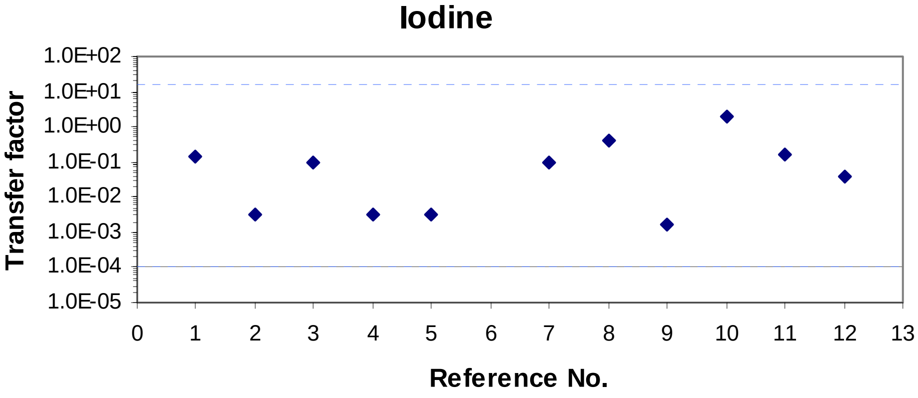
[h] Value for 5 percent clay content in soil

[i] RESRAD default value.

[j] For the references listed in this table, GM = 2.7E+01; GSD = 2.7

Table 6-27. Iodine Soil-to-Plant Transfer Factors for Forage Plants

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 10	1.5E-01 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	3.4E-03 [b]	3.4E-04 to 3.4E-02 [b]
3	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-01 [c]	–
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	3.4E-03 [d]	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	3.4E-03 [e]	lognormal; GSD = 2
6	NCRP 1984 [DIRS 103784], p. 75	–	1.5E-02 to 3.3E+00
7	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-01 [f]	–
8	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-01 [g]	–
9	Sheppard 1995 [DIRS 103789], pp. 55 to 57	1.6E-03 [h]	–
10	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	1.84E+00 [i]	–
11	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.7E-01 [j]	–
12	This analysis - recommendation	–	lognormal; GM = 4.0E-02 [k]; GSD = 10.0 truncation: low = 1.1E-04; high = 1.5E+01



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to forage plants but rather it was developed for vegetative portions of crops (leaves and stems)

[b] Value for grass. Range given as 95-percent confidence range.

[c] Value recommended for screening models

[d] Value for leafy vegetables (human crop types and animal crop types were combined)

[e] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain. Same value as that for leafy vegetables (GENII-S does not distinguish between TFs for the leafy vegetables and forage plants).

[f] Value recommended for screening models.

[g] GENII-S default

[h] Value for 5 percent clay content in soil

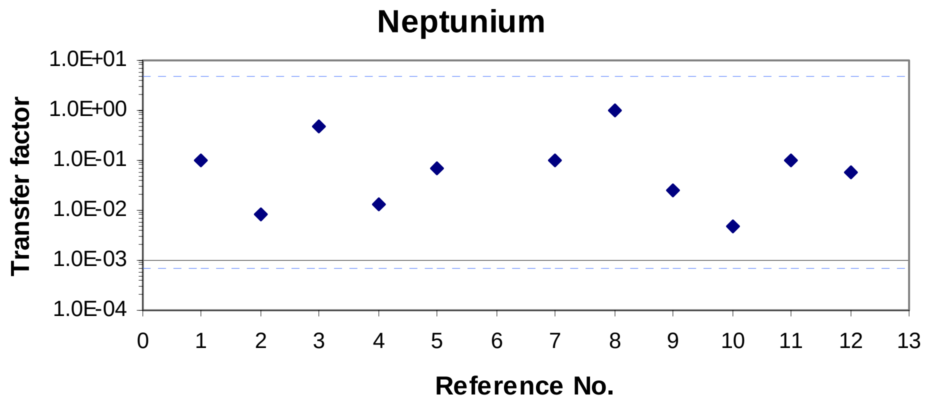
[i] Value for alfalfa, clover, and sorghum

[j] RESRAD default value.

[k] For the references listed in this table, GM = 4.0E-02; GSD = 11.6. The upper bound for the GSD value was used.

Table 6-28. Neptunium Soil-to-Plant Transfer Factors for Forage Plants

No.	Reference	Transfer Factor, dimensionless Best Estimate	 Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 10	1.0E-01 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	8.1E-03 [b]	2.0E-03 to 1.2E-01 [b]
3	IAEA 2001 [DIRS 158519], pp. 67 to 68	5.0E-01 [c]	–
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	1.3E-02 [d]	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	6.9E-02 [e]	lognormal; GSD = 2
6	NCRP 1984 [DIRS 103784], p. 75	–	–
7	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-01 [f]	–
8	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E+00 [g]	–
9	Sheppard 1995 [DIRS 103789], pp. 55 to 57	2.4E-02 [h]	–
10	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	4.8E-03 [i]	–
11	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.0E-01 [j]	–
12	This analysis - recommendation	–	lognormal; GM = 5.8E-02 [k]; GSD = 5.6 truncation: low = 6.8E-04; high = 4.9E+00



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to forage plants but rather it was developed for vegetative portions of crops (leaves and stems)

[b] Value for clover. Range given as 95-percent confidence range.

[c] Value recommended for screening models

[d] Value for leafy vegetables (human crop types and animal crop types were combined)

[e] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain. Same value as that for leafy vegetables (GENII-S does not distinguish between TFs for the leafy vegetables and forage plants).

[f] Value recommended for screening models.

[g] GENII-S default

[h] Value for 5 percent clay content in soil

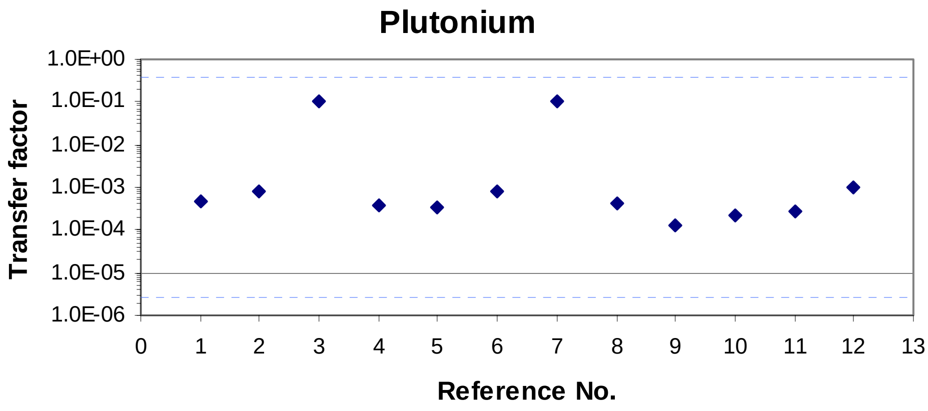
[i] Value for grasses, pH greater than 7

[j] RESRAD default value.

[k] For the references listed in this table, GM = 5.8E-02; GSD = 5.6.

Table 6-29. Plutonium Soil-to-Plant Transfer Factors for Forage Plants

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 10	4.5E-04 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	8.0E-04 [b]	1.1E-04 to 5.1E-02 [b]
3	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-01 [c]	–
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	3.9E-04 [d]	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	3.4E-04 [e]	lognormal; GSD = 2
6	NCRP 1984 [DIRS 103784], p. 75	8.5E-04 [f]	9.2E-06 – 8.5E-04
7	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-01 [g]	–
8	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-04 [h]	–
9	Sheppard 1995 [DIRS 103789], pp. 55 to 57	1.3E-04 [i]	–
10	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	2.3E-04 [j]	–
11	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	2.7E-04 [k]	–
12	This analysis - recommendation	–	lognormal; GM = 1.0E-03 [l]; GSD = 10.0 truncation: low = 2.7E-06; high = 3.9E-01



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to forage plants but rather it was developed for vegetative portions of crops (leaves and stems)

[b] Value for clover and alfalfa. Range given as 95-percent confidence range.

[c] Value recommended for screening models

[d] Value for leafy vegetables (human crop types and animal crop types were combined)

[e] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain. Same value as that for leafy vegetables (GENII-S does not distinguish between TFs for the leafy vegetables and forage plants).

[f] Upper value for the range was used

[g] Vale recommended for screening models.

[h] GENII-S default

[i] Value for 5 percent clay content in soil

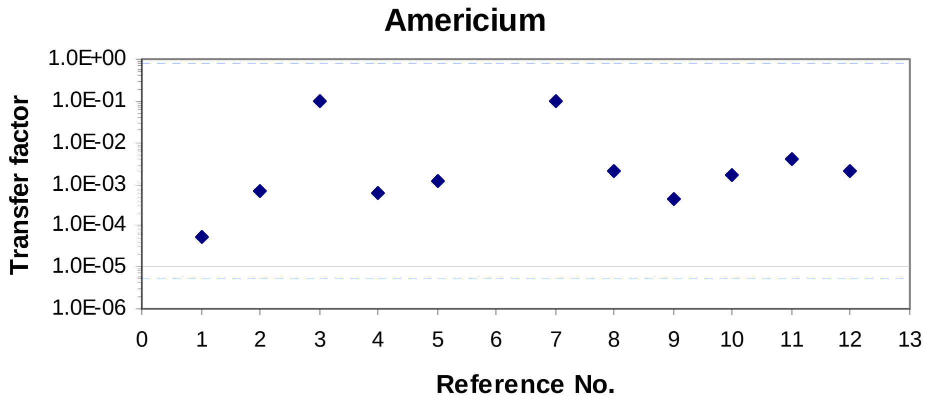
[j] Value for alfalfa, clover, and sorghum

[k] RESRAD default value.

[l] For the references listed in this table, GM = 1.0E-03, GSD = 10.2. The upper bound for the GSD value was used.

Table 6-30. Americium Soil-to-Plant Transfer Factors for Forage Plants

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 10	5.5E-05 [a]	–
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	7.1E-04 [b]	1.8E-04 to 3.1E-03 [b]
3	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-01 [c]	–
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	5.8E-04 [d]	–
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.2E-03 [e]	lognormal; GSD = 2
6	NCRP 1984 [DIRS 103784], p. 75	–	–
7	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-01 [f]	–
8	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-03 [g]	–
9	Sheppard 1995 [DIRS 103789], pp. 55 to 57	4.2E-04 [h]	–
10	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	1.7E-03 [i]	–
11	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	4.0E-03 [j]	–
12	This analysis - recommendation	–	lognormal; GM = 2.1E-03 [k]; GSD = 10.0 truncation: low = 5.5E-06; high = 7.9E-01



NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.
Truncation limits shown in graph as dashed lines.

[a] The value is not specific to forage plants but rather it was developed for vegetative portions of crops (leaves and stems)

[b] Value for clover. Range given as 95-percent confidence range.

[c] Value recommended for screening models

[d] Value for leafy vegetables (human crop types and animal crop types were combined)

[e] Input values for the GENII-S code used in biosphere modeling for Yucca Mountain. Same value as that for leafy vegetables (GENII-S does not distinguish between TFs for the leafy vegetables and forage plants).

[f] Value recommended for screening models.

[g] GENII-S default

[h] Value for 5 percent clay content in soil

[i] Value for alfalfa, clover, and sorghum

[j] RESRAD default value.

[k] For the references listed in this table, GM = 2.1E-03, GSD = 10.4. The upper bound for the GSD value was used.

Table 6-31. Soil-to-Plant Transfer Factors for Forage Plants for Other Elements

	Reference	Transfer Factor, dimensionless (Bq/kg dry-weight crop per Bq/kg dry-weight soil)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Baes et al. 1984 [DIRS 103766], p. 10	7.0E+01	2.5E-02	2.5E+00	3.0E-02	8.0E-02	4.5E-02	1.5E-02	3.5E-03	8.5E-04	2.5E-03	8.5E-03
2	IAEA 1994 [DIRS 100458], pp. 17 to 25	–	–	6.6E-01	–	1.7E-01	1.1E-03	8.0E-02	–	1.1E-02	–	2.3E-02
3	IAEA 2001 [DIRS 158519], pp. 67 to 68	–	1.0E+00	1.0E+01	1.0E+00	1.0E+00	1.0E-01	4.0E-01	1.0E-01	1.0E-01	1.0E-01	2.0E-01
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.25 to 6.27	7.0E+01	2.5E-02	1.6E+00	3.0E-02	1.3E-01	5.8E-03	7.5E-02	3.5E-03	6.6E-03	2.5E-03	1.7E-02
5	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	2.5E-02	1.1E+00	3.0E-02	1.1E-01	1.1E-03	8.0E-02	3.5E-03	1.1E-02	2.5E-03	2.3E-02
6	NCRP 1984 [DIRS 103784], p. 75	–	–	1.8E+00	–	4.1E-02	–	–	–	–	–	–
7	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E+02	5.0E-01	4.0E+00	1.0E+00	1.0E+00	1.0E-01	2.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
8	Rittmann 1993 [DIRS 107744], pp. 35 to 36	5.0E+01	5.0E-01	2.0E+00	1.0E-01	2.0E-02	1.0E-01	1.0E-01	1.0E-02	4.0E-03	5.0E-02	4.0E-03
9	Sheppard 1995 [DIRS 103789], pp. 55 to 57	–	–	1.1E+00	–	7.7E-02	7.8E-03	1.2E-02	–	8.5E-03	–	1.1E-02
10	Peterson 1983 [DIRS 167077], pp. 5-50 to 5-51	–	–	3.1E+00	–	9.3E-02	–	1.0E-01	–	4.6E-03	–	3.9E-04
11	Wang et al. 1993 [DIRS 103839], pp. 25 to 26	1.0E+02	5.0E-01	2.0E+00	1.0E+00	2.0E-01	1.0E-01	2.0E-01	1.0E-01	9.0E-03	1.0E-01	1.0E-01
	GM	7.5E+01	1.5E-01	2.1E+00	1.6E-01	1.3E-01	1.8E-02	8.2E-02	1.7E-02	1.0E-02	1.9E-02	1.7E-02
	GSD	1.3	5.5	2.1	5.8	3.3	7.0	3.0	5.4	4.2	6.7	6.1
	Recommended GSD	2.0 [a]	5.5	2.1	5.8	3.3	7.0	3.0	5.4	4.2	6.7	6.1
	Truncation, lower limit	1.3E+01	1.9E-03	3.2E-01	1.7E-03	6.3E-03	1.2E-04	4.9E-03	2.2E-04	2.5E-04	1.4E-04	1.6E-04
	Truncation, upper limit	4.5E+02	1.3E+01	1.3E+01	1.5E+01	2.8E+00	2.8E+00	1.4E+00	1.3E+00	3.9E-01	2.5E+00	1.9E+00

[a] The lower bound of the value of the GSD was used.

Table 6-32. Plutonium Transfer Factors for Plants Grown in Pot Cultures Using Nevada Test Site Soil

Plant	Range of Transfer Factors	Comments
Ladino clover	10^{-5} to 10^{-4}	TFs increased by a factor of 7 in 5 years
Alfalfa	10^{-5} to 10^{-4}	Highest TFs involve chelate treatment
Barley, fruit heads	10^{-6} to 10^{-3}	
Soybean, forage	10^{-4} to 10^{-3}	Highest TFs involve chelate treatment
Soybean, bean	10^{-6} to 10^{-4}	Highest TFs involve chelate treatment
Barley, grain	10^{-7}	High-fired Pu oxide

Source: Schulz (1977 [DIRS 160550], p. 323); Romney et al. (1977 [DIRS 160558], p. 53).

Table 6-33. Americium Transfer Factors for Plants Grown in Pot Cultures Using Nevada Test Site Soil

Plant	Range of Transfer Factors	Comments
Barley, grain	10^{-5} to 10^{-3}	Highest TFs involve chelate treatment
Wheat, grain	10^{-7} to 10^{-5}	
Alfalfa	10^{-4} to 10^{-2}	Highest TFs involve treatment with soil amendments
Soybean, bean	10^{-4} to 10^{-2}	Highest TFs involve chelate treatment
Soybean, leaves and stems	10^{-3} to 10^{-1}	

Source: Schulz (1977 [DIRS 160550], p. 324); Romney et al. (1977 [DIRS 160558], p. 53).

In another study (Au et al. 1977 [DIRS 160560], pp. 1 to 14), radishes, lettuce, barley, and alfalfa were grown from seeds in undisturbed soil on the NTS to determine the uptake of transuranics under field conditions. The plants were grown in small greenhouses to prevent external deposition of radionuclides. The crops were irrigated with water containing a chelating agent, fertilizer, or both. The soil pH was affected by the irrigation water with additives. The plutonium and americium ratios were higher than most previously reported in the literature (Au et al. 1977 [DIRS 160560], p. 1). The experimental results concerning the TFs for plutonium and americium are shown in Table 6-34.

The TFs for crops used in the experiment do not seem to be greatly affected by the water additives. Other authors who studied the effect of chelating agents on plant uptake of transuranics found that plutonium and americium uptake from soil increased when chelating agents were added. One study found that chelates increased the uptake of plutonium from sand cultures on the order of 1×10^3 (Schulz 1977 [DIRS 160550], p. 326). These findings are not supported by the results presented in Table 6-34, where in most cases chelates decreased root uptake of plutonium and americium. Another inconsistency is the similar uptake of plutonium and americium from soils. The other experiments (Romney et al. 1977 [DIRS 160558], p. 62), as well as the TFs summarized in Tables 6-5 and 6-6, 6-11 and 6-12, 6-17 and 6-18, 6-23 and 6-24, as well as 6-29 and 6-30, also indicate that the uptake of americium from soils is greater than the uptake of plutonium for all types of crops considered in the biosphere model.

Table 6-34. Transfer Factors for Plutonium and Americium to Edible Parts of Crops Grown in Contaminated Soil at Nevada Test Site

Plant	Treatment	Plutonium($^{239\text{-}240}$Pu)	Americium (^{241}Am)
Radish, root	Water	1.7×10^{-2}	2.4×10^{-2}
	Chelate	1.0×10^{-2}	1.1×10^{-2}
	Fertilizer	1.6×10^{-2}	9.4×10^{-3}
	Fertilizer/Chelate	6.3×10^{-3}	7.2×10^{-3}
Lettuce, leaf	Water	7.2×10^{-2}	5.0×10^{-2}
	Chelate	2.1×10^{-2}	4.1×10^{-2}
	Fertilizer	2.1×10^{-2}	4.1×10^{-2}
	Fertilizer/Chelate	3.4×10^{-2}	1.3×10^{-2}
Barley, head	Water	1.4×10^{-2}	7.4×10^{-3}
	Chelate	1.1×10^{-2}	9.2×10^{-3}
	Fertilizer	1.1×10^{-2}	6.8×10^{-3}
	Fertilizer/Chelate	1.2×10^{-2}	7.6×10^{-3}
Alfalfa, stem and leaf	Water	6.0×10^{-2}	1.8×10^{-2}
	Chelate	7.4×10^{-2}	1.5×10^{-2}
	Fertilizer	2.7×10^{-2}	1.0×10^{-2}
	Fertilizer/Chelate	7.6×10^{-2}	2.9×10^{-2}

Source: Au et al. (1977 [DIRS 160560], pp. 8 to 11).

Measurements of transuranic uptake by plants were reviewed by Schulz (1977 [DIRS 160550], pp. 321 to 330), who concluded that the most striking feature of plutonium and americium root uptake was the enormous range of individual TFs, which was 5 orders of magnitude for plutonium uptake (1×10^{-8} to 1×10^{-3}) and 8 orders of magnitude for americium uptake (1×10^{-7} to $1 \times 10^{+1}$) (Schultz 1977 [DIRS 160550], p. 322). Schultz (1977 [DIRS 160550]) also criticized other reviews that suggested plant TFs for plutonium were in the order of 1×10^{-4}. When one reviews the generic values for plutonium uptake by various types of crops contained in Tables 6-5, 6-11, 6-17, 6-23, and 6-29, the TF for plutonium indeed appears to be on the order of 1×10^{-4}. These results are consistent with the ranges of experimental values presented in Table 6-32, which are the averages of several samples. This indicates that TFs developed for plutonium (Tables 6-5, 6-11, 6-17, 6-23, and 6-29), which are on the order of 1×10^{-4}, are appropriate for use in the biosphere model. The TFs for americium calculated in experiments involving soil collected on the NTS are also in reasonable agreement with values developed for the biosphere model (Tables 6-6, 6-12, 6-18, 6-24, and 6-30).

The experiments that resulted in much higher TF values (Table 6-34) were not used in this analysis due to the inconsistencies indicated previously. There is a high level of uncertainty in the TF values, which may be attributable to experimental conditions and the accuracy of the analytical methods used to measure the low levels of plutonium and americium in the vegetation samples.

6.2.1.3 Transfer Factors for the Volcanic Ash Exposure Scenario

The magnitude of the effect of volcanic ash on TFs would depend on the amount of ash deposited by a volcanic eruption. Several processes that may affect radionuclide uptake by plants through their root systems need to be considered in the context of volcanic ash deposits.

Because volcanic ash soils usually are strongly acidic (Fosberg et al. 1979 [DIRS 159471], p. 541), the potential future ash fall may result in an overall increase of soil acidity, with a corresponding decrease in pH. The pH of typical soils in Amargosa Valley currently exceeds 8.0, which represents highly alkaline soils. As noted previously, higher than neutral pH values decrease uptake, while lower values increase intake (IAEA 1994 [DIRS 100458], p. 16). Therefore, the overall decrease in pH may result in higher rates of plant uptake from soils.

Amargosa Valley soils, because of the low clay content and low organic matter content (Section 6.2.1.1.3), have relatively low cation exchange capacity. The cation exchange capacity serves as a reservoir for plant-available nutrients. Clay soils and soils rich in organic matter have a larger cation exchange capacity than sandy soils because clay and organic matter hold cations. Volcanic soils are more fertile because such soils have higher cation exchange capacity, which provides plants with larger amounts of nutrients, especially the metallic cations, if present in the soil. This phenomenon was demonstrated in a series of experiments on the production of selected crops, in which the effects of mixing large amounts of ash into the soil were investigated. Mount St. Helens ash was mixed in different proportions into a soil (Mahler and Fosberg 1983 [DIRS 159472], p. 198). In general, volcanic ash was found to considerably influence the growth and yield of wheat, peas, and alfalfa, although growth of all crops was depressed under 100 percent ash treatments.

The other objective of the Mahler and Fosberg (1983 [DIRS 159472]) study was to determine the effect of volcanic ash on the nutrient uptake and concentration in wheat. It was found that the plant uptake of some nutrients was positively influenced by the addition of ash, while the uptake of others was influenced negatively (Mahler and Fosberg 1983 [DIRS 159472], p. 197). This was observed for macronutrients and micronutrients. This observation may be attributed to the preferential bonding of one cation over another by exchange sites in the soil. This happens when a relatively high proportion of the one cation (macronutrient) inhibits adsorption of another cation. For example, there may be a preferential bonding of Ca over Sr, depending on the specific soil conditions. This effect may also be important for the uptake of specific elements by crops from volcanic soils. In conclusion, there is evidence that decreased pH may result in increased TFs. However, the increased macronutrient supply may inhibit crop uptake of the minerals present in small concentrations.

To evaluate the potential impact of volcanic ash on the environment, the amount of tephra expected to be deposited as the result of a volcanic event must be determined. Ash depths 18 km downwind from Yucca Mountain were predicted to range from 0.07 to 55 cm (based on 100 realizations of the ASHPLUME model). About 35 percent of predicted depths were less than 1 cm, 75 percent were less than 5 cm, and 90 percent were less than 15 cm (BSC 2004 [DIRS 170026], Table 6-4). Ash depths at the location of the RMEI (18 km south of Yucca Mountain) would be about 2 orders of magnitude or more lower under normal, variable wind conditions (CRWMS M&O 2000 [DIRS 153246], Section 3.10.5.1 and Figure 3.10-14) because the wind at Yucca Mountain blows to the south infrequently (BSC 2004 [DIRS 170026], Figure 8-1). If this were the case, the agricultural soils would contain only a small fraction of ash.

The overall effect of volcanic ash on the values of specific TFs is expected to be insignificant. Because the uncertainty ranges for the TFs developed in the previous section are representative of the generic values, they are believed to include the values that might be associated with volcanic soils. Therefore, the TFs developed for soils that are not mixed with volcanic ash are recommended for use in the volcanic ash scenario.

6.2.1.4 Effect of Climate Change on Transfer Factors

The future climate, represented by the upper bound of the glacial-transition climate, is predicted to be wetter and cooler than the present day climate, but not substantially different from the present day climate, and the human exposure pathways are expected to be the same for both climate states. Consequently, the biosphere conceptual model is the same for both climates. Differences in BDCF values for the two climates arise from different values of climate-dependent model input parameters. The future climate is wetter but not substantially wetter than the present day climate (BSC 2004 [DIRS 170002], Section 7.1). However, the glacial-transition climate is cooler than the present day climate (BSC 2004 [DIRS 170002], Section 7.1], so evaporation is lower than during present day times. Consequently, the water content of the soil can be higher. The TFs developed for the biosphere model are primarily based on generic values for these parameters. In addition, the majority of the information on TFs was based on experiments carried out in temperate climates. Therefore, the TFs for the present day climate are appropriate for use in the biosphere modeling for the cooler and wetter future climate.

6.2.1.5 Correlation of Transfer Factors with Partition Coefficients

Many authors indicate the negative correlation of TFs with partition coefficients (K_ds). A negative correlation between these two parameters exists because a strong K_d limits the mobility of an element (the element will be tightly bound to solids) and the availability for root uptake. This is because the element will not be present in appreciable amounts in the aqueous phase (BIOMASS 2001 [DIRS 159468], T1/WD04, pp. 27 to 31). This limited mobility and bioavailability results in a low TF for elements with high K_ds. Correlation coefficients ranging from -0.47 to -0.88 have been reported in the literature (Davis et al. 1993 [DIRS 103767], p. 234; Karlsson et al. 2001 [DIRS 159470], p. 37; Sheppard and Sheppard 1989 [DIRS 160644], p. 653). Because the available information on correlation between the K_ds and TFs is insufficient to develop element-specific correlations, a single value of -0.8 was used for all elements and all crop types. A single value for the correlation coefficient was also used for the agricultural land model by Karlsson et al. (2001 [DIRS 159470], p. 37). The correlation coefficient should be between log-transformed values of TFs and K_ds (Sheppard and Sheppard 1989 [DIRS 160644], p. 653).

If TFs are correlated with partition coefficients, such an approach induces correlations between TFs for individual crop types for a given element. However, there is evidence of positive correlation between the root uptake of a given element by different crops (Karlsson et al. 2001 [DIRS 159470], p. 37). This results from the general availability of an element for root uptake.

For example, if an element is preferentially present in an aqueous phase, as opposed to being adsorbed onto the soil, the availability of that element for uptake by any crop type is greater than that of an element that is highly sorbed onto the soil.

6.2.2 Radionuclide Transfer to Crops by External Surface Contamination

In addition to the root uptake, radionuclides can also be transferred to crops by external surface contamination resulting from deposition of contaminants. Deposition of contaminants on plant surfaces may be due to irrigation with contaminated water or resuspension of contaminated soil. The contributions of these two processes to the activity concentrations in crops are described in the biosphere model (BSC 2004 [DIRS 169460], Sections 6.4.3.2 and 6.4.3.3) as

$$\begin{aligned} Cp_{water,\,i,j} &= \frac{Dw_{i,j}\ f_{o,j}\ Rw_j\ T_j}{\lambda_w\ Y_j}\left(1-e^{-\lambda_w\ t_{g,j}}\right) \\ Cp_{dust,\ i,j} &= \frac{Da_i\ Ra_j\ T_j}{\lambda_w\ Y_j}\left(1-e^{-\lambda_w\ t_{g,j}}\right) \end{aligned} \tag{Eqs. 6-4 and 6-5}$$

where

$Cp_{water,\,i,j}$ = activity concentration of radionuclide *i* in crop type *j* contributed from plant leaf uptake due to interception of contaminated irrigation water ($\mathrm{Bq/kg}_{\text{wet weight}}$)

$Cp_{dust,\,i,j}$ = activity concentration of radionuclide *i* in crop type *j* contributed from plant leaf uptake due to deposition of resuspended particulates on crop surfaces ($\mathrm{Bq/kg}_{\text{wet weight}}$)

$Dw_{i,j}$ = deposition rate of radionuclide *i* due to application of irrigation water on crop type *j* ($\mathrm{Bq/(m^2\ d)}$)

$f_{o,j}$ = fraction of irrigation applied using overhead methods for plant type *j* (dimensionless)

Rw_j = interception fraction of irrigation water for crop type *j* (dimensionless)

T_j = translocation factor for crop type *j* (dimensionless)

λ_w = weathering constant (per d), which can be calculated from weathering half-life (T_w in units of day) by $\lambda_w = \ln(2) / T_w$

$t_{g,\,j}$ = crop growing time for crop type *j* (d)

Y_j = crop yield or wet biomass for crop type *j* ($\mathrm{kg}_{\text{wet weight}}/\mathrm{m}^2$).

Da_i = deposition rate of radionuclide *i* with resuspended particulates ($\mathrm{Bq/(m^2\ d)}$)

Ra_j = interception fraction for airborne particulates for crop type *j* (dimensionless).

The deposition rate of radionuclide *i* with contaminated particulates, Da_i, quantifies the combined effect of contaminant removal from the atmosphere by several processes, such as gravitational settling, diffusion, and turbulent transport. The deposition rate, which can be derived by letting a uniform volumetric activity fall with an average velocity representative of the assembly of particulates for a defined period of time, is mathematically represented (BSC 2004 [DIRS 169460], Section 6.4.3.3) as

$$Da_i = 8.64 \times 10^4 Ca_{p,i} V_d \quad \text{(Eq. 6-6)}$$

where

$Ca_{p,i}$ = activity concentration of radionuclide *i* in the air used for evaluation of activity deposition on crops (Bq/m^3)
V_d = dry deposition velocity for airborne particulates (m/s)
8.64×10^4 = unit conversion factor (s/d).

This analysis develops values for the deposition velocity, V_d; translocation factor, T_j; and weathering constant, λ_w, used in Equations 6-4 and 6-5.

6.2.2.1 Dry Deposition Velocity

Deposition is an atmospheric removal process involving the transport of matter from the atmosphere to environmental surfaces. Resuspension is the process by which material deposited from the atmosphere is subsequently reentrained and resuspended into the atmosphere. Suspension describes the subsequent insertion of particles that were originally deposited on a surface by some nonatmospheric process, such as irrigation with contaminated water, into the atmosphere (Sehmel 1984 [DIRS 158693], p. 533). For the groundwater exposure scenario, the term suspension would seem to be more appropriate. However, in the literature, the combined processes are usually collectively referred to as resuspension because the subsequent behavior of particles is essentially identical regardless of their origin.

Deposition is caused by gravitational settling as well as by diffusion and turbulent transport. Although the detailed mechanisms of deposition are complicated, it is possible to characterize them by a single parameter, called the deposition velocity, which quantifies the atmosphere–soil surface exchange of particulates and gases. The deposition velocity is usually defined as the ratio of the deposition flux divided by the airborne particle concentration per unit volume, at some height above the surface. It has dimensions of distance per unit time, and its value may vary with environmental conditions, such as the presence of the turbulence and eddies in the near-surface atmospheric layer. The deposition velocities for particles depend on particle size and density and also on other variables such as wind speed and surface roughness (ICRU 2001 [DIRS 160339], pp. 13 to 14). In the biosphere model, deposition velocity is used to estimate deposition rate of suspended particulates on crop surfaces. Table 6-35 summarizes the values of deposition velocity reported in the literature.

Table 6-35. Dry Deposition Velocities Used in Biosphere Modeling

No.	Reference	Values (m/s)	Comments
1	Davis et al. 1993 [DIRS 103767], p. 198	lognormal distribution GM = 0.006 m/s, GSD = 2	Values used for the BIOTRAC model
2	IAEA 1982 [DIRS 103768], p. 17	0.002	Particulates <4 μm deposited on vegetation
3	LaPlante and Poor 1997 [DIRS 101079], p. B-2	0.001	Value used in dose assessment for Yucca Mountain
4	Leigh et al. 1993 [DIRS 100464], p. 5-63	0.001	GENII-S default value
6	Yu et al. 2001 [DIRS 159465], p. D-12	Gaseous elements = 0 Halogens = 0.01 Other elements = 0.001	RESRAD default values

The values shown in Table 6-35 do not include uncertainty, and most of them are not particle-size–specific. Therefore, they were not used in the biosphere model. Instead, a distribution of deposition velocities was developed based in part on the site-specific wind and surface roughness information.

Deposition processes and associated parameters were the subject of a comprehensive review by G.A. Sehmel (1984 [DIRS 158693]). Dry deposition velocities for many materials and various deposition surfaces were summarized (Sehmel 1984 [DIRS 158693], pp. 547 to 551), and they were found to range over 5 orders of magnitude, from 1×10^{-5} m/s to 1.8 m/s. Another review (Peterson 1983 [DIRS 167077], p. 5-19) found deposition velocities to range from 1×10^{-5} m/s to 1×10^{-1} m/s. Sehmel and Hodgson (1978 [DIRS 158587]) developed a generalized technique for estimating deposition velocities of particles in which deposition velocity depends on particle properties (e.g., size and density) and environmental properties (e.g., friction velocity, aerodynamic roughness height, and atmospheric stability). Graphical representations of predicted deposition velocities (Sehmel 1984 [DIRS 158693], pp. 553 and 558 to 561) were used to develop the distribution function of deposition velocity for the biosphere model. These graphs represent deposition velocity as a function of particle diameter for different values of friction velocity, terrain roughness, and particle density. Roughness height depends on the type of surface. Because the deposition velocity is used in the biosphere model to calculate contaminant deposition on crop surfaces, the values of surface roughness representative of the fully grown crops, equal to 9 cm to 14 cm (long grass, fully grown crops) (NCRP 1984 [DIRS 103784], p. 48) is adequate for the intended purpose. The friction velocity depends on the surface cover and the wind speed.

The annual average wind speed measured at the Meteorological Monitoring Site 9, the site closest to Amargosa Valley, was 4.4 m/s, measured at 10 m above the ground surface (DTN: MO04019SUM9397.000 [DIRS 167054]) (see CRWMS M&O 1997 [DIRS 100117], Section 2.1 for description of meteorological monitoring stations and their locations). The average wind speed was hand-calculated by taking an average of the monthly average wind speeds, weighted by the number of days in a month. The wind speed in the surface boundary layer decreases toward the ground surface (Section 6.7.2). For such surface and wind speed conditions, the friction velocity can be estimated to be approximately 0.3 m/s (see Table 6-71 and the accompanying text, NCRP 1984 [DIRS 103784], p. 48 where the range of friction velocity is given, and Sehmel 1984 [DIRS 158693], p. 562). The particle density of resuspended particulates is estimated at about 2.5 g/cm^3, based on the typical soil bulk density of 1.5 g/cm^3 and porosity in the range of 0.3 to 0.4.

The particle size distribution for suspended particulates in the Amargosa Valley region is not known. However, since the processes of particulate resuspension and deposition are governed by the general laws of physics, it is possible to predict (and also confirm the predictions by conducting measurements) the ranges of sizes for the particles that were resuspended due to wind or mechanical stresses. It is recommended that for undisturbed soils, suspended soil particles have one mode of particle size, a median diameter in the range of 2 to 6 μm, and a lognormal distribution with a GSD of about 5 (NCRP 1999 [DIRS 155894], p. 68). In a review (Dorrian 1997 [DIRS 159476]) of particle size distributions of radioactive aerosols in the environment, it was found that the distributions of measured activity median aerodynamic diameters were well fitted by single lognormal function with a median value of 6 μm. It was also determined that the measured activity median aerodynamic diameters ranged from 0.3 to 18 μm (Dorrian 1997 [DIRS 159476], pp. 117 and 129). Under disturbed soil conditions or when strong winds are present, a coarse component can be found in the distribution of resuspended particle sizes. The evaluation of the available information on airborne particulates concluded that the coarse mode could be reasonably well described by a lognormal distribution with mass median aerodynamic diameter of 15 to 25 μm and a GSD of approximately 2 (EPA 1996 [DIRS 160121], pp. 3-156 to 3-192). This coarse component should be considered transient because of the short residence times in the atmosphere due to gravitational settling (NCRP 1999 [DIRS 155894], p. 67). Based on the reviewed literature (EPA 1996 [DIRS 160121], Sections 3.7.5 to 3.8; Nieuwenhuijsen et al. 1998 [DIRS 150855]; Pinnick et al. 1993 [DIRS 160312]; Dorrian 1997 [DIRS 159476]), airborne particles originating from local soils, under disturbed and undisturbed conditions, range in size from about 0.1 μm to about 100 μm.

Predicted deposition velocities for the surface roughness, friction velocity, particle density, and particle size distribution representative of Amargosa Valley conditions range from about 5×10^{-4} m/s to about 3×10^{-2} m/s (Sehmel 1984 [DIRS 158693], p. 559), although Schery (2001 [DIRS 159478], p. 268) shows that deposition velocity values range from about 1×10^{-4} m/s to about 1×10^{-1} m/s. As noted before, the expected sizes for suspended particulates can be approximated by a lognormal distribution with the median diameter in the range of 2 to 6 μm and a GSD of about five (NCRP 1999 [DIRS 155894], p. 68). If the median diameter is 4 μm, 68 percent of particles would fall within the range of 0.8 to 20 μm (4 μm/5 to 4 μm × 5), and 99 percent of particles would be in the range of 0.06 to 250 μm (4 μm/$5^{2.58}$ to 4 μm × $5^{2.58}$). Deposition velocities corresponding to these particle sizes range from 1×10^{-3} to 3×10^{-2} m/s for the most likely sizes of resuspended particles and from 3×10^{-4} and 3×10^{-1} m/s for 99 percent of particles. These values were obtained from the graphs given in the literature (Sehmel 1984 [DIRS 158693], p. 559; Schery 2001 [DIRS 159478], p. 268). The deposition velocity for 4 μm particles can be estimated at around 8×10^{-3} m/s (Sehmel 1984 [DIRS 158693], p. 559). Because deposition velocity as a function particle size changes rapidly in the range of the most probable particle sizes and varies by over two orders of magnitude, the ranges are approximate.

It is recommended that the deposition velocity for the biosphere model be represented by the piece-wise linear cumulative distribution, represented here by the following pairs of the parameter value and cumulative probability: (3×10^{-4} m/s, 0 percent), (1×10^{-3} m/s, 16 percent), (8×10^{-3} m/s, 50 percent), (3×10^{-2} m/s, 84 percent), (3×10^{-1} m/s, 100 percent). These data pairs correspond to particle diameters of 0.06, 0.8, 4, 20 and 250 μm, respectively.

Similar values were used for the BIOTRAC model, where deposition velocity was estimated to be 6×10^{-3} m/s with a GSD of 2.0 (Davis et al. 1993 [DIRS 103767], p. 198). The dry deposition velocity values developed for the Yucca Mountain biosphere are higher than most of the values used in, or recommended for, other biosphere modeling applications (Table 6-35). However, these values better represent site-specific conditions.

The values of dry deposition velocity were developed for the typical sizes of environmental particulate matter originating from the soil and for site-specific ground cover and atmospheric conditions. The reference biosphere is not expected to change greatly over the timeframe of biosphere modeling (Section 6.1.5). Also, based on the values of parameters used in modeling volcanic events (DTN: LA0407DK831811.001 [DIRS 170768]), the sizes of airborne particles for the postvolcanic biosphere are expected to be within the range considered for the groundwater exposure scenario and the present day climate. It is therefore recommended that the same dry deposition velocity be used for the volcanic ash exposure scenario and for the future climate.

6.2.2.2 Translocation Factor

Translocation is the process by which a chemical element, initially deposited on the leaf surface of a plant, moves from the site of deposition to other (edible) parts of the plant, even to those which are not directly affected by the deposition process (e.g., roots). The degree of translocation depends on, among other things, the plant species, chemical and physical form of an element, stage of plant development, and weathering conditions. The translocation factor is defined as the mass activity concentration (Bq/kg) in one tissue, typically an edible tissue, divided by the mass activity concentration (Bq/kg) in another tissue of the same crop or plant (ICRU 2001 [DIRS 160339], p. 18). Alternatively, it can be defined as the ratio of activity on 1 m^2 of edible plant parts at harvest (Bq/m^2) to the activity retained on 1 m^2 of foliage at the time of deposition (Bq/m^2) (IAEA 1994 [DIRS 100458], p. 12). The translocation factor is equal to the fraction of a chemical element initially deposited on the leaf surface that is retained and translocated to the edible plant parts. According to this definition, translocation affects externally deposited contamination that becomes incorporated into the edible portions of the plant tissue as well as the external part of the contamination retained on edible portions of the plant.

In the biosphere model, translocation refers to that portion of activity initially deposited on plant surfaces that contributes to activity in the edible parts of the plant, regardless of whether the contamination in the edible parts of the plant is external or internal. This approach was used in the GENII model (Napier et al. 1988 [DIRS 157927]). The ERMYN model allows for a fraction of this activity to be removed by weathering, therefore implicitly placing activity on the exterior of the plant. Conceptually, the translocation factor apportions externally deposited activity into the fraction that is retained in the edible parts and the fraction that is not. Modeling internal plant contamination is done using soil-to-plant TFs (Section 6.2.1.2), and the TF values are based on experimental measurements. In principle, a portion of radionuclide concentration measured in a plant to determine the TF could have been incorporated by absorption of activity deposited on plant surfaces and thus could have been accounted for in the TF value.

Some conservative models, which are used for screening purposes (IAEA 2001 [DIRS 158519]; Regulatory Guide 1.109, Rev. 1, 1977 [DIRS 100067]), do not use translocation factors at all. In these models, the translocation factor is implicitly equal to unity, thereby implying that all externally deposited activity is transported to the edible parts of the crop.

The values of translocation factors used in the different models that include foliar deposition of radionuclides as one of the environmental transport pathways are consistent. These models do not distinguish between the external versus the internal fraction of deposited activity. The summary of the translocation factor values and their sources is presented in Table 6-36. Translocation factors for the biosphere model make up a set of five values for the individual crop types considered for human and animal consumption. Some references give values of translocation factor for the absorbed fraction of activity deposited on crops (Peterson 1983 [DIRS 167077], p. 5-53, Smith et al. 1996 [DIRS 101085], p. 5-31).

Table 6-36. Translocation Factors from Various Sources and the Selected Values

No.	Reference	Crop type	Translocation Factor (Expected Value)	Comments
1	Leigh et al. 1993 [DIRS 100464], p. 5-63 Napier et al. 1988 [DIRS 157927], p. 4.67	Leafy vegetables Root vegetables Fruit Grain Fresh forage for beef cattle Fresh forage for diary cows Stored feed for beef cattle Stored feed for diary cows Stored feed for poultry Stored feed for laying hens	1.0 0.1 0.1 0.1 1.0 1.0 0.1 0.1 0.1 0.1	GENII and GENII-S default values. Napier et al. 1988 [DIRS 157927] uses “other vegetables” category, whereas Leigh et al. 1993 [DIRS 100464] uses “root vegetables” category for nonleafy vegetables.
2	Mills et al. 1983 [DIRS 103781], p. 135	Leafy vegetables Other produce Fresh forage	1.0 0.1 1.0	For all nonleafy vegetables
3	NCRP 1984 [DIRS 103784], p. 70	Leafy vegetables Other produce Fresh forage	1.0 0.1 1.0	For all nonleafy vegetables
4	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.41 to 6.42	Leafy vegetables Other vegetables Fruit Grain Forage for beef cattle Forage for diary cows Stored grain for poultry Stored grain for laying hens	1.0 0.1 0.1 0.1 1.0 1.0 0.1 0.1	
5	Yu et al. 2001 [DIRS 159465], p. D-12	Leafy vegetables Root vegetables, Fruit, and Grain Fresh forage	1.0 0.1 1.0	Parameter named in the reference the “foliage-to-food radionuclide transfer coefficient.”

Table 6-36. Translocation Factors from Various Sources and the Selected Values (Continued)

No.	Reference	Crop type	Translocation Factor (Expected Value)	Comments
6	LaPlante and Poor 1997 [DIRS 101079], p. B-8	Leafy vegetables Root vegetables Fruit Grain Fresh forage for beef cattle Fresh forage for diary cows Stored feed for poultry Stored feed for laying hens	1.0 0.1 0.1 0.1 1.0 1.0 0.1 0.1	GENII-S default values
7	Values selected for the biosphere model	Leafy vegetables Root vegetables Fruit Grain Fresh forage for beef cattle and diary cows	1.0 See comments See comments See comments 1.0	For crop types other than leafy vegetables and fresh forage a piece-wise cumulative distribution with the minimum value of 0.05, 50% value of 0.1, and the maximum value of 0.3 is recommended.

Internal and external activity in edible parts of crops can be removed during food processing, such as washing and cooking. The biosphere model does not consider further removal of the contaminant following its translocation.

Translocation factor is a very important parameter in the biosphere model because the activity concentration in plants from external deposition is directly proportional to this parameter. The references used to develop the values of individual translocation factors for the biosphere model indicate that fixed values for this parameter are appropriate. The value of 1 for leafy vegetables and forage plants is appropriate because the site of contaminant deposition (leaves) is also the edible part of the plant. However, a fixed value for the other crops may not be an appropriate site-specific choice. Most of the models and their associated input parameters shown in Table 6-36 were developed for temperate climates where the direct deposition pathway is generally less important than root uptake. In the arid and semi-arid climate of the Yucca Mountain region, direct deposition is usually a significant environmental transport pathway for most radionuclides of interest. In the case of highly sorbing elements, such as plutonium, it is more important than the root uptake (Romney and Wallace 1977 [DIRS 160549], p. 295).

There is an uncertainty associated with the fraction of contaminant that is translocated from the site of its deposition to the edible parts of a plant. Considering the importance of this parameter within the biosphere model, representing translocation factors for crops other than leafy vegetables and forage plants by fixed values does not account for the uncertainty in those parameters. No information was found on which an uncertainty distribution for the translocation factors could be based. Therefore, the assumption was made (Assumption 1) that the translocation factor for root (other) vegetables, fruit, grain, and stored feed for laying hens and other poultry be represented by a piece-wise linear cumulative distribution represented by the following pairs (0.05, 0 percent), (0.1, 50 percent), and (0.3, 100 percent). It is also recommended that the same values of translocation factor as those developed for the groundwater exposure scenario and the present day climate be used for the volcanic ash exposure scenario and for the future climate. This is because the translocation factors were developed based on generic values that are also applicable to the future climate.

6.2.2.3 Weathering Rate Constant

Radionuclide concentrations on vegetation may be reduced by a variety of processes, such as the action of the wind, washout, surface abrasion, volatilization, and addition of new tissue. The combined effect of radionuclide removal from vegetation, by processes other than radioactive decay, can be described by a first-order removal model. The model uses an aggregated parameter called the weathering rate constant, or the weathering rate (IAEA 2001 [DIRS 158519], Section 5.1.1.2; also ICRU 2001 [DIRS 160339], p. 16 for the generic definition of the rate constant). There is evidence that the weathering rate constant may depend on the plant type and the radionuclide (Smith et al. 1996 [DIRS 101085], p. 5-30); however, this dependence is usually not included in the biosphere models. In the biosphere model for Yucca Mountain, the dependence of weathering rate on the plant type and radionuclide is included in the uncertainty range associated with the parameter value. A typically used value of the weathering rate constant is based on the half-life of the crop surface–deposited contamination of 14 days. The relationship (ICRU 2001 [DIRS 160339], p. 15) between any process half-life and the process rate constant is expressed as

$$T = \frac{\ln 2}{\lambda} \qquad \text{(Eq. 6-7)}$$

where

T = process half-life, days
λ = process rate constant, days^{-1}.

The value of 14 days for the weathering half-life (or 0.05 d^{-1} for the weathering rate constant) is used in many documents, including the recent recommendations from the IAEA (2001 [DIRS 158519], p. 63-64). The summary of the weathering half-lives used in several radiological assessments is given in Table 6-37.

Table 6-37. Values of Weathering Half-Life from Various Sources

No.	Reference	Weathering half-life, days	Comments
1	Baes et al. 1984 [DIRS 103766], p. 124	14 8 (iodine)	Cited from NRC Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067] and other references
2	IAEA 2001 [DIRS 158519], p. 63	14 (all plant surfaces)	Values given as removal constants, converted using Eq. 6-7
3	LaPlante and Poor 1997 [DIRS 101079], p. B-7	14	GENII-S default value
4	Leigh et al. 1993 [DIRS 100464], p.5-63	14	GENII-S default
5	Mills et al. 1983 [DIRS 103781], p. 137	14	Cited from NRC Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067]

Table 6-37. Values of Weathering Half-Life from Various Sources (Continued)

No.	Reference	Weathering half-life, days	Comments
6	NCRP 1984 [DIRS 103784], p. 70	14	Cited from NRC Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067]
7	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-69	14	Based on NRC staff's judgments, as stated in the notes.
8	Smith et al. 1996 [DIRS 101085], p. 5-30	5 (Np, Pu, and Am on grain and leafy vegetables) 14 (pasture, root vegetables, fruit, and leafy vegetables, except for Np, Pu, and Am) 30 (grain except for Np, Pu, and Am)	Element and crop dependent values; half-times were calculated using Equation 6-7 from the weathering rates given in the reference.
9	Peterson 1983 [DIRS 167077], pp. 5-36 to 5-37	3.7-14	Range of the results of the long-term retention studies, short-term (weathering) component of the retention function
10	Yu et al. 2001 [DIRS 159465], p. D-12	12.7 (13 days)	Calculated from weathering removal constant of 20 yr^{-1} using Equation 6-7 and unit conversion.
11	Value selected for the biosphere model	Piece-wise cumulative distribution: 5 days, 0% 14 days, 50% 30 days, 100%	

The weathering half-life supports modeling of direct activity deposition on plant surfaces. As described in the previous section, for most radionuclides deposition of activity on plant surfaces is a more important environmental transport pathway than the root uptake. The weathering half-life is a parameter that quantifies the amount of contaminant remaining on the crops following external deposition. As explained in Section 6.2.2.2, it is important to correctly represent the uncertainty in the value of parameters supporting the direct deposition environmental transport pathway. The values of the weathering half-life, given in Table 6-37, range from 5 days to 30 days, with a mode of 14 days. Considering this information, it is recommended that the weathering half-life be represented by the following piece-wise cumulative distribution: (5 days, 0 percent), (14 days, 50 percent), and (30 days, 100 percent). The short weathering half-life corresponds to the crops irrigated using an overhead sprinkler system. The longer weathering half-life is appropriate for contaminant removal from crops irrigated using flood, ditch, drip, or other types of irrigation that do not involve the overhead method and thus are not accompanied by the rapid removal of contaminants from the crop surfaces.

It is also recommended that the distribution developed for the groundwater exposure scenario and the present day climate should be used for the volcanic ash exposure scenario and for the future climate. This is because the distribution of the weathering half-life is based on a wide range of values that also apply for the future climate.

6.3 RADIONUCLIDE TRANSPORT TO ANIMAL PRODUCTS

Another set of environmental transport pathways considered in the biosphere model is concerned with the processes leading to contamination of animal products meant for human consumption. The values of environmental transport parameters for the animal product submodel of the biosphere model are developed in this section. A brief description of the animal product submodel is presented in Section 6.3.1. Section 6.3.2 documents the development of parameter values for animal feed, water, and soil consumption rates. The development of animal intake-to-animal product TCs is described in Section 6.3.3.

The biosphere model includes four types of animal products: beef, poultry, milk, and eggs. Therefore, the parameters employed in the submodels of radionuclide transport to animal products correspond to these four animal products.

6.3.1 Description of the Animal Product Submodel

Calculation of radionuclide concentration in animal products, such as meat, milk, and eggs, is based in the biosphere model on the media equilibrium model, which relates radionuclide concentration in animal products to an animal's daily radionuclide intake through the use of the TCs. The TCs represent the fraction of the animal's daily intake of a radionuclide that appears in each unit of mass or volume of the product. The daily radionuclide intake is comprised of contributions from the animal's feed, water, and direct ingestion of surface soil.

The concentration of a radionuclide in specific animal product ($Cd_{i,k}$) (BSC 2004 [DIRS 169460], Section 6.4.4) can be estimated as

$$Cd_{i,k} = Cd_{feed,\ i,k} + Cd_{water,\ i,k} + Cd_{soil,\ i,k} \qquad \text{(Eq. 6-8)}$$

where

$Cd_{i,k}$ = activity concentration of radionuclide i in animal product k (Bq/kg $_{\text{fresh weight}}$ or Bq/L for milk)
k = animal product index; k = 1 for beef, 2 for milk, 3 for poultry, 4 for eggs
$Cd_{feed,\ i,k}$ = activity concentration of radionuclide i in animal product k due to ingestion of contaminated animal feed (Bq/kg or Bq/L for milk)
$Cd_{water,\ i,k}$ = activity concentration of radionuclide i in animal product k due to ingestion of contaminated water (Bq/kg or Bq/L for milk)
$Cd_{soil,\ i,k}$ = activity concentration of radionuclide i in animal product k due to ingestion of contaminated soil (Bq/kg or Bq/L for milk).

The activity concentration of a radionuclide in animal products contributed from ingesting contaminated animal feed, water, and soil is described in the biosphere model (BSC 2004 [DIRS 169460], Sections 6.4.4.1 through 6.4.4.3) as

$$\begin{aligned} Cd_{feed,\,i,k} &= Fm_{i,k}\; Cp_{i,j}\; Qf_k \\ Cd_{water,\,i,k} &= Fm_{i,k}\; Cw_i\; Qw_k \\ Cd_{soil,\,i,k} &= Fm_{i,k}\; Cs_{m,i}\; Qs_k \end{aligned} \qquad \text{(Eqs. 6-9 to 6-11)}$$

where

$Fm_{i,k}$ = animal intake–to–animal product TC for radionuclide *i* and animal product *k* (d/kg $_{\text{fresh weight}}$ or d/L for milk)
$Cp_{i,j}$ = activity concentration of radionuclide *i* in animal feed *j* (Bq/kg $_{\text{fresh weight}}$)
Qf_k = animal consumption rate of feed (kg/d)
Cw_i = activity concentration of radionuclide *i* groundwater (Bq/L)
Qw_k = animal consumption rate of drinking water (L/d)
$Cs_{m,i}$ = saturation activity concentration of radionuclide *i* in the surface soil per unit mass (Bq/kg)
Qs_k = animal consumption rate of soil (kg/d).

Of the parameters in Equations 6-8 to 6-11, this analysis develops the values of animal intake-to -animal product TCs and the animal consumption rates for the animal feed, water, and soil. Another term used in radioecology for the animal intake–to–animal product TC is the feed TC (ICRU 2001 [DIRS 160339], p. 14). However, this term is not precise in the context of the ERMYN model because the animal radionuclide intake is not only due to the ingestion of feed but also to the ingestion of water and soil.

The intake of food, water, and soil by animals depends on species, mass, age, growth rate, digestibility of feed, and, in the case of lactating animals, milk yield (IAEA 2001 [DIRS 158519], p. 69). The type of feed depends on the animal species. Typical feed for the dairy cows includes grass products, corn, clover, alfalfa, and sugar beets, whereas beef cattle are fed a diet of grass products and corn (IAEA 1994 [DIRS 100458], p. 32). Laying hens and chickens are fed cereals and protein feed. For the biosphere model calculations, grazing animals (beef cattle and diary cows), are assumed to be on a diet of fresh pasture only, and laying hens and poultry are assumed to be fed grain.

6.3.2 Animal Consumption Rates for Water, Feed, and Soil

To develop the animal water, feed, and soil consumption rates appropriate for the biosphere model, eleven documents were reviewed. The relevant parameter values are shown in Table 6-38. The biosphere model uses animal feed consumption rates expressed in units of wet-weight. In many instances, as indicated in the table, the feed intakes of domestic animals were given on a dry-weight basis in the references. In theory, the conversion from one set of values to the other can be accomplished through the use of the dry-to-wet weight ratios. In many cases, the dry-to-wet weight ratios (IAEA 1982 [DIRS 103768]; NCRP 1984 [DIRS 103784]; IAEA 1994 [DIRS 100458]) or the fractions of different types of animal feed in an animal diet

(Kennedy and Strenge 1992 [DIRS 103776]) were not given, and the wet-weight-based consumption rates could not be calculated.

The exposure pathways involving animal product consumption have not been of significance for most radionuclides in the previous iterations of biosphere modeling supporting TSPA (BSC 2003 [DIRS 169674], Tables 6.2-10 and 6.2-11; BSC 2003 [DIRS 167287], Table 6.2-7). Because the significance of these pathways has not been evaluated for the current biosphere model, it is recommended that the animal consumption rates include the consideration of uncertainty and be represented by probability distribution functions.

The values of the feed consumption rates range from 29 kg/d to 68 kg/d for beef cattle, 50 kg/d to 73 kg/d for diary cows, and 0.11 kg/d to 0.4 kg/d for chickens. It is recommended that the uniform distributions based on the minimum and maximum values for given ranges be used in the biosphere model.

The animal water consumption rates are reported to range from 20 L/d to 60 L/d for beef cattle, from 50 L/d to 100 L/d for diary cows, and 0.1 L/d to 0.3 L/d for chickens (IAEA 1994 [DIRS 100458], p. 33). Most of the values listed in other documents (Table 6-38) fall within these ranges. The diary cow water consumption rate estimated by Yu et al. (2001 [DIRS 159465], p. D-15) is vastly inconsistent with the remaining values. This value was calculated as the sum of the water ingestion rate for beef cattle plus an additional 1 gallon for every 3 pounds of milk produced. If a production rate of 10 gal/d of milk is assumed, then the water ingestion rate for diary cows would be about 160 L/d (Yu et al. 1993 [DIRS 160561], p. 132). This high value was compared with the estimated water requirements for diary cows, considering the site-specific conditions, as described below.

The daily consumption of water for diary cows (Mason 2003 [DIRS 160415]), $Q_{w,3}$, in L/d, can be approximated as

$$Q_{w,3} = 15.99 + 1.58\, DM + 0.9\, MY + 0.05\, NI + 1.2\, AT \qquad \text{(Eq. 6-12)}$$

where

DM = dry mass of feed intake (kg/d)
MY = milk yield (kg/d)
NI = sodium (Na) intake (g/d)
AT = weekly average minimum temperature (°C).

Dry mass of feed intake can be taken from Table 6-38. Several references listed in the table give the feed consumption rate in terms of dry mass as 16 kg/d. The milk yield per diary cow can be calculated based on the information from the Amargosa Dairy (Sepulveda 1999 [DIRS 160413]). In this dairy, in March 1999, there were on average 2,612 lactating cows that produced 4,503,280 pounds (2.04×10^6 kg) of milk. The average daily milk yield per cow is thus 25.3 kg/d. This value may be considered representative of the annual average daily yield. The sodium intake was conservatively taken at 100 g/d, which is the highest value, rounded-up to one significant digit, given in the examples provided by Mason (2003 [DIRS 160415]). The average minimum temperature can be obtained from the data for Meteorological Monitoring Site 9

(Gate 510) (DTN: MO04019SUM9397.000 [DIRS 167054]), which is the southernmost Yucca Mountain Site station in the direction of Amargosa Valley (CRWMS M&O 1999 [DIRS 102877], p. 5). The annual average minimum temperature was used, instead of the weekly average minimum temperature, because the value of water intake by diary cows in the biosphere model applies to the annual average conditions. The annual average minimum temperature for Site 9 is 10.1°C. This value was hand-calculated from data in DTN: MO04019SUM9397.000 [DIRS 167054] by taking an average of the monthly average minimum temperatures weighted by the number of days in a month. Using these values, the estimated daily water intake by diary cows is about 80 L/d, which is a half of the value calculated by Yu et al. (2001 [DIRS 159465], p. D-15). This value may also be corroborated by the data from Bernard and Montgomery (2002 [DIRS 160609], p. 5) that presented the results of the study that evaluated the water intake of diary cows at a range of temperatures from 68°F to 104°F. The corresponding daily water intake (not to be mistaken for the annual average water daily intake) was in the range of 18 gal/d (68 L/d) to 31.7 gal/d (120.0 L/d). The milk yield ranged from 59.5 lbs/d (27.0 kg/d) for the lowest temperature to 26.5 lbs/d (12.0 kg/d) for the highest temperature.

From these data, it appears that the diary cow consumption rate of water of 160 L/d used by Yu et al. (2001 [DIRS 159465]) is unsubstantiated. The range of values provided by the IAEA (1994 [DIRS 100458]), of 50 L/d to 100 L/d, with most of the remaining references listed in Table 6-38 using 60 L/d, is representative of the average water consumption by diary cows. Considering the site-specific conditions, especially with regard to the actual milk yield and the higher-than-typical temperatures, the expected value of 80 L/d and the uncertainty represented by the uniform distribution in the range of 60 L/d to 100 L/d are considered appropriate for diary cow consumption for the biosphere model.

The water consumption rates for chickens provided by Davis et al. (1993 [DIRS 103767], p. 253); Smith et al. (1996, p. 5-24) are greater than the values reported by the IAEA (1994 [DIRS 100458], p. 33), but they may be appropriate for the hot, dry climate of the Yucca Mountain region. In this climate, the animal water consumption needs may be higher than for the animals raised in the temperate climate. Therefore, the upper values of the data reported in the literature were recommended for the biosphere model. The recommended values are shown in Table 6-38.

The soil consumption rates were calculated based on the feed consumption rates using the approach from the IAEA (1994 [DIRS 100458], p. 33); Kennedy and Strenge (1992 [DIRS 103776], p. 6.19); Davis et al. (1993 [DIRS 103767], p. 253). The soil consumption rate for grazing animals is calculated as a fraction of the feed consumption rate: 6 percent for beef cattle and diary cows and 10 percent for chickens. The values of feed consumption rate were converted to dry weight (the formula applies to the dry-weight of the feed) using the dry-to-wet ratio of 0.25 for fresh forage and 0.91 for grain, based on the mid-range values given by the IAEA (1994 [DIRS 100458], p. 15). It is recommended that the soil consumption rates be represented by uniform distributions based on the calculated ranges.

Table 6-38. Animal Feed, Water, and Soil Consumption Rates from Various Sources, and the Selected Values

No.	Reference	Animal Type	Feed (kg wet/d)	Water (L/d)	Soil (kg/d)	Comment
1	Leigh et al. 1993 [DIRS 100464], p. 5-63 Napier et al. 1988 [DIRS 157927], p. 4.72	Beef cattle Diary cows Poultry Laying hen	68 (fresh/stored) 55 (fresh/stored) 0.12 (dry-weight) 0.13 (wet-weight) 0.12 (dry-weight) 0.13 (wet-weight)	50 60 0.3 0.3	Not included	GENII-S and GENII default values. Napier et al. (1988 [DIRS 157927], p. 4.72) does not include the value for laying hens. The dry-to-wet ratio of 0.91 was used to convert the values for chicken feed (Kennedy and Strenge 1992 [DIRS 103776], p. 6.28).
2	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-38	Beef cattle Diary cows	50 50	50 60	Not included	–
3	IAEA 2001 [DIRS 158519], p. 70	Beef cattle Diary cows	12 (dry-weight) 48 (wet-weight) 16 (dry-weight) 64 (wet-weight)	40 60	Not included	The feed consumption rates based on dry-weight were converted to wet-weight using a mid-point (0.25) of the dry-to-wet ratio range of 0.19 to 0.31 (IAEA 1994 [DIRS 100458], p. 15).
4	Mills et al. 1983 [DIRS 103781], p. 143	Beef cattle Diary cows Poultry	68 55 0.12	50 60 –	Not included	–
5	NCRP 1984 [DIRS 103784], pp. 70 to 71	Beef cattle Diary cows	12 (dry-weight) 48 (wet-weight) 16 (dry-weight) 64 (wet-weight)	50 60	Not included	The feed consumption rates based on dry-weight were converted to wet-weight using a mid-point (0.25) of the dry-to-wet ratio range of 0.19 to 0.31 (IAEA 1994 [DIRS 100458], p. 15).
6	Kennedy and Strenge 1992 [DIRS 103776], p. 6.19	Beef cattle Diary cows Poultry Laying hen	12 (dry-weight) 16 (dry-weight) 0.11 (dry-weight) 0.12 (wet-weight) 0.11 (dry-weight) 0.12 (wet-weight)	50 60 0.3 0.3	5% of dry matter intake 0.6 to 0.8 kg/d 10% of dry matter intake 0.01 kg/d	Total intakes for beef cattle and diary cows is a combination of fresh forage, stored hay, and grain intake rates. For poultry and laying hens, it consists of fresh forage and grain intakes. The cattle and milk cow feed consumption rates based on dry-weight were not converted to wet-weight because of the unknown fraction of forage or hay and grain. The dry-to-wet ratio of 0.91 was used to convert the values for chicken feed (Kennedy and Strenge 1992 [DIRS 103776], p. 6.28).
7	Yu et al. 2001 [DIRS 159465], p. D-15	Beef cattle Diary cows	68 55	50 160	0.5 0.5	RESRAD default values

Table 6-38. Animal Feed, Water, and Soil Consumption Rates from Various Sources, and the Selected Values (Continued)

No.	Reference	Animal Type	Feed (kg wet/d)	Water (L/d)	Soil (kg/d)	Comment
8	Davis et al. 1993 [DIRS 103767], p. 253	Beef cattle	50	40	1.0	Ingestion rates are assumed to be normally distributed, GSDs are given.
		Diary cows	60	60	0.8	
		Poultry	0.4	0.4	0.006	
		Laying hen	0.4	0.4	0.006	
					based on 6 to 7% of dry-weight feed or forage ingestion	
9	IAEA 1994 [DIRS 100458], p. 33	Beef cattle	7.2 (dry-weight) 29 (wet-weight)	20 to 60	6% of feed for grazing cattle; corresponds to 0.4 to 1.0 kg/d	The feed consumption rates, based on dry-weight, were converted to wet-weight using a midpoint (0.25) of the dry-to-wet ratio range of 0.19 to 0.31 (IAEA 1994 [DIRS 100458], p. 15). Mean fraction of soil intake expressed as fraction of feed intake
		Diary cows	16.1 (dry-weight) 64 (wet-weight)	50 to100		
		Poultry	0.07 (dry-weight)	0.1 to 0.3		
		Laying hen	0.1 (dry-weight)	0.1 to 0.3		
10	Smith et al. 1996 [DIRS 101085], p. 5-24	Dairy cows and beef cattle	60	60	0.6	Beef cattle and diary cows are not distinguished; neither are laying hens and poultry.
		Chicken	0.3	0.5	0.02	
11	LaPlante and Poor 1997 [DIRS 101079], p. B-8	Beef cattle	33 (fresh/stored)	60	Not included	Cited from the IAEA (1994) with updated dry-to-wet ratio conversion.
		Diary cows	73 (fresh/stored)	100		
		Poultry	0.08	0.3		
		Laying hen	0.11	0.3		
12	BIOMASS 2003 [DIRS 168563], pp. 449 to 450	Cattle	70	70	0.6	No distinction between beef cattle and dairy cows
		Birds	0.3	0.1	0.03	Values for birds based on hens and chickens
	Recommended values	Beef cattle	29 to 68 (fresh)	60	0.4 to 1.0	It is recommended that the animal consumption rates be represented by the uniform distributions with the minimum and maximum corresponding to the lower and upper limits of the range of values. The water consumption rates for beef cattle, poultry, and laying hens are represented by fixed values.
		Diary cows	50 to 73 (fresh)	60 to100	0.8 to 1.1	
		Poultry	0.12 to 0.4	0.5	0.01 to 0.03	
		Laying hen	0.12 to 0.4	0.5	0.01 to 0.03	

The ingestion of soil was measured in an experiment conducted at the NTS (Gilbert et al. 1988 [DIRS 160553], p. 324). The ingestion rate was determined by measuring the weight of soil in the reticulum and rumen of two rumen-fistulated steers and a cow that grazed at the site. The approximate weight of soil in the rumens of the two steers after 24 hours of grazing was 0.057 kg and 0.278 kg, while the weight of soil in the cow's rumen on the day of sacrifice was 0.0085 kg (Gilbert et al. 1988 [DIRS 160553], p. 329). The results of these experiments indicated that the total amount of soil ingested by animals is much less than 2 kg/d and that a reasonable estimate would be between 0.25 to 0.5 kg (Smith 1977 [DIRS 160559], p. 147). Gilbert et al. (1988 [DIRS 160553], p. 329) also reports the results of another study carried out in a similar arid environment in Idaho where the amount of soil ingested by cattle ranged from 0.1 to 1.5 kg/d with a median of 0.5 kg/d. Based on these values, the soil ingestion rates for beef cattle and for diary cows recommended for the biosphere model are not likely to underestimate the amount of soil ingested by these animals. It is recommended that the same values be used for the volcanic ash exposure scenario and for the future climate.

6.3.3 Transfer Coefficients

The TCs are defined as the mass or volume activity concentration in the tissue or product of an animal (Bq/kg wet mass or Bq/L) divided by the transfer rate (Bq/d) of the radionuclide to the animal by ingestion (ICRU 2001 [DIRS 160339], p. 14). The TC is the fraction of the animal's daily intake of a radionuclide that is transferred to 1 kilogram of animal product at equilibrium or at the time of slaughter. The availability for gut uptake of radionuclides differs markedly, depending on the chemical and physical form of the radionuclide and constituents of the diet (IAEA 1994 [DIRS 100458], p. 34). To incorporate the uncertainty associated with the process of activity transfer from animal food to animal products, the values of the TCs for the biosphere model were developed as probability distribution functions, as described in this section.

Data from direct measurements of TCs are scarce (IAEA 1994 [DIRS 100458], p. 38). Many of the published values were derived from sources other than explicit experimental data, such as stable element concentrations in feed and animal tissues, extrapolation from single dose tracer experiments, and the assumption of analogous behavior of elements that are chemically similar. Many documents use the value for beef to represent all meat and cow milk to represent all kinds of milk. For example, IAEA (2001 [DIRS 158519], p. 69) TCs for meat and milk are based on values for beef and dairy cattle. However, the values are stated to be conservative, and they are not expected to substantially underestimate concentration of radionuclides in meat or milk of other animals (IAEA 2001 [DIRS 158519], p. 69). The same approach was followed in this analysis (i.e., beef was used to represent meat, and cow milk was used to represent milk).

The TCs for the biosphere model were developed using a method similar to that used for the development of TFs for radionuclide transfer to plants (Section 6.2.1). The method was based on review of the pertinent published compendia of generic values or reports containing the recommendations or applications of TC values in other biosphere models. Such an approach is appropriate for development of TC values for the biosphere model. Because of the diversity of the sources of information and the wide range of the published TC values, GMs calculated using the TC values from relevant references are considered the best representations of the parameter values (BIOMASS 2001 [DIRS 159468] 2001, T1/WD04, p. 12). The distributions for TCs are considered lognormal (LaPlante et al. 1997 [DIRS 101079], p. 2-14; Davis et al. 1993 [DIRS 103767], pp. 236 to 238).

Just as in the case of TFs, the uncertainty in TC values was represented by the element-specific GSDs for the data points, which were used as estimates of the GSDs of the associated lognormal distributions. In a few instances, the TCs reported in the literature span several orders of magnitude (see Tables 6-39 through 6-63). There are a variety of reasons for such a spread of values. If the TC values are similar from report to report, this means either that the values are well studied and known or that few studies are available and the values cited in reports are based on the same limited pool of research data. In the case of elements for which TCs were not obtained through experiments but rather evaluated based on the chemical similarities with the elements for which TCs were measured, the scatter may be significant, owing to the nature of the evaluation process. Similar to the recommendations developed for the TFs (see discussion in Section 6.2.1.1.5), it is recommended for the cases of large data spread (GSD greater than 10) that the GSD for the TC distributions be capped at 10. If the calculated GSD is less than 2, it is recommended that a GSD equal to 2 be used. Considering the large number of biosphere model realizations (the biosphere model uses a large number of uncertain parameters, and consequently, the number of model realizations has to be sufficient to obtain stable results), it is recommended that the truncated distributions of the TCs be used to avoid sampling of unrealistic values (see Section 6.2.1.1.5 for additional discussion). The upper and the lower truncation limits were calculated using Equation 6-3 for the 99-percent confidence interval for the mean.

As explained in Section 6.1.4, a more detailed treatment was given to radionuclides (elements) that were shown in the previous performance assessments to be important dose contributors. Additional comments for those radionuclides are included in the corresponding tables.

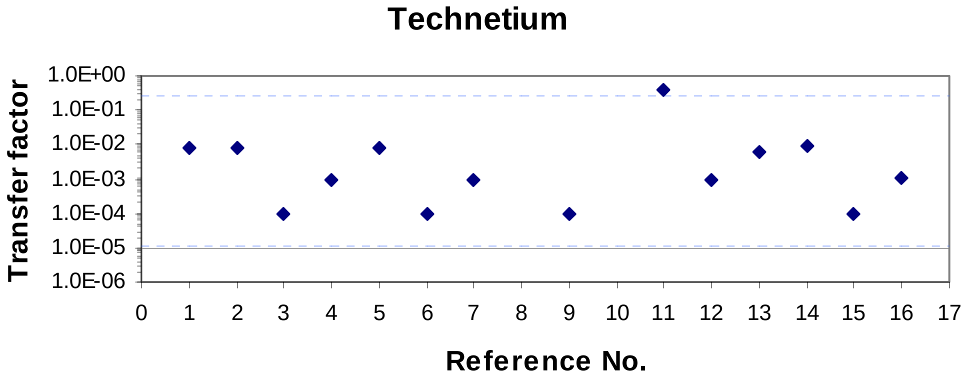
For all animal products, it is recommended that the values of TC developed for the groundwater exposure scenario and the present day climate be used for the volcanic ash release scenario and the future climate. This is because the TC values developed in this analysis are primarily based on generic information and are not specific to the climate or the mode of contamination release.

6.3.3.1 Transfer Coefficients for Meat

The values of TCs for meat and references that were used to develop them are listed in Tables 6-39 through 6-44. Calculation of GMs, standard deviations, and truncation limits for the TCs were preformed using Microsoft Excel 2000, as described in Appendix A. Also, see the discussion on the technetium TC values for milk, which is also applicable to the transfer of this element to meat.

Table 6-39. Technetium Transfer Coefficients for Meat

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 51	8.5E-03 [a]	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	8.5E-03	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 37	1.0E-04 [b]	1.0E-06 to 1.0E-04
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-03 [c]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	8.5E-03 [a]	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.0E-04 [d]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	9.9E-04 [a]	–
8	NCRP 1984 [DIRS 103784], p. 85	–	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E−04 [e]	–
10	Ng 1982 [DIRS 160322], p. 63	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	4.0E-01 [f]	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	9.9E-04 [a]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	6.0E-03 [d]	–
14	Peterson 1983 [DIRS 167077], p. 5-87	8.7E-03 [a]	–
15	Wang et al. 1993 [DIRS 103839], pp. 27 to 29; Yu et al. 2001 [DIRS 159465], p. D-16	1.0E-04 [g]	–
16	This analysis	–	lognormal; GM = 1.1E-03 [h]; GSD = 7.2 truncation: low = 6.9E-06; high = 1.8E-01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value for beef

[b] Value for beef; used the more conservative value of those given.

[c] Value recommended for screening models; based on values for dairy and beef cattle.

[d] Value for beef; value used in the biosphere modeling for Yucca Mountain.

[e] Value recommended for screening models; based on TC for beef.

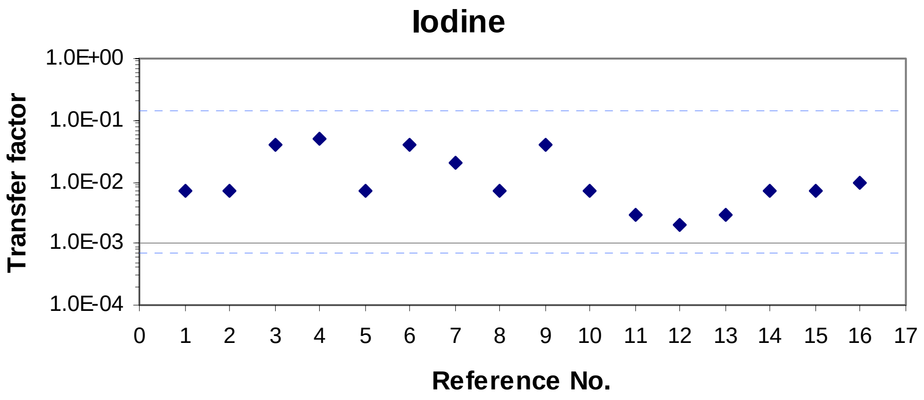
[f] This value was not included in the calculation of GM and GSD because it was inconsistent with the remaining values (almost 2 orders of magnitude greater)—see text for discussion.

[g] RESRAD default value; “suggested” value from Wang et al. 1993 [DIRS 103839], pp. 27 to 29.

[h] For the references listed in this table, GM with ref. # 11 = 1.7E-03; without 1.1E-03; with ref. #11 GSD = 12.1; without #11, GSD = 7.2.

Table 6-40. Iodine Transfer Coefficients for Meat

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 51	7.0E-03 [a]	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	7.0E-03	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 37	4.0E-02 [a]	7.0E-03 to 5.0E-2
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	5.0E-02 [b]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	7.0E-03 [a]	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	4.0E-02 [c]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	2.0E-02 [a]	–
8	NCRP 1984 [DIRS 103784], p. 85	7.0E-03 [a]	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	4.0E-02 [d]	–
10	Ng 1982 [DIRS 160322], p. 63	7.2E-03 [a]	7.2E-03 to 2.0E-02
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	2.9E-03	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-03 [a]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	3.0E-03 [c]	–
14	Peterson 1983 [DIRS 167077], p. 5-87	7.2E-03 [a]	–
15	Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	7.0E-03 [e]	–
16	This analysis	–	lognormal; GM = 1.0E-02 [f]; GSD = 2.8 truncation: low = 6.8E-04; high = 1.5E-01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value for beef.

[b] Value recommended for screening models; based on values for dairy and beef cattle.

[c] Value for beef; value used in the biosphere modeling for Yucca Mountain.

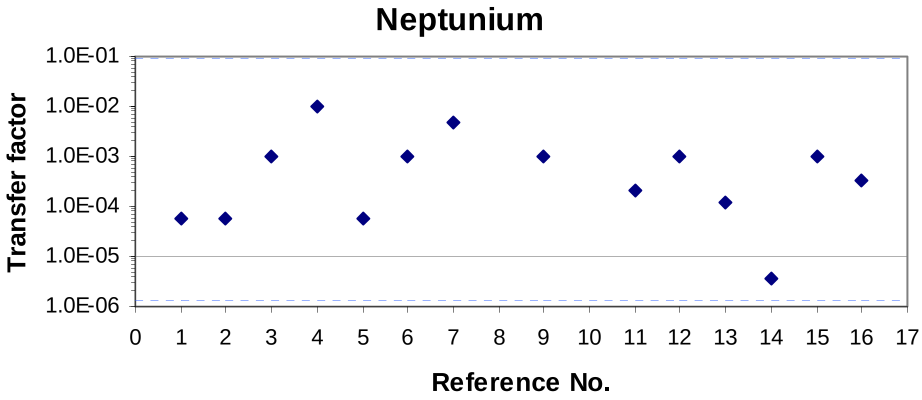
[d] Value recommended for screening models; based on TC for beef.

[e] RESRAD default value; “suggested” value from Wang et al. 1993 [DIRS 103839], pp. 27 to 29.

[f] For the references listed in this table, GM = 1.0E-02; GSD = 2.8.

Table 6-41. Neptunium Transfer Coefficients for Meat

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 51	5.5E-05 [a]	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	5.5E-05	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 37	1.0E-03 [a]	–
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-02 [b]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	5.5E-05 [a]	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.0E-03 [c]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	5.0E-03 [a]	–
8	NCRP 1984 [DIRS 103784], p. 85	–	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-03 [d]	–
10	Ng 1982 [DIRS 160322], p. 63	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	2.0E-04	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E-03 [a]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	1.2E-04 [c]	–
14	Peterson 1983 [DIRS 167077], p. 5-87	3.6E-06 [e]	–
15	Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	1.0E-03 [f]	–
16	This analysis	–	lognormal; GM = 3.4E-04 [g]; GSD = 8.8 truncation: low = 1.3E-06; high = 9.0E-02



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value for beef

[b] Value recommended for screening models; based on values for dairy and beef cattle.

[c] Value for beef; value used in the biosphere modeling for Yucca Mountain.

[d] Value recommended for screening models; based on TC for beef.

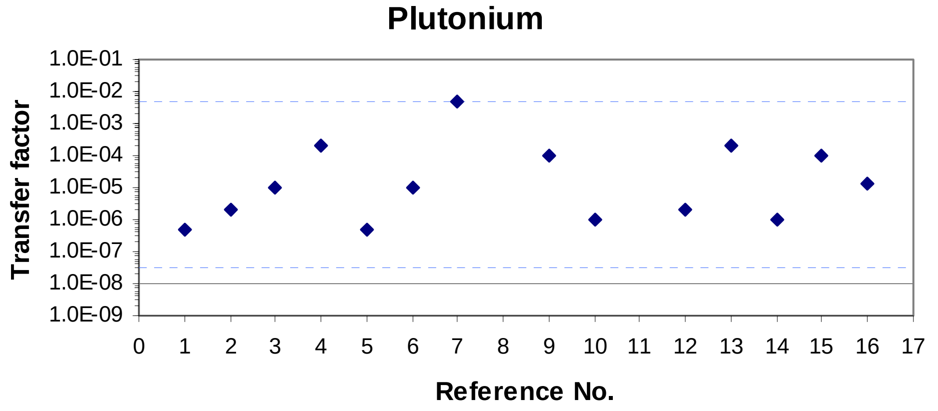
[e] Value for beef for transuranics

[f] RESRAD default value; "suggested" value from Wang et al. 1993 [DIRS 103839], pp. 27 to 29.

[g] For the references listed in this table, GM = 3.4E-04; GSD = 8.8.

Table 6-42. Plutonium Transfer Coefficients for Meat

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 51	5.0E-07 [a]	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	2.0E-06	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 37	1.0E-05 [a]	2.0E-07 to 2.0E-04
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	2.0E-04 [b]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	5.0E-07 [a]	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.0E-05 [c]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	5.0E-03 [a]	–
8	NCRP 1984 [DIRS 103784], p. 85	–	5.0E-09 to 2.0E-05 [a]
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-04 [d]	–
10	Ng 1982 [DIRS 160322], p. 63	1.0E-06 [a]	1.3E-07 to 5.8E-06
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	–	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-06 [a]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	2.0E-04 [c]	–
14	Peterson 1983 [DIRS 167077], p. 5-87	1.0E-06 [a]	–
15	Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	1.0E-04 [e]	–
16	This analysis	–	lognormal; GM = 1.3E-05 [f]; GSD = 10.0 truncation: low = 3.3E-08; high = 4.7E-03

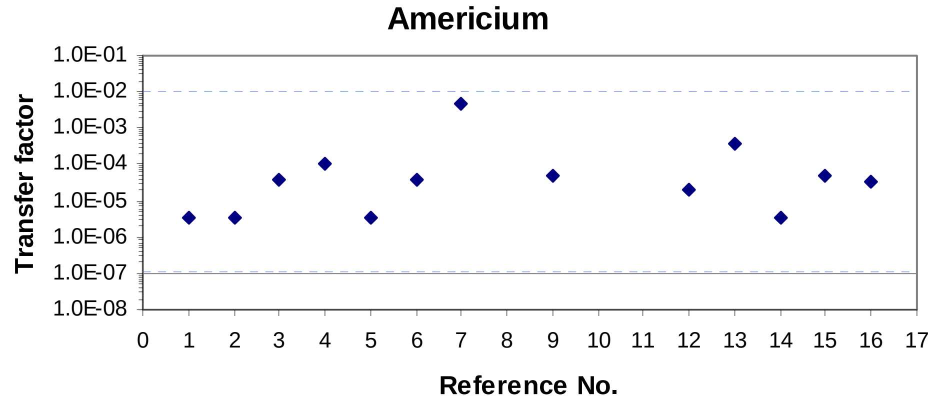


NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value for beef.
[b] Value recommended for screening models; based on values for dairy and beef cattle.
[c] Value for beef; value used in the biosphere modeling for Yucca Mountain.
[d] Value recommended for screening models; based on TC for beef.
[e] RESRAD default value; "suggested" value from Wang et al. 1993 [DIRS 103839], pp. 27 to 29.
[f] For the references listed in this table, GM = 1.3E-05, GSD = 18.0. The upper bound for the GSD value was used.

Table 6-43. Americium Transfer Coefficients for Meat

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 51	3.5E-06 [a]	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	3.5E-06	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 37	4.0E-05 [a]	4.0E-06 to 1.0E-04
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-04 [b]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	3.5E-06 [a]	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	4.0E-05 [c]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	5.0E-03 [a]	–
8	NCRP 1984 [DIRS 103784], p. 85	–	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	5.0E-05 [d]	–
10	Ng 1982 [DIRS 160322], p. 63	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	–	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-05 [a]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	4.0E-04 [c]	–
14	Peterson 1983 [DIRS 167077], p. 5-87	3.6E-06 [a]	–
15	Wang et al. 1993 [DIRS 103839], pp. 27 to 29; Yu et al. 2001 [DIRS 159465], p. D-16	5.0E-05 [e]	–
16	This analysis	–	lognormal; GM = 3.4E-05 [f]; GSD = 9.0 truncation: low = 1.2E-07; high = 9.9E-03



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value for beef

[b] Value recommended for screening models; based on values for dairy and beef cattle.

[c] Value for beef; value used in the biosphere modeling for Yucca Mountain.

[d] Value recommended for screening models; based on TC for beef.

[e] RESRAD default value; "suggested" value from Wang et al. 1993 [DIRS 103839], pp. 27 to 29.

[f] For the references listed in this table, GM = 3.4E-05; GSD = 9.0.

Table 6-44. Transfer Coefficients for Meat for Other Elements

No.	Reference	Transfer Coefficient, d/kg (Bq/kg of animal product per Bq/d of radionuclide intake)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Baes et al. 1984 [DIRS 103766], p. 51	8.0E-02	1.5E-02	3.0E-04	8.0E-02	2.0E-02	3.0E-04	2.5E-04	2.5E-05	6.0E-06	1.0E-05	2.0E-04
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	–	1.5E-02	8.1E-04	8.0E-02	2.6E-02	4.0E-04	9.0E-04	2.5E-05	6.0E-06	1.0E-05	2.0E-04
3	IAEA 1994 [DIRS 100458], p. 37	2.0E-02	–	8.0E-03	–	5.0E-02	4.0E-04	9.0E-04	–	–	–	3.0E-04
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	–	1.0E-01	1.0E-02	1.0E-02	5.0E-02	7.0E-04	5.0E-03	2.0E-05	1.0E-04	5.0E-06	3.0E-03
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	8.0E-02	1.5E-02	3.0E-04	8.0E-02	2.0E-02	3.0E-04	2.5E-04	2.5E-05	6.0E-06	1.0E-05	2.0E-04
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	1.5E-02	8.0E-03	8.0E-02	5.0E-02	4.0E-04	9.0E-04	2.5E-05	6.0E-06	1.0E-05	3.0E-04
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	–	1.0E+00	3.0E-04	9.9E-04	3.0E-02	9.9E-04	9.9E-04	5.0E-03	5.0E-03	5.0E-03	5.0E-03
8	NCRP 1984 [DIRS 103784], p. 85	–	–	8.0E-04	–	3.0E-02	–	5.0E-04	–	–	–	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	4.0E-02	1.0E-01	1.0E-02	1.0E-02	5.0E-02	8.0E-04	1.0E-03	2.0E-05	1.0E-04	5.0E-06	8.0E-04
10	Ng 1982 [DIRS 160322], p. 63	–	–	3.0E-04	–	2.0E-02	–	–	–	–	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	–	–	6.0E-04	–	4.0E-03	–	–	–	–	–	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	3.0E-02	1.0E+00	8.0E-04	1.0E-02	3.0E-02	4.0E-04	9.0E-04	4.0E-04	5.0E-03	5.0E-03	2.0E-04
13	Smith et al. 1996 [DIRS 101085], p. 5-27	–	5.4E-01	–	–	5.0E-02	1.0E-02	1.3E-03	1.6E-03	2.7E-03	5.0E-05	6.9E-04
14	Peterson 1983 [DIRS 167077], p. 5-87	–	–	8.1E-04	–	2.0E-03	4.0E-04	5.1E-04	–	2.0E-04	–	3.4E-04
15	Wang et al. 1993 [DIRS 103839], pp. 27 to 29 Yu et al. 2001 [DIRS 159465], p. D-16	6.0E-02	1.0E-01	8.0E-03	1.0E-02	3.0E-02	8.0E-04	1.0E-03	2.0E-05	1.0E-04	5.0E-03	3.4E-04
	GM	4.6E-02	8.8E-02	1.4E-03	1.9E-02	2.4E-02	6.3E-04	8.1E-04	7.9E-05	1.1E-04	6.6E-05	4.8E-04

Table 6-44. Transfer Coefficients for Meat for Other Elements (Continued)

No.	**Reference**	**Transfer Coefficient, d/kg (Bq/kg of animal product per Bq/d of radionuclide intake)**										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
	GSD	1.8	5.8	4.4	4.6	2.6	2.6	2.1	8.2	15.1	21.2	3.0
	Recommended GSD	2.0 [a]	5.8	4.4	4.6	2.6	2.6	2.1	8.2	10.0 [b]	10.0 [b]	3.0
	Truncation, lower limit	7.7E-03	9.6E-04	3.1E-05	3.8E-04	2.1E-03	5.4E-05	1.1E-04	3.5E-07	2.8E-07	1.8E-07	2.9E-05
	Truncation, upper limit	2.7E-01	8.0E+00	6.2E-02	9.9E-01	2.7E-01	7.5E-03	5.7E-03	1.8E-02	4.0E-02	2.5E-02	7.8E-03

[a] The lower bound of the GSD value was used.

[b] The upper bound of the GSD value was used.

The transfer of aged plutonium from soil and native vegetation to the blood and tissues of beef cattle grazing within fenced enclosures at a plutonium-contaminated site was studied at the Nellis Bombing and Gunnery Range in Nevada (Gilbert et al. 1988 [DIRS 160553], p. 324). The grazing area was divided into two enclosures: a less contaminated outer enclosure and a more contaminated inner enclosure. The data from that experiment allow calculation of the TCs for meat (beef) for individual animals. The results of these calculations are presented in Table 6-45. To calculate TCs the measured activity concentration in the muscle tissue of the animals was divided by the estimated daily activity intake from vegetation and soil. The plutonium ingestion rate, *r*, (Gilbert et al. 1988 [DIRS 160553], p. 328) is calculated as

$$r = C\, f_{sv}\, I_v + C\, I_s \tag{Eq. 6-13}$$

where C is the mean plutonium concentration in surface soil, f_{sv} is the concentration ratio of the activity of plutonium in native vegetation and in nearby surface soil, and I_v and I_s are ingestion rates of vegetation and soil, respectively. It was estimated that the arithmetic mean concentration of plutonium in surface soil was 22.5 ± 5 and 1.88 ± 0.24 kBq/kg dry-weight for the inner and outer enclosures, respectively. The vegetation-to-soil activity concentration ratio was estimated to be 0.1 for the inner enclosure and 0.17 for the outer enclosure (Gilbert et al. 1988 [DIRS 160553], pp. 328 to 329). The ingestion rate of vegetation I_v was modeled as 0.101 $W^{0.73}$ kg/d, where W is the wet-weight (kg) of the cow at time of sacrifice (Gilbert 1988 [DIRS 160553], p. 329). The ingestion rate of soil, I_s, was assumed to be 0.25 kg/d, based on the measurements of soil weight in the reticulum and rumen of rumen-fistulated steers and a cow that grazed at the study site (Gilbert et al. 1988 [DIRS 160553], p. 329).

The results of the calculation indicate that the TCs for plutonium for meat are in the range of 2.9×10^{-7} to 1.9×10^{-5} d/kg with the average value of 6.2×10^{-6} d/kg. The GM calculated for the references listed in Table 6-42 and recommended for the biosphere model is 1.3×10^{-5} d/kg, which is in the upper part of the range of the experimental values. However, plutonium at the site of the experiment was in the form of aged plutonium oxides, which are relatively insoluble and generally characterized by low uptake from the gastrointestinal system to the blood (Eckerman et al. 1988 [DIRS 101069], p. 188). If the chemical species of plutonium in the biosphere are more soluble, their bioavailability and their uptake by animals are greater. Therefore, the value of the plutonium TC for meat recommended for the biosphere model (Table 6-42) is considered appropriate for the intended use.

Table 6-45. Calculation of Transfer Coefficients for Cattle Grazing on Contaminated Land in Nevada

Animal number	Enclosure [a]	Weight at sacrifice kg	Duration in enclosure d	Pu concentr. in soil Bq/kg	Vegetation-to-soil activity concentr. ratio	Ingestion rate of vegetation kg/d	Ingestion rate of soil kg/d	Pu ingestion rate Bq/d	Pu concentr. in muscle Bq/kg	Transfer coefficient [b] d/kg
2	I	409	176	22500	0.1	8.14	0.25	23951	0.007	2.9E-07
10	I	285	1001	22500	0.1	6.26	0.25	19703	0.059	3.0E-06
11	I	32	5	22500	0.1	1.27	0.25	8478	error	
18	I	184	262	22500	0.1	4.55	0.25	15854	0.18	1.1E-05
1	O	252	431	1880	0.17	5.72	0.25	2298	0.0018	7.8E-07
3	O	432	176	1880	0.17	8.48	0.25	3179	0.0015	4.7E-07
4	O	300	431	1880	0.17	6.50	0.25	2546	0.0074	2.9E-06
5	O	298	636	1880	0.17	6.46	0.25	2536	0.0059	2.3E-06
6	O	325	431	1880	0.17	6.89	0.25	2671	lost	
8	O	328	176	1880	0.17	6.93	0.25	2686	0.013	4.8E-06
9	O	382	1064	1880	0.17	7.75	0.25	2946	0.03	1.0E-05
13	O	250	544	1880	0.17	5.69	0.25	2287	0.0081	3.5E-06
14	O	405	843	1880	0.17	8.09	0.25	3054	0.059	1.9E-05
15	O	311	576	1880	0.17	6.67	0.25	2601	0.047	1.8E-05
16	O	409	948	1880	0.17	8.14	0.25	3073	0.021	6.8E-06
19	O	173	226	1880	0.17	4.35	0.25	1859	0.012	6.5E-06
20	O	302	871	1880	0.17	6.53	0.25	2556	0.0059	2.3E-06

Source: Gilbert et al. 1988, [DIRS 160553], pp. 327 to 329.

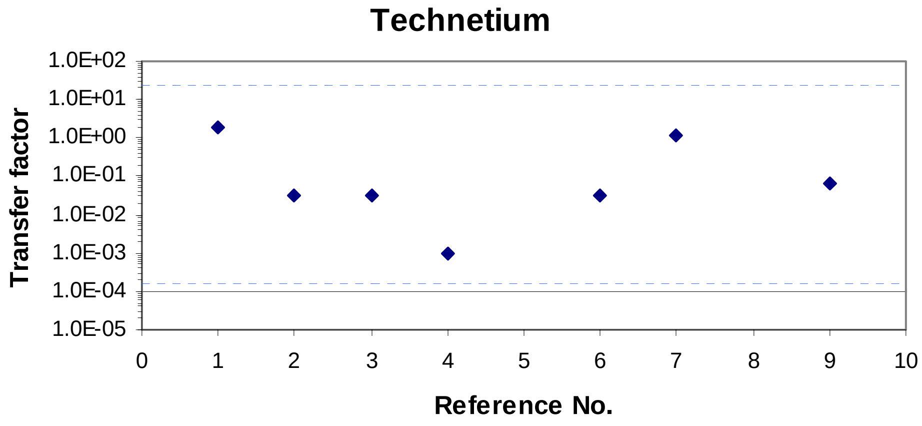
[a] I = inner enclosure; O = outer enclosure.
[b] Calculated as the ratio of Pu concentration in muscle to Pu ingestion rate.

6.3.3.2 Transfer Coefficients for Poultry

The values of TCs for poultry and references that were used to develop them are listed in Tables 6-46 to 6-51. Calculation of GMs, standard deviations, and truncation limits for the TCs were preformed using Microsoft Excel 2000, as described in Appendix A.

Table 6-46. Technetium Transfer Coefficients for Poultry

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	1.9E+00 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 40	3.0E-02	3.0E-02 to 2.0E-01
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	3.0E-02	–
4	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	9.9E-04	–
5	Ng 1982 [DIRS 160322], p. 63	–	–
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	3.0E-02 [b]	–
7	Smith et al. 1996 [DIRS 101085], p. 5-29	1.2E+00 [c]	–
8	This analysis	–	lognormal; GM = 6.3E-02 [d]; GSD = 10.0 truncation: low = 1.7E-04; high = 2.4E+01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value was used for poultry and eggs. The value selected for technetium seems to reflect the TCs for eggs, which are higher than the values for poultry.

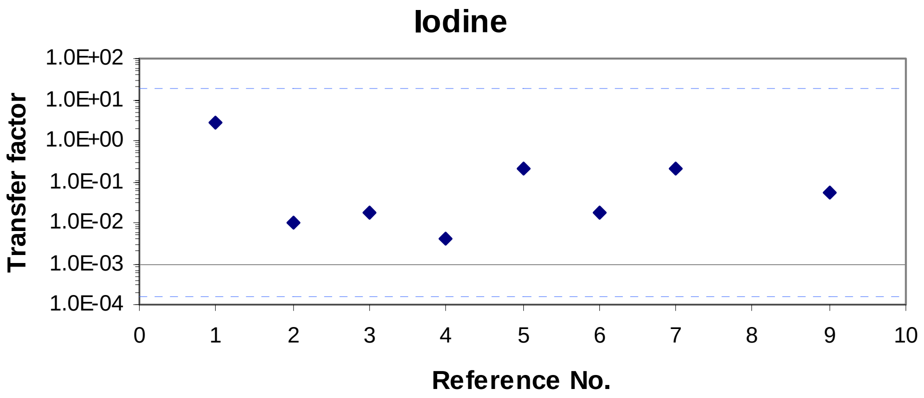
[b] GENII default

[c] Value used in the biosphere modeling for Yucca Mountain.

[d] For the references listed in this table, GM = 6.3E-02, GSD = 16.4. The upper bound for the value of GSD was used.

Table 6-47. Iodine Transfer Coefficients for Poultry

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	2.8E+00 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 40	1.0E-02	–
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	1.8E-02	–
4	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	4.0E-03	–
5	Ng 1982 [DIRS 160322], p. 63	2.0E-01	8.0E-03 to 2.0E-01
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.8E-02 [b]	–
7	Smith et al. 1996 [DIRS 101085], p. 5-29	2.0E-01 [c]	–
8	This analysis	–	lognormal; GM = 5.5E-02 [d]; GSD = 9.7 truncation: low = 1.6E-04; high = 1.9E+01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value was used for poultry and eggs. The value selected for iodine seems to reflect the TCs for eggs, which are higher than the values for poultry.

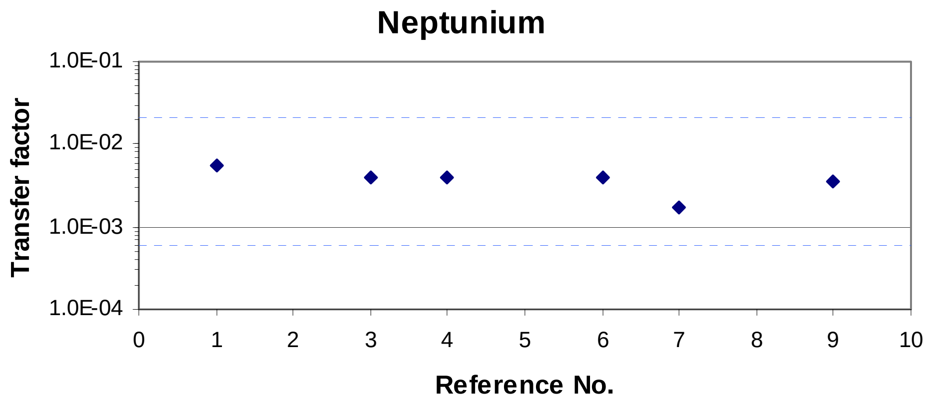
[b] GENII default

[c] Value used in the biosphere modeling for Yucca Mountain.

[d] For the references listed in this table, GM = 5.5E-02; GSD = 9.7.

Table 6-48. Neptunium Transfer Coefficients for Poultry

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	5.5E-03 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 40	–	–
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	4.0E-03	–
4	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	4.0E-03	–
5	Ng 1982 [DIRS 160322], p. 63	–	–
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	4.0E-03 [b]	–
7	Smith et al. 1996 [DIRS 101085], p. 5-29	1.7E-03 [c]	–
8	This analysis	–	lognormal; GM = 3.6E-03 [d]; GSD = 2.0 truncation: low = 6.0E-04; high = 2.1E-02

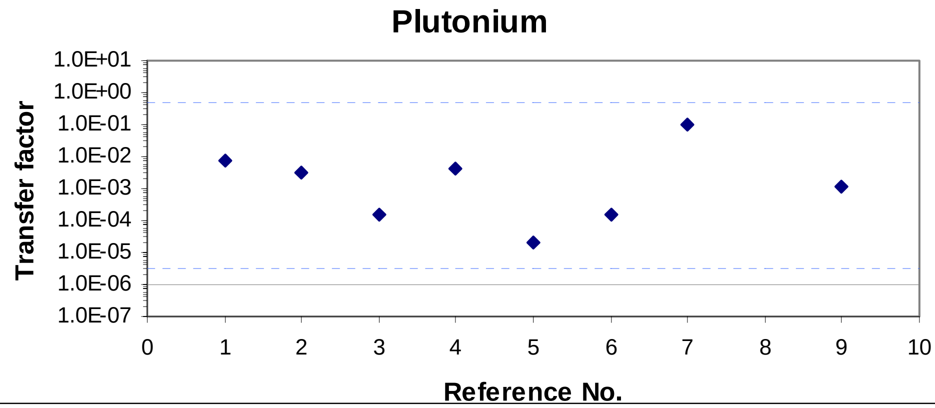


NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value was used for poultry and eggs.
[b] GENII default
[c] Value used in the biosphere modeling for Yucca Mountain.
[d] For the references listed in this table, GM = 3.6E-03; GSD = 1.6. The lower bound for the value of GSD was used.

Table 6-49. Plutonium Transfer Coefficients for Poultry

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	7.6E-03 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 40	3.0E-03	2.0E-05 to 3.0E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	1.5E-04	–
4	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	4.0E-03	–
5	Ng 1982 [DIRS 160322], p. 63	2.0E-05 [b]	–
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.5E-04 [c]	–
7	Smith et al. 1996 [DIRS 101085], p. 5-29	1.0E-01 [d]	–
8	This analysis	–	lognormal; GM = 1.2E-03 [e]; GSD = 10.0 truncation: low = 3.2E-06; high = 4.6E-01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value was used for poultry and eggs.

[b] Value for PuO_2

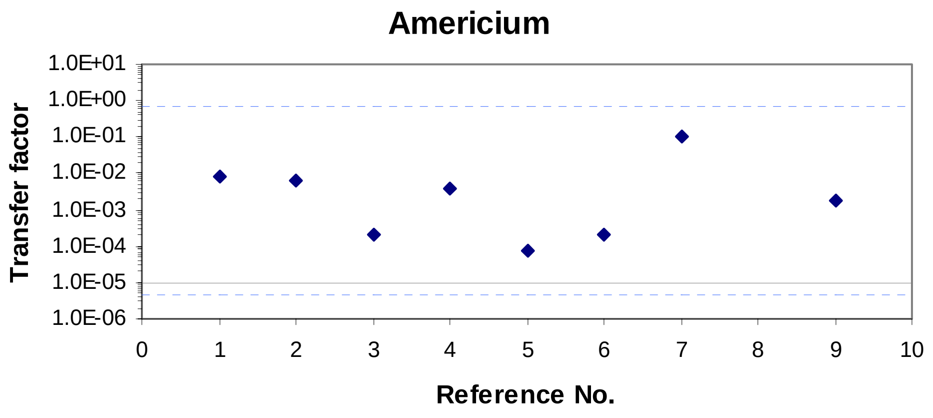
[c] GENII default

[d] Value used in the biosphere modeling for Yucca Mountain.

[e] For the references listed in this table, GM = 1.2E-03, GSD = 18.3. The upper bound on the value of GSD was recommended.

Table 6-50. Americium Transfer Coefficients for Poultry

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	8.5E-03 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 40	6.0E-03	2.0E-05 to 6.0E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	2.0E-04	–
4	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	4.0E-03	–
5	Ng 1982 [DIRS 160322], p. 63	7.2E-05	–
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-04 [b]	–
7	Smith et al. 1996 [DIRS 101085], p. 5-29	1.0E-01 [c]	–
8	This analysis	–	lognormal; GM = 1.8E-03 [d]; GSD = 10.0 truncation: low = 4.8E-06; high = 6.7E-01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value was used for poultry and eggs.

[b] GENII default

[c] Value used in the biosphere modeling for Yucca Mountain.

[d] For the references listed in this table, GM = 1.8E-03, GSD = 13.5. The upper bound on the value of GSD was recommended.

Table 6-51. Transfer Coefficients for Poultry for Other Elements

No.	Reference	Transfer Coefficient, d/kg (Bq/kg of animal product per Bq/d of radionuclide intake)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	–	9.3E+00	3.0E-01	8.0E+00	4.4E+00	4.0E-02	9.0E-02	2.5E-03	6.0E-04	1.0E-03	1.2E+00
2	IAEA 1994 [DIRS 100458], p. 40	–	9.0E+00	8.0E-02	–	1.0E+01	–	–	–	–	–	1.0E+00
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	3.0E-02	8.5E+00	3.5E-02	2.0E-01	4.4E+00	2.0E-01	3.0E-02	4.0E-03	4.0E-03	4.0E-03	1.2E+00
4	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	–	3.7E-01	9.0E-04	9.9E-04	4.5E+00	9.9E-04	9.9E-04	4.0E-03	4.0E-03	4.0E-03	1.2E-03
5	Ng 1982 [DIRS 160322], p. 63	–	–	3.2E-02	–	4.4E+00	–	–	–	–	–	–
6	Rittmann 1993 [DIRS 107744], pp. 35 to 36	3.0E-02	8.5E+00	3.5E-02	9.9E-04	4.4E+00	9.9E-04	9.9E-04	4.0E-03	4.0E-03	4.0E-03	1.2E+00
7	Smith et al. 1996 [DIRS 101085], p. 5-29	–	8.3E+00	–	–	1.2E+01	1.2E+00	4.8E-01	6.6E-03	1.8E-01	4.1E-03	1.0E-01
8	Peterson 1983 [DIRS 167077], p. 5-87	–	–	3.5E-02	–	1.0E-02	–	–	–	–	–	–
	GM	3.0E-02	5.1E+00	3.1E-02	3.5E-02	2.6E+00	2.5E-02	1.7E-02	4.0E-03	5.9E-03	3.0E-03	2.4E-01
	GSD	1.0	3.6	5.8	81.1	9.8	24.0	15.8	1.4	8.0	1.9	16.1
	Recommended GSD	2.0 [a]	3.6	5.8	10.0 [b]	9.8	10.0 [b]	10.0 [b]	2.0 [a]	8.0	2.0 [a]	10.0 [b]
	Truncation, lower limit	5.0E-03	1.9E-01	3.4E-04	9.4E-05	7.2E-03	6.6E-05	4.4E-05	6.7E-04	2.7E-05	5.1E-04	6.5E-04
	Truncation, upper limit	1.8E-01	1.4E+02	2.9E+00	1.3E+01	9.3E+02	9.3E+00	6.3E+00	2.4E-02	1.3E+00	1.8E-02	9.2E+01

[a] The lower bound of the value of the GSD was used.
[b] The upper bound of the value of the GSD was used.

6.3.3.3 Transfer Coefficients for Milk

To derive TCs for milk, the same references were used as those for meat. TCs for milk reported in the recent literature (IAEA 1994 [DIRS 100458]; IAEA 2001 [DIRS 155188]) indicate that technetium transfer from animal diet to milk tends to be lower than was previously considered (Davis et al. 1993 [DIRS 103767], p. 236). In the older literature, the value appears to be 2 to 3 orders of magnitude higher, on the order of 1×10^{-2} d/L, when compared with the newly developed expected value, which is on the order of 1×10^{-5} d/L. For example, see the values in Table 6-52 from Baes et al. (1984 [DIRS 103766]), Mills et al. (1983 [DIRS 103781]), Peterson (1983 [DIRS 167077]), and Regulatory Guide 1.109, Rev. 1 (1997 [DIRS 100067]), and compare with data from the IAEA (2001 [DIRS 155188]). The earlier values were developed based on the assumption that the metabolism of technetium in the animal system is the same as that of iodine, which was studied much more extensively. The most recent studies indicate that technetium transfer to milk is much lower than initially assumed and that the experimentally determined values are two to three orders of magnitude less than those reported for iodine (Davis et al. 1993 [DIRS 103767]). A reason for the lower technetium TC values is believed to be reduction of TcO_4 (pertechnetate) in the cow's rumen to TcO_2, for which absorption is quite low (IAEA 2001 [DIRS 155188], p. 43). Based on the Eh-pH diagram for technetium, the stability region for TcO_2 is very limited (Brookins 1988 [DIRS 105092], p. 98), so it is likely that pertechnetate (TcO_4^-) would be reduced in the rumen to compounds other than TcO_2, which may also be poorly absorbed from the rumen. To calculate the technetium TC for cow's milk, the highest values, greater than or equal to those for iodine, were excluded from calculations, based on the previous understanding of the metabolic behavior of technetium in the bovine system. The resulting GM is only one order of magnitude lower than that of iodine, not two to three as indicated in the literature. The reason for this discrepancy might be that many compendia of generic TC values continue to recommend more conservative values than would be indicated by the recent measurements. Such an approach may, however, be appropriate for the biosphere model as explained below.

Technetium is a redox-sensitive element with a substantial conversion between oxidized and reduced species occurring over the range of redox potentials (Brookins 1988 [DIRS 105092], p. 98). The environmental conditions will determine which species are present. The formation of other species, such as TcO_2, in the rumen is influenced by the rumen's acidity. Ideally, the pH of the rumen should be close to neutral. If the cows are fed a diet consisting of grasses, alfalfa, or clover, the pH of their rumen remains neutral because of the physiology of the cow's digestive system. To increase the production of meat and milk, the cows are fed a high–corn silage diet, which decreases rumen pH, compared with a high-alfalfa diet (Ruppert et al. 1996 [DIRS 159487]). The biosphere model assumes that the dairy cows and beef cattle are primarily fed alfalfa, not a corn-rich diet. The pH of such cows' rumen should remain closer to neutral, and, according to the Eh-pH diagram (Brookins 1988 [DIRS 105092], p. 98), TcO_2 would not be a likely species to form, although it is possible that other insoluble species of technetium may be produced. Considering the information presented above, the TC for technetium that is only one order of magnitude less than that for iodine is appropriate for the biosphere model.

A similar effect may also be of significance for technetium transfer to meat. Reduction of technetium to insoluble species in the cattle's rumen may limit the transfer of this element to meat. Although the cautious approach was exercised regarding the TC for milk, the value from

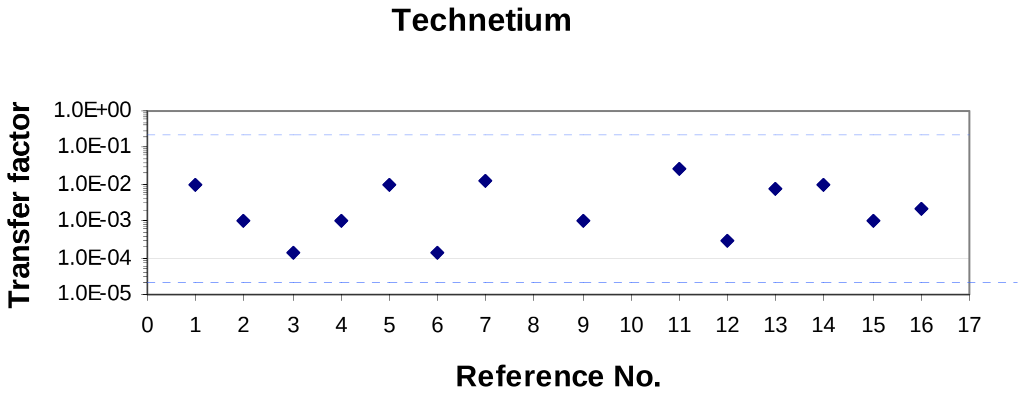
Regulatory Guide 1.109, Rev. 1 (1977 [DIRS 100067] p. 1.109-37), which is about two orders of magnitude higher than any of the remaining values, was not used in this analysis.

The TCs for milk are listed in Tables 6-52 to 6-57. Calculation of GMs, standard deviations, and truncation limits for the TCs were preformed using Microsoft Excel 2000, as described in Appendix A.

While TCs for other animal products are given in d/kg, the TCs for milk are given in units of d/L, which is how they are presented by the majority of the data sources used to derive these values. Milk density ranges from 1.028 g/cm^3 to 1.035 g/cm^3 (Weast 1977 [DIRS 106266], p. F-3). Therefore, reporting the TCs for milk in d/kg without correcting for milk density introduces a very small error (about 3 percent). This error is insignificant, relative to the large uncertainty range in the TC values themselves, and can be neglected.

Table 6-52. Technetium Transfer Coefficients for Milk

		Transfer Coefficient, d/L	
No.	**Reference**	**Best Estimate**	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 50	1.0E-02	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	9.9E-04	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 35	1.4E-04 [a]	2.3E-05 to 1.1E-03
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-03 [b]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	1.0E-02	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.4E-04 [c]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	1.2E-02	–
8	NCRP 1984 [DIRS 103784], pp. 82 to 83	–	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-03 [b]	–
10	Ng 1982 [DIRS 160322], p. 62	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	2.5E-02	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	3.0E-04 [c]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	7.5E-03 [d]	–
14	Peterson 1983 [DIRS 167077], p. 5-86	9.9E-03	–
15	Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	1.0E-03 [e]	–
16	This analysis	–	lognormal; GM = 2.1E-03 [f]; GSD = 6.0 truncation: low = 2.0E-05; high = 2.1E-01

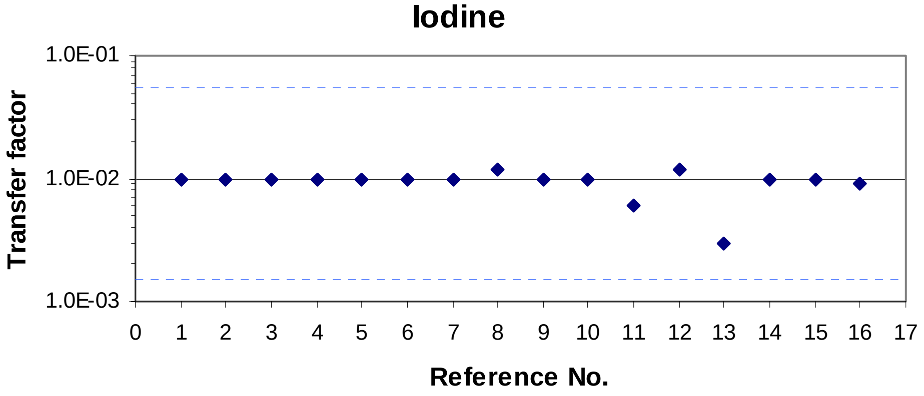


NOTES: TCs are in units of Bq/L of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Used the more conservative value of those given.
[b] Value recommended for screening models
[c] GENII default
[d] Value used in the biosphere modeling for Yucca Mountain.
[e] RESRAD default value
[f] For the references listed in this table, GM = 2.1E-03; GSD = 6.0.

Table 6-53. Iodine Transfer Coefficients for Milk

No.	Reference	Transfer Coefficient, d/L Best Estimate	Transfer Coefficient, d/L Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 50	1.0E-02	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	9.9E-03	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 35	1.0E-02	1.0E-03 to 3.5E-02
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	1.0E-02 [a]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	1.0E-02	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.0E-02 [b]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	1.0E-02	–
8	NCRP 1984 [DIRS 103784], pp. 82 to 83	1.2E-02 [c]	2.7E-03 to 3.5E-02
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-02 [a]	–
10	Ng 1982 [DIRS 160322], p. 62	9.9E-03	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	6.0E-03	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.2E-02 [d]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	3.0E-03 [b]	–
14	Peterson 1983 [DIRS 167077], p. 5-86	9.9E-03	–
15	Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	1.0E-02 [e]	–
16	This analysis	–	lognormal; GM = 9.1E-03 [f]; GSD = 2.0 truncation: low = 1.5E-03; high = 5.4E-02

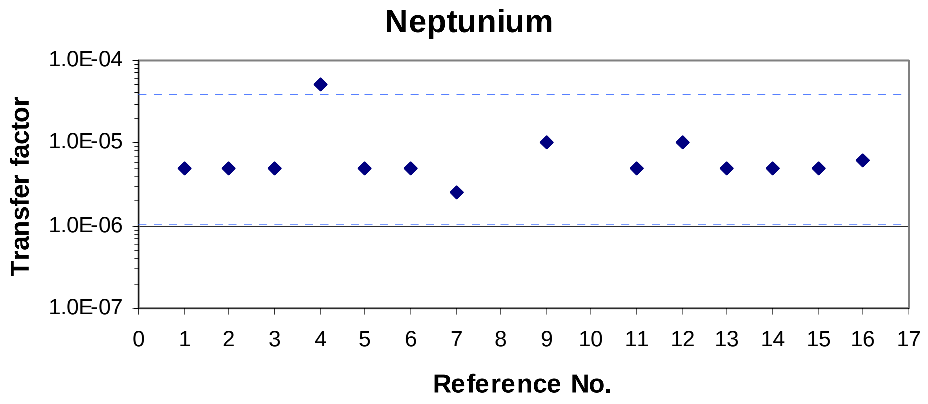


NOTES: TCs are in units of Bq/L of animal product per Bq/d of radionuclide intake.
Truncation limits shown as dashed lines.

[a] Value recommended for screening models
[b] Value used in the biosphere modeling for Yucca Mountain
[c] GSD = 1.7; 99th percentile = 3.6E-02
[d] GENII default
[e] RESRAD default value
[f] For the references listed in this table, GM = 9.1E-03; GSD = 1.4. The lower bound of the value of GSD of 2.0 was used.

Table 6-54. Neptunium Transfer Coefficients for Milk

No.	Reference	Transfer Coefficient, d/L	
		Best Estimate	**Range and Distribution**
1	Baes et al. 1984 [DIRS 103766], p. 50	5.0E-06	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	5.0E-06	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 35	5.0E-06	–
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	5.0E-05 [a]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	5.0E-06	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	5.0E-06 [b]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	2.5E-06	–
8	NCRP 1984 [DIRS 103784], pp. 82 to 83	–	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-05 [a]	–
10	Ng 1982 [DIRS 160322], p. 62	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	5.0E-06	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E-05 [c]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	5.0E-06 [b]	–
14	Peterson 1983 [DIRS 167077], p. 5-86	5.0E-06	–
15	Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	5.0E-06 [d]	–
16	This analysis	–	lognormal; GM = 6.3E-06 [e]; GSD = 2.0 truncation: low = 1.0E-06; high = 3.9E-05

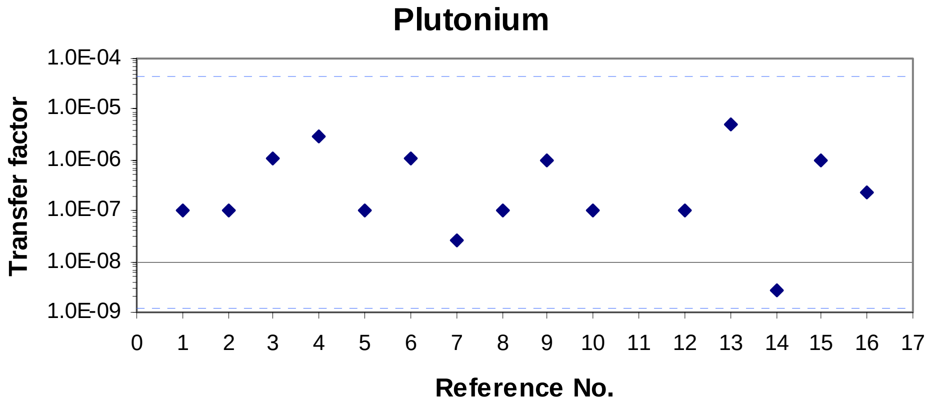


NOTES: TCs are in units of Bq/L of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value recommended for screening models
[b] Value used in the biosphere modeling for Yucca Mountain
[c] GENII default
[d] RESRAD default value
[e] For the references listed in this table, GM = 6.3E-06; GSD = 2.0.

Table 6-55. Plutonium Transfer Coefficients for Milk

No.	Reference	Transfer Coefficient, d/L	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 50	1.0E-07	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	1.0E-07	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 35	1.1E-06	3.0E-09 to 3.0E-06
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	3.0E-06 [a]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	1.0E-07	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.1E-06 [b]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	2.5E-08	–
8	NCRP 1984 [DIRS 103784], pp. 82 to 83	1.0E-07 [c]	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	1.0E-06 [a]	–
10	Ng 1982 [DIRS 160322], p. 62	1.0E-07	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	–	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	1.0E-07 [d]	–
13	Smith et al. 1996 [DIRS 101085], p. 5-27	5.0E-06 [b]	–
14	Peterson 1983 [DIRS 167077], p. 5-86	2.7E-09 [e]	–
15	Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	1.0E-06 [f]	–
16	This analysis	–	lognormal; GM = 2.3E-07 [g]; GSD = 7.7 truncation: low = 1.2E-09; high = 4.4E-05



NOTES: TCs are in units of Bq/L of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value recommended for screening models

[b] Value used in the biosphere modeling for Yucca Mountain

[c] Value for plutonium citrate

[d] GENII default

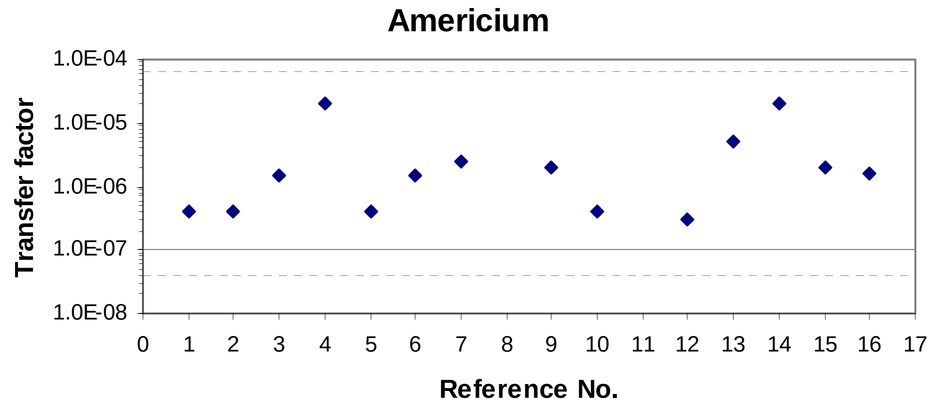
[e] Value for PuO_2

[f] RESRAD default value

[g] For the references listed in this table, GM = 2.3E-07; GSD = 7.7.

Table 6-56. Americium Transfer Coefficients for Milk

No.	Reference	Transfer Coefficient, d/L	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [DIRS 103766], p. 50	4.0E-07	–
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	4.1E-07	lognormal; GSD = 3.2
3	IAEA 1994 [DIRS 100458], p. 35	1.5E-06	4.0E-07 to 2.0E-05
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	2.0E-05 [a]	–
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	4.0E-07	–
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	1.5E-06 [b]	lognormal; GSD = 2
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	2.5E-06	–
8	NCRP 1984 [DIRS 103784], pp. 82 to 83	–	–
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	2.0E-06 [a]	–
10	Ng 1982 [DIRS 160322], p. 62	4.1E-07	–
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	–	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	3.0E-07 [d]	GENII-S default
13	Smith et al. 1996 [DIRS 101085], p. 5-27	5.0E-06 [b]	–
14	Peterson 1983 [DIRS 167077], p. 5-86	2.0E-05 [c]	–
15	Wang et al. 1993 [DIRS 103839], pp. 30 to 32 Yu et al. 2001 [DIRS 159465], p. D-16	2.0E-06 [e]	–
16	This analysis	–	lognormal; GM = 1.6E-06 [f]; GSD = 4.2 truncation: low = 3.9E-08; high = 6.3E-05



NOTES: TCs are in units of Bq/L of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Value recommended for screening models
[b] Value used in the biosphere modeling for Yucca Mountain
[c] Value for transuranics
[d] GENII default
[e] RESRAD default value
[f] For the references listed in this table, GM = 1.6E-06; GSD = 4.2.

Table 6-57. Transfer Coefficients for Milk for Other Elements

No.	Reference	Transfer Coefficient, d/L (Bq/L of animal product per Bq/d of radionuclide intake)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Baes et al. 1984 [DIRS 103766], p. 50	1.5E-02	4.0E-03	1.5E-03	1.0E-03	7.0E-03	2.5E-04	4.5E-04	2.0E-05	5.0E-06	5.0E-06	6.0E-04
2	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	–	4.0E-03	1.4E-03	1.2E-03	7.1E-03	2.6E-04	4.0E-04	2.0E-05	5.0E-06	5.0E-06	3.7E-04
3	IAEA 1994 [DIRS 100458], p. 35	1.7E-02	–	2.8E-03	–	7.9E-03	–	1.3E-03	–	–	–	4.0E-04
4	IAEA 2001 [DIRS 158519], pp. 67 to 68	–	1.0E-03	3.0E-03	1.0E-03	1.0E-02	3.0E-04	1.0E-03	2.0E-06	5.0E-06	5.0E-06	6.0E-04
5	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	1.5E-02	4.0E-03	1.5E-03	1.0E-03	7.0E-03	2.5E-04	4.5E-04	2.0E-05	5.0E-06	5.0E-06	6.0E-04
6	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	4.0E-03	3.0E-03	1.0E-03	7.9E-03	2.5E-04	1.3E-03	2.0E-05	5.0E-06	5.0E-06	4.0E-04
7	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	–	2.3E-02	1.5E-03	1.3E-03	5.0E-03	1.0E-05	2.0E-04	2.5E-06	2.5E-06	2.5E-06	6.0E-04
8	NCRP 1984 [DIRS 103784], p. 83	–	–	1.4E-03	–	7.1E-03	–	4.0E-04	–	–	–	4.0E-04
9	NCRP 1996 [DIRS 101882], pp. 52 to 54	2.0E-02	1.0E-02	2.0E-03	1.0E-03	1.0E-02	3.0E-04	1.0E-03	2.0E-06	5.0E-06	5.0E-06	4.0E-04
10	Ng 1982 [DIRS 160322], p. 62	1.7E-02	4.0E-03	1.4E-03	1.2E-03	7.1E-03	2.6E-04	4.0E-04	–	–	–	3.7E-04
11	Regulatory Guide 1.109, Rev. 1 1977 [DIRS 100067], p. 1.109-37	–	–	8.0E-04	–	1.2E-02	–	–	–	–	–	–
12	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-02	2.3E-02	1.3E-03	1.0E-03	7.0E-03	3.0E-05	2.0E-04	2.0E-05	2.5E-06	2.5E-06	6.0E-04
13	Smith et al. 1996 [DIRS 101085], p. 5-27	–	4.0E-03	–	–	8.0E-03	3.0E-04	1.3E-03	4.0E-07	5.0E-06	5.0E-06	4.0E-04
14	Peterson 1983 [DIRS 167077], p. 5-86	–	–	1.4E-03	–	7.1E-03	2.6E-04	4.5E-04	2.0E-05	5.0E-06	5.0E-06	6.1E-04
15	Wang et al. 1993 [DIRS 103839], pp. 30 to 32; Yu et al. 2001 [DIRS 159465], p. D-16	2.0E-02	1.0E-02	2.0E-03	1.0E-03	8.0E-03	3.0E-04	1.0E-03	2.0E-05	5.0E-06	5.0E-06	6.0E-04
	GM	1.8E-02	5.7E-03	1.7E-03	1.1E-03	7.7E-03	1.7E-04	5.8E-04	7.6E-06	4.4E-06	4.4E-06	4.9E-04
	GSD	1.1	2.5	1.4	1.1	1.2	3.0	2.0	4.1	1.3	1.3	1.3

Table 6-57. Transfer Coefficients for Milk for Other Elements (Continued)

No.	Reference	Transfer Coefficient, d/L (Bq/L of animal product per Bq/d of radionuclide intake)										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
	Recommended GSD	2.0 [a]	2.5	2.0 [a]	2.0 [a]	2.0 [a]	3.0	2.0	4.1	2.0 [a]	2.0 [a]	2.0 [a]
	Truncation, lower limit	2.9E-03	5.5E-04	2.8E-04	1.8E-04	1.3E-03	1.0E-05	1.0E-04	2.0E-07	7.4E-07	7.4E-07	8.1E-05
	Truncation, upper limit	1.0E-01	6.0E-02	1.0E-02	6.3E-03	4.6E-02	2.9E-03	3.4E-03	2.9E-04	2.6E-05	2.6E-05	2.9E-03

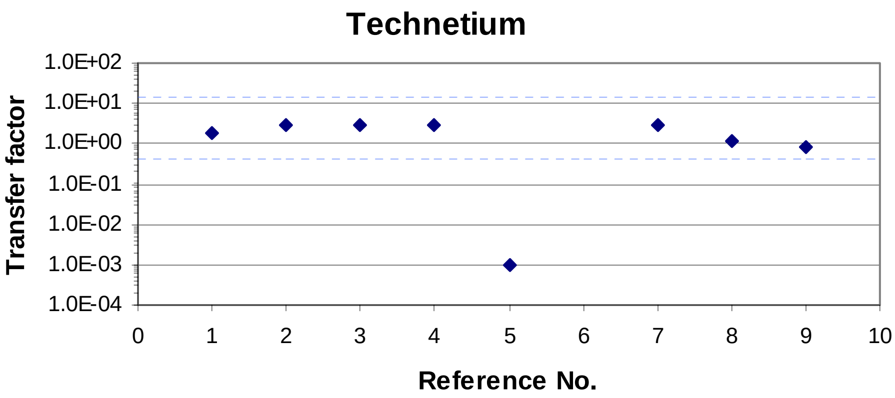
[a] The lower bound of the value of the GSD was used.

6.3.3.4 Transfer Coefficients for Eggs

The values of TCs for eggs and references that were used to develop them are listed in Tables 6-58 to 6-63. Calculation of GMs, standard deviations, and truncation limits for the TCs were preformed using Microsoft Excel 2000, as described in Appendix A.

Table 6-58. Technetium Transfer Coefficients for Eggs

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	1.9E+00 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 41	3.0E+00	–
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	3.0E+00	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	3.0E+00 [b]	lognormal; GSD = 2
5	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	9.9E-04 [c]	–
6	Ng 1982 [DIRS 160322], p. 63	–	–
7	Rittmann 1993 [DIRS 107744], pp. 35 to 36	3.0E+00	GENII-S default
8	Smith et al. 1996 [DIRS 101085], p. 5-29	1.2E+00 [b]	–
9	This analysis	–	lognormal; GM = 2.4E+00 [e]; GSD = 2.0 truncation: low = 4.0E-01; high = 1.4E+01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value used for poultry and eggs

[b] Value used in the biosphere modeling for Yucca Mountain.

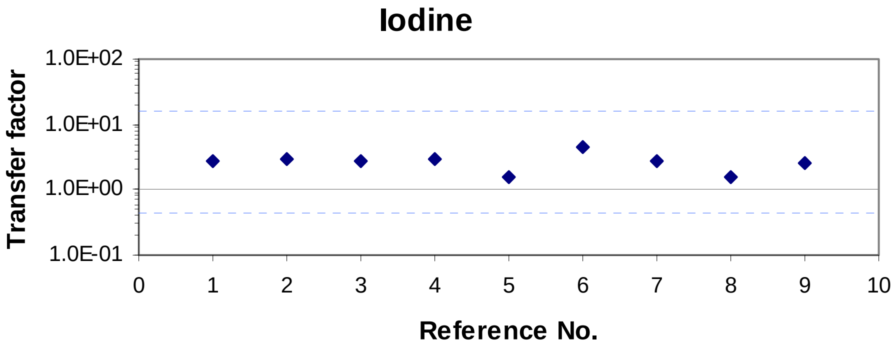
[c] This value is three orders of magnitude lower than the remaining ones and was therefore not included in calculation of GM and GSD.

[d] GENII default

[e] For the references listed in this table, excluding reference #5, GM = 2.4E+00; GSD = 1.5. Lower bound of GSD of 2.0 was recommended.

Table 6-59. Iodine Transfer Coefficients for Eggs

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	2.8E+00 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 41	3.0E+00	2 to 4
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	2.8E+00	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	3.0E+00 [b]	lognormal; GSD = 2
5	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	1.6E+00	–
6	Ng 1982 [DIRS 160322], p. 63	4.4E+00	3.7E+00 to 5.2E+00
7	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.8E+00 [c]	–
8	Smith et al. 1996 [DIRS 101085], p. 5-29	1.6E+00 [b]	–
9	This analysis	–	lognormal; GM = 2.6E+00 [d]; GSD = 2.0 truncation: low = 4.4E-01; high = 1.6E+01

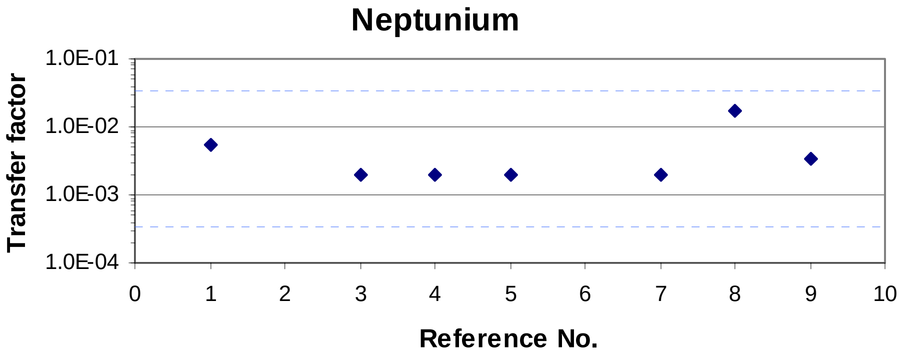


NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value used for poultry and eggs (Davis et al. 1993 [DIRS 103767], p. 238)
[b] Value used in the biosphere modeling for Yucca Mountain
[c] GENII default
[d] For the references listed in this table, GM = 2.6E+00; GSD = 1.4. Lower bound of GSD was recommended.

Table 6-60. Neptunium Transfer Coefficients for Eggs

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	**Range and Distribution**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	5.5E-03 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 41	–	–
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	2.0E-03	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	2.0E-03 [b]	lognormal; GSD = 2
5	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	2.0E-03	–
6	Ng 1982 [DIRS 160322], p. 63	–	–
7	Rittmann 1993 [DIRS 107744], pp. 35 to 36	2.0E-03 [c]	–
8	Smith et al. 1996 [DIRS 101085], p. 5-29	1.7E-02 [b]	–
9	This analysis	–	lognormal; GM = 3.4E-03 [d]; GSD = 2.4 truncation: low = 3.4E-04; high = 3.3E-02

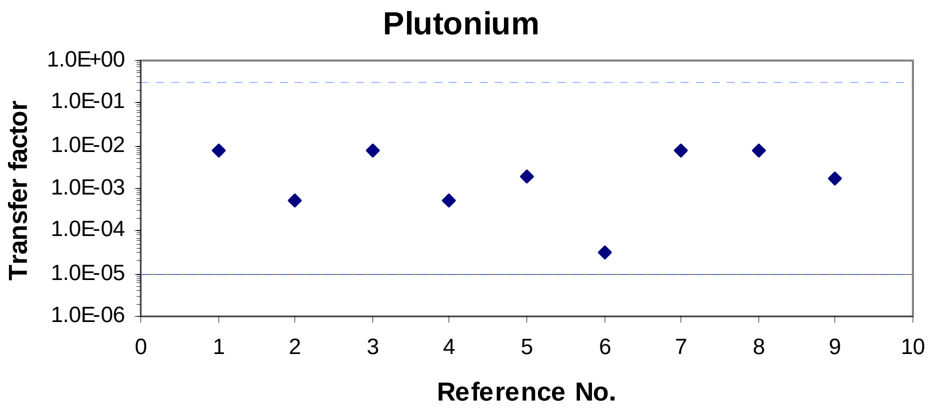


NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value used for poultry and eggs
[b] Value used in the biosphere modeling for Yucca Mountain
[c] GENII default
[d] For the references listed in this table, GM = 3.4E-03; GSD = 2.4.

Table 6-61. Plutonium Transfer Coefficients for Eggs

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	7.6E-03 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 41	5.0E-04	3.0E-05 to 8.0E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	8.0E-03	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	5.0E-04 [b]	lognormal; GSD = 2
5	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	2.0E-03	–
6	Ng 1982 [DIRS 160322], p. 63	3.3E-05	–
7	Rittmann 1993 [DIRS 107744], pp. 35 to 36	8.0E-03 [c]	–
8	Smith et al. 1996 [DIRS 101085], p. 5-29	8.0E-03 [b]	–
9	This analysis	–	lognormal; GM = 1.7E-03 [d]; GSD = 7.4 truncation: low = 9.7E-06; high = 2.9E-01



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value used for poultry and eggs

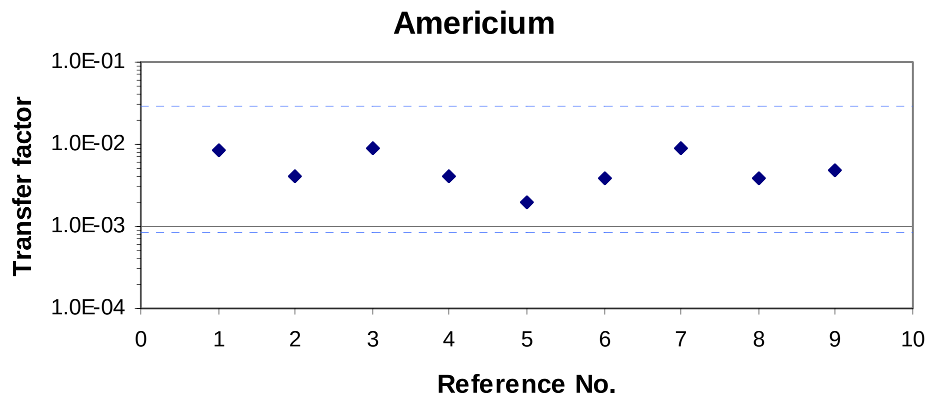
[b] Value used in the biosphere modeling for Yucca Mountain

[c] GENII default

[d] For the references listed in this table, GM = 1.7E-03; GSD = 7.4.

Table 6-62. Americium Transfer Coefficients for Eggs

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	8.5E-03 [a]	lognormal; GSD = 3.2
2	IAEA 1994 [DIRS 100458], p. 41	4.0E-03	1.0E-03 to 9.0E-03
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	9.0E-03	–
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	4.0E-03 [b]	lognormal; GSD = 2
5	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	2.0E-03	–
6	Ng 1982 [DIRS 160322], p. 63	3.9E-03	–
7	Rittmann 1993 [DIRS 107744], pp. 35 to 36	9.0E-03 [c]	–
8	Smith et al. 1996 [DIRS 101085], p. 5-29	3.9E-03 [b]	–
9	This analysis	–	lognormal; GM = 4.9E-03 [d]; GSD = 2.0 truncation: low = 8.2E-04; high = 2.9E-02



NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.
Truncation limits shown in graph as dashed lines.

[a] Same value used for poultry and eggs
[b] Value used in the biosphere modeling for Yucca Mountain
[c] GENII default
[d] For the references listed in this table, GM = 4.9E-03; GSD = 1.7. Lower bound of GSD was recommended.

Table 6-63. Transfer Coefficients for Eggs for Other Elements

	Reference	**Transfer Coefficient, d/kg (Bq/kg of animal product per Bq/d of radionuclide intake)**										
		Cl	**Se**	**Sr**	**Sn**	**Cs**	**Pb**	**Ra**	**Ac**	**Th**	**Pa**	**U**
1	Davis et al. 1993 [DIRS 103767], pp. 233 to 234	–	9.3E+00	3.0E-01	8.0E+00	4.4E+00	4.0E-02	9.0E-02	2.5E-03	6.0E-04	1.0E-03	1.2E+00
2	IAEA 1994 [DIRS 100458], p. 41	–	9.0E+00	2.0E-01	–	4.0E-01	–	–	–	–	–	1.0E+00
3	Kennedy and Strenge 1992 [DIRS 103776], pp. 6.29 to 6.30	2.0E+00	9.3E+00	3.0E-01	8.0E-01	4.9E-01	8.0E-01	2.0E-05	2.0E-03	2.0E-03	2.0E-03	9.9E-01
4	LaPlante and Poor 1997 [DIRS 101079], p. 2-13	–	9.0E+00	2.0E-01	8.0E-01	4.0E-01	8.0E-01	2.0E-05	2.0E-03	2.0E-03	2.0E-03	1.0E+00
5	Mills et al. 1983 [DIRS 103781], pp. 145 to 146	–	2.1E+00	4.0E-01	9.9E-04	5.0E-01	9.9E-04	2.0E-05	2.0E-03	2.0E-03	2.0E-03	3.4E-01
6	Ng 1982 [DIRS 160322], p. 63	–	–	2.2E-01	–	4.3E-01	–	–	–	–	–	–
7	Rittmann 1993 [DIRS 107744], pp. 35 to 36	9.9E-04	9.3E+00	3.0E-01	9.9E-04	4.9E-01	9.9E-04	2.0E-05	2.0E-03	2.0E-03	2.0E-03	9.9E-01
8	Smith et al. 1996 [DIRS 101085], p. 5-29	–	8.3E+00	–	–	4.0E-01	1.2E+00	2.5E-01	1.6E-02	1.8E-01	4.1E-03	1.0E-01
9	Peterson 1983 [DIRS 167077], p. 5-87	–	–	3.0E-01	–	5.0E-03	–	–	–	–	–	–
	GM	4.4E-02	7.3E+00	2.7E-01	8.7E-02	3.5E-01	5.6E-02	3.9E-04	2.9E-03	3.5E-03	2.0E-03	6.3E-01
	GSD	217.4	1.7	1.3	66.3	5.8	28.6	101.4	2.3	7.3	1.6	2.5
	Recommended GSD	10.0 [b]	2.0 [a]	2.0 [a]	10.0 [b]	5.8	10.0 [b]	10.0 [b]	2.3	7.3	2.0 [a]	2.5
	Truncation, lower limit	1.2E-04	1.2E+00	4.5E-02	2.3E-04	3.7E-03	1.5E-04	1.0E-06	3.4E-04	2.0E-05	3.4E-04	6.0E-02
	Truncation, upper limit	1.7E+01	4.4E+01	1.6E+00	3.3E+01	3.3E+01	2.1E+01	1.5E-01	2.5E-02	5.9E-01	1.2E-02	6.7E+00

[a] The lower bound of the value of the GSD equal to 2.0 was used.
[b] The upper bound of the value of the GSD equal to 10.0 was used.

6.4 RADIONUCLIDE TRANSPORT TO AQUATIC FOOD

Groundwater, in addition to the application for crop irrigation and animal watering, can also be used for fish farming. The incorporation of radionuclides into aquatic food may contribute to human exposure. Because there is a history of catfish farming in Amargosa Valley, the fish consumption pathway was included in the biosphere model.

6.4.1 Basic Model for Aquatic Food Chain Transport

The model usually used for assessing the transport of radionuclides in aquatic systems assumes that the assimilation of radionuclides by aquatic organisms is proportional to the level of radionuclide concentration in the water (IAEA 2001 [DIRS 158519], p. 72). This model applies to aquatic systems that are in equilibrium. For such systems, radionuclide accumulation in aquatic fauna is usually quantified in terms of equilibrium concentration ratios, also called the bioaccumulation factors. The bioaccumulation factor is defined as the ratio of the activity concentration in edible portions of animal tissue to that in the water (Bq/kg wet or dry-weight per Bq/L).

The application of the bioaccumulation factor to the calculation of activity concentration in fish is expressed in the biosphere model (BSC 2004 [DIRS 169460], Section 6.4.5) as

$$Cf_i = Cw_{f,i}\ BF_i = Cw_i\ \ MF_i\ \ BF \tag{Eq. 6-14}$$

where

Cf_i = activity concentration of radionuclide i in fish (Bq/kg $_{wet}$)
$Cw_{f,i}$ = activity concentration of radionuclide i in fishpond water at the time of harvest (Bq/L)
BF_i = bioaccumulation factor for radionuclide i in freshwater fish (L/kg)
Cw_i = activity concentration of radionuclide i in groundwater (Bq/L)
MF_i = water concentration modifying factor for radionuclide i (dimensionless).

This analysis develops the values of the bioaccumulation factors, BF_i, and the water concentration modifying factors, MF_i. The bioaccumulation factors are element- and species-dependent, but for a given element and organism, the bioaccumulation factor value can range over several orders of magnitude (IAEA 2001 [DIRS 158519], p. 72). The most important parameter governing the value of a bioaccumulation factor is the trophic level of the organism (IAEA 2001 [DIRS 158519], p. 72). The trophic level is the term used to denote a level of consumption, or a position of the organism, in a food chain. Generally, bioaccumulation tends to be proportional to trophic level. However, bottom-feeding fish have higher bioaccumulation factors (take up more radioactivity) than the piscivorous (fish eating) fish (IAEA 1994 [DIRS 100458], p. 46-47).

6.4.2 Fish Farming in Amargosa Valley

Livestock production activities in Amargosa Valley include catfish farming at the Deer Catfish Farm (CRWMS M&O 1997 [DIRS 101090], pp. 3 to 17; YMP 1999 [DIRS 158212], pp. 15

to 16). During the period from 1988 to 1998, which included the time of the food consumption survey (DOE 1997 [DIRS 100332]), the farm was fully operational. The production has since declined, but the farm still remains in operation (Roe 2002 [DIRS 160674]). The farm consisted of five ponds: two breeding ponds, and three grow-out ponds. According to reports summarizing the socioeconomic data (CRWMS M&O 1997 [DIRS 101090], pp. 3 to 17; YMP 1999 [DIRS 158212], pp. 15 to 16), the number of catfish (channel catfish, *Ictalurus punctatus*) at the farm in 1997 through 1999 was around 15,000. The main customer for the catfish produced in Amargosa Valley was Nevada Department of Wildlife. The fish were used for stocking various ponds and lakes in Southern Nevada. Their average size was 13 to 14 in. (0.33 to 0.36 m), and the average weight per fish was 0.58 to 0.76 lbs (0.26 to 0.35 kg). The farm owner also allowed individuals, including residents of Amargosa Valley, to fish the ponds, although the number and the average size of fish harvested from the ponds is unknown (Roe 2002 [DIRS 160674]).

The following information about catfish farming, relevant to the biosphere modeling, was obtained from the Mississippi State University Extension Service (2002 [DIRS 159489]). (Mississippi is the major catfish producer in the U.S., accounting for about ¾ of U.S. catfish production.) It takes about 2 years to grow a catfish, and a full-grown fish weighs 1 to 2 pounds. The amount of food that is needed to grow the fish is 2 pounds of feed per 1 pound of fish. Catfish are fed a high-protein feed for which the main ingredient is soybean meal with some corn and rice ingredients. In the second year of growth, 5,000 to 8,000 catfish can be stocked per acre, and the average production is 5,000 pounds per acre.

The majority of the fish raised at the Deer Catfish Farm were harvested before they were full-grown because they were used for stocking other ponds and lakes where they would grow further. The investigation conducted at the Deer Catfish Farm indicated that the fish lived in grow-out ponds for at least a year (Roe 2002 [DIRS 160674]). This value provides a lower bound on the duration of the fish raising cycle. The fish used for stocking recreational ponds were relatively small, so it is possible that the fish sold directly to individuals in Amargosa Valley were larger and thus were kept in the ponds longer than 1 year. There is no information available regarding the size of fish that were harvested for local consumption or how long it took to raise them. Catfish reach full-grown size in about two years (Mississippi State University Extension Service 2002 [DIRS 159489]), and this value was used as an upper bound on the duration of the fish raising cycle.

6.4.3 Application of the Model Based on Concentration Ratios to the Amargosa Valley Context

The most frequently used model of radionuclide accumulation in fish is based on equilibrium among all components of the aquatic system, including the water, sediments, and aquatic fauna and flora. Such models apply best to bodies of water with individual components of the system (water, aquatic organisms, plants, and sediments) in equilibrium and not subject to rapid condition changes. In the case of the catfish farm in Amargosa Valley, the components of the system are not in equilibrium because the fish are raised using uncontaminated commercial food. In addition, activity concentration in the fishpond water is not constant, but rather it changes with time because throughout each year, fresh water must be added to the ponds on a continual basis to replace the water lost by evaporation. This change is represented in the model by the water concentration modifying factor. The modifying factor is a multiplier that, when combined with the radionuclide concentration in the water at the well, gives the actual radionuclide concentration in the fishpond water. This time-dependent addition to the system causes deviation from the equilibrium conditions called for by the simple concentration ratio-based model.

The small volume of the ponds also limits the amount of activity available for uptake by the fish. Although the effect of radionuclide depletion in water due to uptake is relatively small for most elements, it can be significant for a few elements for which uptake by aquatic organisms is high. In the biosphere model, the decrease of radionuclide concentration in water due to uptake by the fish is not considered.

Despite the lack of equilibrium between the system components, a simple model based on concentration ratios (bioaccumulation factors) can still provide an adequate estimate of the radionuclide uptake by aquatic organisms. Bioaccumulation factors include contributions from radionuclide intake by fish from water and through food. As noted before, fish food is not contaminated. Use of bioaccumulation factors will thus overestimate the concentration of radionuclides in the fish. The degree of overestimation is unknown because information is not available regarding radionuclide bioaccumulation in fish raised using uncontaminated feed.

Bioaccumulation factors for freshwater fish, BF_i, were developed based on a literature review. Comparison of the bioaccumulation factor values from the reviewed documents is presented in Table 6-64, together with GMs and GSDs for the reported values. The range of values is wide because it includes planktivorous, piscivorous, and bottom-feeding fish. The bottom-feeding fish take up more radioactivity than the piscivorous fish (IAEA 1994 [DIRS 100458], pp. 46 to 47), and the piscivorous fish, which occupy higher trophic level, take up more radioactivity than the planktivorous fish. Channel catfish are bottom-feeders, and thus should be associated with higher values of bioaccumulation factors. In natural aquatic systems, for which the bioaccumulation factors were developed, fish receive radionuclides directly from the water and the food. However, this is not the case for the fish farm, where the fish are fed commercial, uncontaminated feed. Therefore, bioaccumulation factors provide an upper bound of the estimated uptake, and their mean values should not underestimate the transfer of radionuclides from water to aquatic food. It is recommended that the bioaccumulation factors be represented by a lognormal distribution with the GM and GSD calculated based on the values in the selected references. Analogous to the calculations of the soil-to-plant TFs (Section 6.2.1.1) and the TCs for the animal products (Section 6.3.3), truncated distributions are recommended for the bioaccumulation factor, and the GSD was rounded up to 2.0 for values less than 2.0. The upper and lower truncation limits for the 99-percent confidence interval are shown in Table 6-65. Calculations are described in Appendix A. Additional information on the ranges of bioaccumulation factors have been provided by the IAEA (1994 [DIRS 100458], p. 45). The distribution of bioaccumulation factors represents the uncertainty in the upper bound of the parameter value rather than in the uncertainty in the parameter itself. There is additional uncertainty due to the unknown percentage of the uptake of an element that is derived from the water (contaminated) as opposed to that derived from the feed (uncontaminated).

Table 6-64. Bioaccumulation Factors for Fresh Water Fish from Various Sources (L/kg)

Element	Davis et al. 1993 [DIRS 103767], pp. 233-234	IAEA 1994 [DIRS 100458], p. 45	IAEA 2001 [DIRS 158519], p. 73	Kennedy and Strenge 1992 [DIRS 103776], p. 6.32	Mills et al. 1983 [DIRS 103781], pp. 148-149	Napier et al. 1988 [DIRS 100953], pp. 5.769-5.770	NCRP 1996 [DIRS 101882], pp. 58-60	Reg. Guide 1.109 [DIRS 100067, p. 1.109-13	Peterson 1983 [DIRS 167077, p. 5-98 to 5-103	Wang et al. 1993 [DIRS 103839], p. 33-35; Yu et al. 2001 [DIRS 159465], p. D-19	Geometric Mean and Standard Deviation	
C	5.0E+04	5E+04	–	4.6E+03	4.6E+03	9.0E+03	5.0E+04	4.6E+03	–	5.0E+04	1.6E+04	3.3
Cl	–	–	–	5.0E+01	–	5.0E+01	1.0E+03	–	–	1.0E+03	2.2E+02	5.6
Se	1.7E+02	–	2.0E+02	1.7E+02	1.7E+02	1.0E+03	2.0E+02	–	–	2.0E+02	2.3E+02	1.9
Sr	1.0E+02	6E+01	3.4E+01 [a]	5.0E+01	3.0E+01	5.0E+01	6.0E+01	3.0E+01	2.8E+01	6.0E+01	4.6E+01	1.5
Tc	1.5E+01	2E+01	2.0E+01	1.5E+01	1.5E+01	1.5E+01	2.0E+01	1.5E+01	7.8E+01	2.0E+01	2.0E+01	1.7
Sn	3.0E+03	3E+03	–	3.0E+03	–	1.0E+03	3.0E+03	–	–	3.0E+03	2.5E+03	1.6
I	5.0E+01	4E+01	4.0E+01	5.0E+02	1.5E+01	5.0E+01	4.0E+01	1.5E+01	4.4E+01	4.0E+01	4.5E+01	2.6
Cs	1.0E+04	2E+03	4.5E+03 [b]	2.0E+03	2.0E+03	1.5E+04	2.0E+03	2.0E+03	5.6E+03	2.0E+03	3.5E+03	2.2
Pb	3.0E+02	3E+02	3.0E+02	1.0E+02	1.0E+02	2.0E+03	3.0E+02	–	–	3.0E+02	2.9E+02	2.5
Ra	5.0E+01	5E+01	5.0E+01	7.0E+01	5.0E+01	5.0E+01	5.0E+01	–	5.2E+02	5.0E+01	6.7E+01	2.2
Ac	2.5E+01	–	1.5E+01	2.5E+01	2.5E+01	3.3E+02	1.5E+01	–	–	1.5E+01	2.9E+01	3.0
Th	1.0E+03	1E+02	1.0E+02	1.0E+02	3.0E+01	1.0E+02	1.0E+02	–	8.0E+01	1.0E+02	1.1E+02	2.5
Pa	1.1E+01	1E+01	1.0E+01	1.1E+01	1.1E+01	3.0E+01	1.0E+01	–	–	1.0E+01	1.2E+01	1.5
U	5.0E+01	1E+01	1.0E+01	5.0E+01	2.0E+00	5.0E+01	1.0E+01	–	7.5E+00	1.0E+01	1.4E+01	3.0
Np	2.5E+03 [c]	3E+01	3.0E+01	2.5E+02	1.0E+01	2.5E+03 [c]	3.0E+01	1.0E+01	–	3.0E+01	3.0E+01	2.9
Pu	2.5E+02	3E+01	3.0E+01	2.5E+02	3.5E+00	2.5E+02	3.0E+01	–	8.0E+00	3.0E+01	4.1E+01	4.7
Am	1.0E+02	3E+01	3.0E+01	2.5E+02	2.5E+01	1.0E+02	3.0E+01	–	–	3.0E+01	5.2E+01	2.3

[a] Calculated as the GM of the lower and upper bounds of the reported range of values: 1.5E+00 to 7.5E+01

[b] Calculated as the GM of the lower and upper bounds of the reported range of values: 2.0E+03 to 1.0E+04

[c] Values not used to calculate the GM and GSD. These values are inconsistent with the remaining values. The value recommended in the more recent references is two orders of magnitude lower. An additional recent reference not used in Table 6-64 recommends the value of bioaccumulation factor =10 L/kg for neptunium (BIOMASS 2003 [DIRS 168563], p. 459).

Table 6-65. Bioaccumulation Factors and Truncation Limits for Element Concentrations in Fishpond Water

Element	Geometric Mean L/kg	Geometric Standard Deviation	Truncation Lower Limit [a] L/kg	Truncation Upper Limit [a] L/kg
Carbon	4.6E+03	3.2	2.3E+02	9.2E+04
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
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

[a] Calculated using values shown in Table 6-64 (except for carbon, per Assumption 3), see Appendix A. When GSD was less than 2, a GSD of 2 was used to calculate truncation limits.

The biosphere model considers that the initial activity concentration in the pond water increases due to the replacement of water lost by evaporation. This effect is quantified through a water concentration modifying factor.

The biosphere model considers fish that are raised in ponds filled with contaminated groundwater. The source of water for fish farming is a private well (Roe 2002 [DIRS 160674], p. 2). Because of evaporation, the pond water needs to be replenished. According to the Regional Data Analysis Investigation, there is no detectable seepage of water from the ponds, so evaporation is the only water loss mechanism (Roe 2002 [DIRS 160674]). It is assumed that during the fish-growing cycle, which lasts 1 to 2 years, there is no loss of radionuclides from the system, except for ^{14}C, which is discussed later. It is also assumed that the activity accumulates in the ponds for up to 2 years (Assumption 2). After all the fish have been harvested, the ponds are drained, and the water is completely replaced.

The water concentration modifying factor can thus be calculated using the ratio of the volume of water used throughout the fish raising cycle to the volume of the water in the ponds. The volume of water used throughout the fish raising cycle is the sum of the volume of the water that the ponds can hold and the volume of water added to make up for the evaporated water. Because the pond surface area cancels out, this ratio is simply equal to the ratio of the sum of pond depth and the total depth of evaporated water over the fish raising cycle to the pond depth, as expressed by Equation 6-15.

$$MF_i = \frac{PD + AE \times RC}{PD} \qquad \text{(Eq. 6-15)}$$

where

PD = pond depth (meters)
AE = annual evaporation rate (m/yr)
RC = duration of fish raising cycle (year).

The fishpond depth, *PD*, can be determined from the results of the Regional Data Analysis Investigation (Roe 2002 [DIRS 160674], p. 2). Grow-out pond dimensions, surface area, and volume are given in Table 6-66. The depth of the ponds is in the range of 0.8 m to 1.7 m.

Table 6-66. Dimensions of the Grow-out Ponds

Pond No.	Length	Width	Depth	Surface Area	Volume
1	192 ft (59.2 m)	70 ft (21.6 m)	2.5 ft (0.8 m)	13,440 ft^2 (1,278 m^2)	33,600 ft^3 (986 m^3 = 9.86 × 10^5 L)
2	200 ft (61.7 m)	82 ft (25.3 m)	5.5 ft (1.7 m)	16,400 ft^2 (1,560 m^2)	90,200 ft^3 (2,646 m^3 = 2.65 × 10^6 L)
3	182 ft (56.1 m)	82 ft (25.3 m)	5.5 ft (1.7 m)	14,924 ft^2 (1,419 m^2)	82,082 ft^3 (2,408 m^3 = 2.41 × 10^6 L)
Total				44,764 ft^2 (4,258 m^2)	205,882 ft^3 (6,039 m^3 = 6.04 × 10^6 L)

Source: DTN: MO0211SPADIMEN.005 [DIRS 160653].

The volume of water added to compensate for evaporation losses, V_{evap}, can be estimated based on the local free water surface evaporation. The *Evaporation Atlas for the Contiguous 48 United States* (Farnsworth et al. 1982 [DIRS 160564], Map 3) includes the average annual free water (shallow lake) surface evaporation for the United States. The annual evaporation rate for the Amargosa Valley area is between 75 and 80 in. (for the map isopleths closest to the Amargosa Valley). Based on this information, the value of 80 in. (2.03 m) was selected as an annual rate of water evaporation from the fishponds.

Some other references confirm the level of water evaporation in the region. Houghton et al. (1975 [DIRS 106182], p. 62) include a map of annual evaporation from lakes in Nevada. The value for the map isopleths closest to the Amargosa Valley is 72 in. In the Mojave Desert, at Silver Lake, California (Blaney 1957 [DIRS 159504], p. 212), where climate is similar to that in the Amargosa Valley, annual evaporation is about 80 in. (79.46 in. [2.03 m]).

Considering the annual evaporation rate of 2.03 m/yr, the depth of water that evaporates from the ponds and needs to be replaced during a fish raising cycle lasting between 1 and 2 years is between 2.0 and 4.1 m (rounded off to two significant digits). Thus, the water concentration modifying factor is (Equation 6-15) in the range of 2.2, for the pond depth of 1.7 m and a 1-year evaporation, to 6.1, for the pond depth of 0.8 m and a two-year evaporation. It is recommended that a uniform distribution with a minimum value of 2.2 and a maximum value of 6.1 be used for the water concentration modifying factor. This distribution is recommended for the biosphere model for the present day climate for all elements except carbon. For carbon, it is recommended that the modifying factor is equal to 1. The technical bases for this recommendation are explained in the following section.

6.4.4 Carbon Transfer through Aquatic Food Chain

In aquatic food chains, ^{14}C transport involves an additional loss mechanism not included in the model for the other radionuclides: ^{14}C can be lost from the water column via emission of gaseous species to the atmosphere. Consideration of the modifying factor for the ^{14}C concentration in water should thus include ^{14}C loss by emission of gaseous species. The flux of CO_2 from the water depends on the dissolved inorganic carbon inventory, molecular diffusion coefficient of CO_2 in water, the depth of the water column, and other parameters (Davis et al. 1993 [DIRS 103767], p. 102). The emission rate constant of ^{14}C for three Canadian lakes was found to be about 0.9 yr^{-1} (Bird and Ewing 1996 [DIRS 159491], p. 5). However, the lakes were deeper than the fishponds, with a mean depth of 5.7 to 11.6 m (Bird and Ewing 1996 [DIRS 159491], p. 5). Shallow lakes are predicted to have large gaseous ^{14}C emission rates, whereas deep lakes are predicted to have lower emission rates (Davis et al. 1993 [DIRS 103767]. p. 104). Therefore, taking into account the geometry of the fishponds with depths that do not exceed 1.7 m, the gaseous emission rate should be greater than that predicted for the Canadian lakes. In addition, the water aeration system used in the fishponds would promote more rapid gas exchange between the water and the air, and thus greater carbon loss from the water. The rate of water (and activity) addition to offset evaporation losses is equal to 1.4 yr^{-1}. This value can be calculated based on the volume of the ponds (6,039 m^3) and the volume of water that evaporates from the ponds in 1 year (2.03 m/yr × 4,258 m^2 = 8,644 m^3/yr). The annual rate of water (and activity) addition to the ponds is equal to 8,644 m^3/yr divided by 6,039 m^3 (i.e., on average, about 1.4 yr^{-1}). This value is comparable with the emission rate constant for CO_2 in water, as explained in the previous section. Therefore, the activity gain due to the addition of water would be compensated by the loss due to emission of gaseous species of carbon, and the ^{14}C concentration in the water would not increase. It could be argued that the concentration of ^{14}C in the fishpond water could be much less than that in groundwater because of loss caused by the water aeration system and rapid turnover of carbon in solution. In addition, the ^{14}C uptake by the fish could further decrease the activity concentration of this radionuclide in water. However, the calculation does not account for the activity that may become fixed in the sediments at the bottom of the ponds and subsequently taken up by the bottom-feeding catfish. To compensate for this possible effect, no credit is taken for the reduction of ^{14}C concentration in the pond water below that of the groundwater. Considering the above, it is recommended that the water concentration modifying factor of 1 be used for evaluation of ^{14}C concentration in the fishpond water.

Carbon uptake by fish occurs by two basic mechanisms: the transfer of carbon from food and the respiration of carbon during water circulation through the gills. Because the catfish at the Deer Catfish Farm are raised using commercial feed, which is not contaminated (Roe 2002 [DIRS 160674]), calculating ^{14}C uptake using the bioaccumulation factor overestimates the concentration of this radionuclide in fish. It is therefore recommended that the lowest value of the bioaccumulation factor from the range of values reported in the literature (4.6×10^3 [see Table 6-65]) be used for the biosphere model to represent the GM. This value is recommended by three of the seven pertinent references that give the bioaccumulation factor for carbon. The uncertainty distribution is assumed to be lognormal with the GSD equal to 3.2, to include the values of bioaccumulation factor from the remaining references (Assumption 3). For such a distribution, the confidence interval spans one order of magnitude (a factor of 10) on either side of the mean at the 95-percent confidence level (Equation 6-3), that is,

$$GSD^{1.96} = 10$$

$$GSD = 10^{\frac{1}{1.96}} = 3.2$$

The upper and lower truncation limits for this distribution, for the 99-percent confidence interval, are calculated as for other elements and are shown in Table 6-65.

Even if the lowest value from the references is selected for the GM of the carbon bioaccumulation factor distribution, it can be shown that such an approach will not underestimate the risk to the receptor even if carbon in fish were in equilibrium with carbon in the water. Therefore, no credit is taken for the dilution of radioactive carbon intake with stable carbon in fish food.

Concentration of carbon in the Nye County well water has been measured (DTN: GS030908312322.002 [DIRS 170051]). The concentrations of inorganic carbon are listed in terms of HCO_3, and the average value is 284 mg/L (DTN: GS030908312322.002 [DIRS 170051]). The carbon fraction of HCO_3 is 0.2, so the average concentration of inorganic carbon in well water can be calculated as 56 mg/L.

According to Cember (1983 [DIRS 108074], p. 77), specific activity of ^{14}C ($T_{1/2}$ = 5730 yr) (Eckerman and Ryman 1993 [DIRS 107684], Table A.1) can be calculated as

$$\frac{6.022 \times 10^{23} \; \frac{atoms}{mole}}{14 \; \frac{g}{mole}} \times \frac{\ln(2)}{5730\, yr \times 365.25 \frac{d}{yr} \times 24 \frac{h}{d} \times 3600 \frac{s}{h}} = 1.65 \times 10^{11} \; \frac{Bq}{g} \qquad \text{(Eq. 6-16)}$$

If the activity concentration of ^{14}C in the water is 1 Bq/L, and the specific activity of ^{14}C is 1.65×10^{11} Bq/g, the mass concentration of ^{14}C in the water is 6.06×10^{-12} g/L. The ratio of ^{14}C to carbon in water is thus

$$\frac{6.06 \times 10^{-12} \dfrac{g}{L}}{56 \dfrac{mg}{L} \times 0.001 \dfrac{g}{mg}} = 1.08 \times 10^{-10} \frac{g_{^{14}C}}{g_C} \tag{Eq. 6-17}$$

Assuming that the carbon content of fish is the same as that of poultry (i.e., 0.2 [Section 6.7.4]), and that the ratio of ^{14}C to carbon in fish is the same as that in the water, the activity concentration of ^{14}C in fish can be calculated as

$$0.2 \frac{g_C}{g_{fish}} \times 1.08 \times 10^{-10} \frac{g_{^{14}C}}{g_C} \times 1.65 \times 10^{11} \frac{Bq}{g_{^{14}C}} \times 1000 \frac{g}{kg} = 3.6 \times 10^3 \frac{Bq}{kg} \tag{Eq. 6-18}$$

This value is numerically equal to the bioaccumulation factor for carbon because it was derived for the unit activity concentration (1 Bq/L) of ^{14}C in the water. The corresponding bioaccumulation factor value would be 3.6×10^3 L/kg.

If the carbon content of fish were 0.25 (same as for meat), then the value of bioaccumulation factor would be 4.5×10^3 L/kg. If the concentration of carbon in the water were 20 mg/L (the value assumed for the biosphere model, as described in Section 6.7.4), the bioaccumulation factor would be 1.0×10^4 L/kg. If both the carbon content of fish were higher and carbon concentration in water were lower, the bioaccumulation factor would be 1.25×10^4 L/kg. These values are well within the range recommended for the biosphere model.

6.4.5 Consideration of Climate Change

The only parameter of the submodel for accumulation of radionuclides in fish that may be affected by the climate change is the rate of water evaporation from the fishponds. For the cooler and wetter climate, the evaporation will be reduced. The annual average free water evaporation for the analogue site, Spokane, Washington, is between 30 and 35 in. (0.76 m to 0.89 m) (Farnsworth et al. 1982 [DIRS 160564], Map 3). Considering the annual evaporation rate of 0.89 m/yr, the depth of water that would evaporate from the ponds during a 1- to 2-year fish raising cycle and would need to be added to the ponds to compensate for the evaporation losses, is between 0.9 m and 1.8 m (rounded off to two significant digits). The water concentration modifying factor can be calculated, using Equation 6-15, to be in the range of 1.5, for the pond depth of 1.7 m and 1-year evaporation, to 3.3, for the pond depth of 0.8 m and 2-year evaporation. The increase of activity concentration in the pond water is thus less than that for the present day climate. It is recommended that the uniform distribution with a minimum value of 1.5 and a maximum value of 3.3 be used for the water concentration modifying factor.

Applying the same approach as that used to develop the values of the modifying factor for the present day climate, it is recommended that the modifying factor be equal to 1 for carbon.

6.5 RADIONUCLIDE TRANSPORT VIA EVAPORATIVE COOLERS

According to a survey (DOE 1997 [DIRS 100332], p. 20), 73 percent of the Amargosa Valley residents lived in homes that had evaporative coolers. Therefore, inhalation of radionuclides introduced into the indoor air by the operation of evaporative coolers was included as one of the environmental transport and exposure pathways.

6.5.1 Evaporative Cooler Operation

Evaporative coolers produce effective cooling by combining water evaporation with an air-moving system. Outside air is pulled through a saturated evaporative media (a water-wetted pad), cooled by evaporation, and circulated by a blower. Because the resulting air is more humid than the outside air, evaporative air cooling is primarily used in areas with low humidity. In dry climates, evaporative air cooling can provide essentially equivalent comfort conditions in residential buildings to refrigerated air cooling, but at about one-third the energy consumption of mechanical air conditioning or heat pumps (AdobeAir 2002 [DIRS 159493]).

As the water in an evaporative cooler evaporates, fresh water (makeup water) is brought into the cooler. However, the minerals brought into the cooler with the makeup water do not evaporate, and the concentration of minerals in circulating water continually increases. Eventually, the water becomes saturated and the minerals precipitate out. During operation, most of the water evaporation occurs at the air inlet side, leaving scale on that surface. The life of the pads can be extended by rotating them so that the previously downstream face becomes the upstream face.

To prevent the water from becoming saturated with minerals, some units include a bleed-off system or a sump dump system. In the bleed-off system, a small amount of water is diverted from the sump to a drain or to the ground. The sump dump system evacuates the water from the sump every six hours or so while the cooler is operating. However, even with these systems, it is rare for the water in a cooler not to become saturated with minerals in most desert environments (Otterbein 1996 [DIRS 159495]).

When an evaporative cooling system is operating, windows or ceiling vents need to be open. The evaporative cooling causes a very rapid indoor air exchange. As shown in the next section the exchange rate may be as high as 20 to 30 h^{-1}.

The natural tendency is for the air to pull the water off the pad. The maximum air velocity without water carryover is approximately 700 FPM. Most engineers design systems for an average velocity of 550 FPM or less to allow for variance in air distribution (Cool Edge 2002 [DIRS 160429]). However, there is general agreement, even among domestic manufacturers, that U.S.-made evaporative coolers are not as energy- or water-efficient as they could be (City of Phoenix 2003 [DIRS 159496]). These products are targeted heavily to middle-, lower-middle-, and low-income households, and appear to be designed against a one- to two-year capital payback, rather than optimum operational efficiency. Inefficiencies in less expensive units include:

- Underpowered, inexpensive aluminum-wound fan motors rather than more energy-efficient, larger copper-wound motors;

- Recirculating pumps that run faster and hotter than necessary to compensate for a lack of volume capacity;
- Fans that run up to 20 percent over design capacity to move larger volumes of air at increased velocity to make up in wind movement what is lost in evaporative efficiency (City of Phoenix 2003 [DIRS 159496]).

The water carry-over can also be caused by damaged, used, or poor quality pads. The most common pads are made of shredded aspen wood fibers packed in a plastic net; they are 1 to 2 in. thick; the least expensive pads are usually the thinnest. Fiber pads must operate at low air velocities to prevent water from being pulled off the pad by the air stream. Therefore, they should be used on coolers that have air inlets on many sides (Otterbein 1996 [DIRS 159495]). As the water causes the fibers to shrink into the center of the pad leaving gaps or thin spots at the corners, extra air then rushes to the thin spots causing a loss of performance and, in extreme cases, water carryover. The airflow can also pull small particles of previously deposited minerals off the pads and thus add contamination to the air stream.

6.5.2 Evaluation of Exposure from Evaporative Cooler Operation

Although evaporated water is unlikely to carry waterborne radionuclides, water droplets with their radionuclide content intact or even enhanced can play a role in contributing to human exposure. Most minerals dissolved in water used in an evaporative cooler precipitate out on the pads or in the sump. However, a fraction of the dissolved minerals, including potential contaminants, may be transferred into the air stream as aerosols and carried into the house. Water droplets suspended in the air stream will not have the same activity concentration of radionuclides as the water that is used to operate the evaporative cooler. The reason is that the water carried into the house will come in contact with the scale on the pads and may become saturated with minerals. Therefore, although the fraction of water carryover may be small, it is possible that the concentration of contaminants in the water may be considerable.

In an evaporative cooler without the bleed-off system, the unit recirculates the water used for wetting the pads. In such a unit, the concentration of dissolved minerals reaches saturation. Ideally, all dissolved minerals should remain on the pads and in the sump. However, it is possible that water and contaminant carryover occurs.

Radionuclide concentrations in the air, resulting from evaporative cooler operation, are estimated in the biosphere model based on the operating characteristics of an average evaporative cooler. Radionuclide concentrations in air (BSC 2004 [DIRS 169460], Section 6.4.2.2) are calculated as

$$Ca_{e,i} = f_{evap} \frac{M_{water}}{F_{air}} Cw_i \qquad \text{(Eq. 6-19)}$$

where

$Ca_{e,i}$ = activity concentration of radionuclide i in the air resulting from operating evaporative coolers (Bq/m^3)
f_{evap} = fraction of radionuclides in water transferred to indoor air (dimensionless)
M_{water} = water evaporation rate (water use) for evaporative coolers (m^3/hr)

F_{air} = airflow rate for evaporative coolers (m^3/hr)
Cw_i = activity concentration of radionuclide i in the groundwater (Bq/m^3).

In this analysis, the values of the f_{evap}, M_{water}, and F_{air} are developed. All of these parameters (e.g., fraction of contamination transferred to the air, evaporation rate, and airflow rate) depend on the operating specifications of evaporative air conditioning units.

Accounting for nearly 90 percent of all homes in the Amargosa Valley, the majority are manufactured homes. The Bureau of the Census (2002 [DIRS 159728], Table H30) identified total Amargosa Valley housing by structure type. Total housing is 536, of which 456 (85 percent) are manufactured homes. The Bureau of the Census (2002 [DIRS 159728], Table H31) also provides information on vacant housing by structure. Vacant housing is equal to 114, of which 81 are manufactured homes. Based on this information, there are 422 occupied homes in Amargosa Valley, of which 375 (88.9 percent) are manufactured homes. The remainder are single-family houses. The 2000 Census data indicates that 91.3 percent of the total Amargosa Valley population (1043 of 1142 people) lived in manufactured homes (Bureau of the Census 2002 [DIRS 159728], Table H33). Therefore, manufactured homes can be used to represent a typical residential structure in Amargosa Valley.

Most manufactured homes are single- or double-wide. Single-wide homes are 12 to 18 feet wide and 30 to 80 feet long; double-wide houses are 24 to 28 feet wide and 40 to 80 feet long. According to the report prepared by the NAHB Research Center for the U.S. Department of Housing and Urban Development, the average square footage is 1,056 ft^2 for the single-wide (single-section) homes and 1,629 ft^2 for double-wide (double-section) homes and 1,955 ft^2 for multi-section homes (NAHB Research Center 1998 [DIRS 160428], p. 35). The single-wide houses constitute 46.2 percent and the double-wide home 51.2 percent of the manufactured homes, with the remainder (2.6 percent) being multi-section structures. Considering the size of homes and the corresponding share of the total housing pool, the average size of the manufactured home is 1,327 ft^2. The average size of a conventional single-family home is 2,048 ft^2 (NAHB Research Center 1998 [DIRS 160428], p. 35).

The interior wall height (ceiling height) of the manufactured homes can be calculated from the data obtained from the NAHB report (NAHB Research Center 1998 [DIRS 160428], p. 38), which are summarized in Table 6-67.

Table 6-67. Wall Height in Manufactured Homes

Wall Height	Percent of Total
7 feet or less (assume 7 feet)	48.2
7½ feet	37.4
8 feet	5.1
8½ feet	1.5
9 feet	7.7

Source: NAHB Research Center 1998 [DIRS 160428], p. 38.

Using the data in Table 6-67, the average wall height for the manufactured homes can be calculated as 7.4 feet. The volume of the average manufactured home is then about 9,800 ft^3. The sizing of an evaporative cooler for such house can be based on the required airflow, which is typically 3 to 4 cubic feet per minute (CFM) per ft^2 in hot desert climates (ToolBase Services 2002 [DIRS 159507]). Using the numbers rounded off to two significant digits, a 3,900 to 5,200 CFM evaporative cooler should be adequate for a 1,300-ft^2 home. Another method of determining the size of an evaporative cooler is based on the cubic footage of the homes. The cubic footage is divided by two and the cooler with an airflow rate value in CFM closest to the result should be adequate (Karpiscak and Marion 1994 [DIRS 159501], p. 3). In this case, the airflow adequate for a 9,800-ft^3 home is 4,900 CFM. The airflow depends on the individual model of the evaporative cooler. Sizes vary with fan power and can range from a few hundred to several thousand CFM for the residential units. The smallest units may be “portables,” which are operated indoors with outputs ranging from a few hundred CFM up to about 2,000 CFM (Watt and Brown 1997 [DIRS 159497], pp. 131, 132, and 135). Window-mounted evaporative coolers may provide an airflow rate of between about 1,000 and 2,000 CFM (Watt and Brown 1997 [DIRS 159497], p. 121). The bigger units are mounted outdoors, either on the roof or at ground level. The output of such units for the residential houses ranges from about 1,000 CFM to over 6,000 CFM (Watt and Brown 1997 [DIRS 159497], Chapters VII and VIII), depending on the model and fan speed. The industry standard rating, in terms of CFM for inlet airflow rate, does not give the actual airflow rate because the actual airflow rate depends on the static pressure (duct pressure loss).

It is recommended that the evaporative cooler flow rate, F_{air}, for the biosphere model be represented by a piece-wise linear distribution with a 0-percent value of 1,000 CFM (1,700 m^3/h), a 50-percent value of 4,900 CFM (8,300 m^3/h), and a 100-percent value of 6,000 CFM (10,200 m^3/h). The airflow rate may decrease with time because of the increased resistance as more scale builds up on the pads. No correction for this effect is made in the biosphere model.

The water use of an evaporative cooler, M_{water}, depends on the airflow rate and the air humidity. In the study performed by Karpiscak et al. (1998 [DIRS 160563]) household water use was tracked for houses equipped with evaporative coolers. The data obtained in the study are presented and summarized in Table 6-68. The average daily water use by evaporative coolers for the two summers of the study, 1993 and 1994, was about 27 L/hr run time. This value varied considerably, depending on whether the cooler was equipped to bleed-off water or evaporate all the water that came into the pan. Coolers without a bleed-off system used an average of about 15.5 L/hr of run time, while coolers with bleed-off systems used an average of over 34.3 L/hr of run time (Karpiscak et al. 1998 [DIRS 160563]). Households were selected for the study on the basis of home size and cooler size (4,500 CFM to 6,500 CFM). The airflow rates for the coolers that were used in Karpiscak’s study were somewhat higher than the range of the airflow rates recommended for the biosphere model. However, it is believed that the results of this study are appropriate for development of the airflow rate values for the biosphere model.

Table 6-68. Evaporative Cooler Water Use

House No.	System Configuration [a]				Water Use		Bleed-off		Operating Hours	Water Use Rate, L/hr [b]	Water Evaporation Rate, L/hr [c]
	BS	NBS	AC	NAC	gallons	liters	gallons	liters			
46	x		x		4483	16970	no data	no data	1661.8	10.21	
42	x		x		15325	58011	no data	no data	2070	28.02	
43	x		x		16471	62349	no data	no data	1922.4	32.43	
46	x		x		2645	10012	no data	no data	532.8	18.79	
38	x		x		9730	36832	no data	no data	1160.3	31.74	
42	x		x		12806	48476	no data	no data	984.5	49.24	
31	x		x		6429	24336	1715	6492	1045.5	23.28	17.07
22	x		x		7103	26888	1755	6643	1605.5	16.75	12.61
34	x		x		9313	35253	3068	11614	1201.8	29.33	19.67
47	x		x		10309	39024	2471	9354	1222.4	31.92	24.27
9	x		x		11636	44047	6931	26237	1815.8	24.26	9.81
15	x		x		11817	44732	4880	18473	3310.8	13.51	7.93
25	x		x		11834	44796	3256	12325	2364.4	18.95	13.73
18	x		x		13658	51701	4155	15728	1898.6	27.23	18.95
21	x		x		14192	53722	5854	22160	1414.5	37.98	22.31
16	x		x		15290	57879	4279	16198	1370	42.25	30.42
32	x		x		16105	60964	10375	39274	1141.6	53.40	19.00
17	x		x		21463	81246	6005	22731	1467.8	55.35	39.87
25	x		x		7675	29053	2475	9369	1088.3	26.70	18.09
16	x		x		8652	32751	1864	7056	895.6	36.57	28.69
18	x		x		8774	33213	2739	10368	1181.5	28.11	19.34
32	x		x		11823	44755	7356	27845	1081.4	41.39	15.64
24	x			x	11801	44672	4182	15831	1439.6	31.03	20.03
2	x			x	12890	48794	1291	4887	1932.8	25.25	22.72
8	x			x	18734	70916	5337	20203	2649.2	26.77	19.14
3	x			x	23141	87598	7687	29098	3211	27.28	18.22
6	x			x	24588	93075	7749	29333	3493.5	26.64	18.25
19	x			x	30960	117196	21812	82567	1746.5	67.10	19.83
30	x			x	36188	136986	7773	29424	3478.8	39.38	30.92

Table 6-68. Evaporative Cooler Water Use (Continued)

House No.	System Configuration [a]				Water Use		Bleed-off		Operating Hours	Water Use Rate, L/hr [b]	Water Evaporation Rate, L/hr [c]
	BS	NBS	AC	NAC	gallons	liters	gallons	liters			
35	x			x	37782	143020	20979	79414	2825.5	50.62	22.51
28	x			x	46346	175438	21336	80765	2431.5	72.15	38.94
24	x			x	11753	44490	1782	6746	1720.5	25.86	21.94
19	x			x	16245	61494	3587	13578	2115.3	29.07	22.65
8	x			x	19575	74099	7434	28141	3804	19.48	12.08
37	x			x	25472	96422	14687	55596	3418.2	28.21	11.94
28	x			x	42184	159683	20528	77707	1838.3	86.86	44.59
14		x	x		2032	7692	–	–	701	10.97	10.97
41		x	x		4061	15373	–	–	991.2	15.51	15.51
29		x	x		4593	17386	–	–	2040	8.52	8.52
39		x	x		5529	20929	–	–	1001.6	20.90	20.90
33		x	x		6056	22924	–	–	1716.8	13.35	13.35
44		x	x		6386	24174	–	–	658.4	36.72	36.72
40		x	x		6739	25510	–	–	1891.6	13.49	13.49
26		x	x		7174	27156	–	–	2657.3	10.22	10.22
1		x	x		7334	27762	–	–	1066.9	26.02	26.02
23		x	x		7502	28398	–	–	1871.2	15.18	15.18
36		x	x		7758	29367	–	–	2314.6	12.69	12.69
11		x	x		7843	29689	–	–	1492.1	19.90	19.90
13		x	x		9909	37510	–	–	1700.4	22.06	22.06
27		x	x		10098	38225	–	–	4580.6	8.34	8.34
38		x	x		11616	43971	–	–	1780.2	24.70	24.70
29		x	x		1798	6806	–	–	1877.9	3.62	3.62
11		x	x		5029	19037	–	–	1031.3	18.46	18.46
26		x	x		5730	21690	–	–	3477.1	6.24	6.24
33		x	x		8807	33338	–	–	2081.7	16.01	16.01
27		x	x		11771	44558	–	–	3567.9	12.49	12.49
13		x	x		19365	73304	–	–	3437	21.33	21.33
37		x		x	4336	16413	–	–	3912.8	4.19	4.19
4		x		x	15110	57197	–	–	3778.4	15.14	15.14
5		x		x	18684	70726	–	–	3952.6	17.89	17.89

Table 6-68. Evaporative Cooler Water Use (Continued)

House No.	System Configuration [a]				Water Use		Bleed-off		Operating Hours	Water Use Rate, L/hr [b]	Water Evaporation Rate, L/hr [c]
	BS	NBS	AC	NAC	gallons	liters	gallons	liters			
4		x		x	17243	65272	–	–	4560.4	14.31	14.31
Average water use rate, all systems										26.6	
Average water use rate, BS										34.3	
Average water evaporation rate, BS											21.4
Average water evaporation rate, NBS											15.5
Average water evaporation rate, all systems (BS + NBS)											18.7

Source: Karpiscak et al. 1998 [DIRS 160563], p. 122.

NOTES: The table includes measurements from 1993 and 1994.

[a] NBS = no bleed-off system
BS = bleed-off system
AC = air conditioner
NAC = no air conditioner

[b] Total water use rate for evaporative coolers equipped with bleed-off system calculated as a ratio of the cooler water use to number of operating hours.

[c] Water evaporation rate calculated for the units with and without bleed-off system. For coolers without bleed-off system it is a ratio of cooler water use to number of operating hours; for coolers with bleed-off system it is equal to cooler water use minus bleed-off divided by operating hours. For coolers without bleed-off, water use rate is the same as water evaporation rate.

Figure 6-1 shows a histogram of the water evaporation rate for all coolers for which sufficient data were collected. Water evaporation rate per hour of run time for coolers without bleed-off systems is equal to the water use divided by the number of operating hours. This is because in such units, practically all in-flow water evaporates. To calculate water evaporation rates for units with bleed-off systems, the amount of bleed-off water needs to be subtracted from the water used, and then the product divided by the number of operating hours.

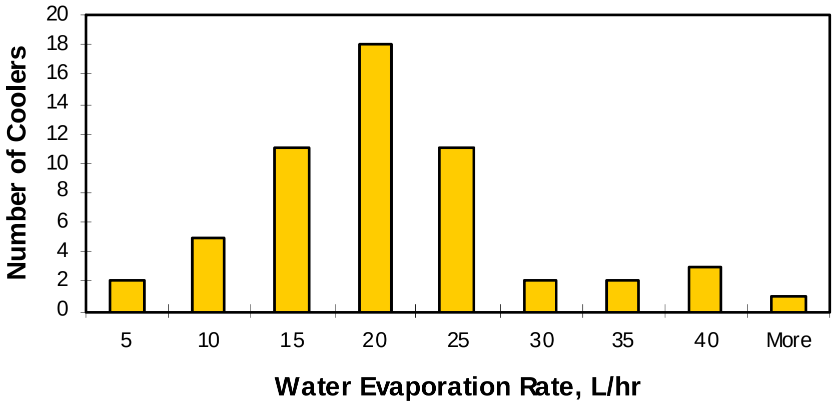


Figure 6-1. Distribution of Measured Water Evaporation Rate for Evaporative Coolers

The distribution of the water evaporation rate for the coolers is approximately lognormal. The GM for the data shown in Table 6-68 is 16.8 L/hr and the GSD is 1.7. Using the values rounded off to two significant digits, it is recommended that the evaporation rate for the evaporative coolers be represented by a lognormal distribution with a GM of 17 L/hr and a GSD of 1.7.

There is a positive correlation between the airflow rate and the water use rate because increased airflow causes increased evaporation and thus increases water use (Karpiscak and Marion 1994 [DIRS 159501], p. 4). All things being equal, a cooler with a lower airflow rate will use less water than a cooler with a higher airflow rate. Research has shown that some units evaporate water more efficiently, and thus produce more cooling per unit of water use (Karpiscak and Marion 1994 [DIRS 159501], p. 3). The correlation coefficient for the airflow rate and the water use rate is less than unity because of the cooler geometry, air humidity, and cooler operating parameters. Sometimes coolers work under less-than-optimum performance. If air velocity is too low, damp air films may isolate the dry air from the wet surfaces, reducing evaporation. If the velocity is too high, there may be insufficient air–water contact time and localized drying of the evaporative cooler pads (Watt and Brown 1997 [DIRS 159497], p. 103).

Introducing a positive correlation between the airflow rate and the water use rate will influence the variance in the value of radionuclide concentration in air calculated using Equation 6-19. Because the radionuclide concentration in air is calculated using the ratio of the water evaporation rate and the airflow rate, the variance is at its maximum when the correlation is zero and falls as the correlation increases to unity. This can be seen intuitively, as in the case of fully correlated variables. When the large value of one variable is selected, a large value of the other variable is also selected; and when the low value of one variable is selected, a low value of the other variable is also selected; so the ratio is not subject to large variations. When there is no correlation, all variables are sampled at random, thereby increasing the variance. The data on the value of correlation coefficient are lacking, but it can be reasonably estimated, based on the available information and the understanding of the processes involved, that the value of the correlation coefficient between the airflow rate and the water use rate is about 0.8. This value is recommended for the biosphere model.

The evaporative cooler water transfer fraction, the fraction of radionuclide concentration in water that is transferred into the air, is the most uncertain parameter of the evaporative cooler submodel. This parameter can range between 0 and 1. No equivalent model was found in the literature. Although considerable scaling (accumulation of solids) occurs during operation of an evaporative cooler, the degree of radionuclide transfer into the air is unknown. Considering the lack of information on this parameter, it was assumed that the probability distribution function for the fraction of contaminant carried over to the outlet air is uniform, ranging from 0 to 1 (Assumption 4). (The uniform distribution of all possible parameter values allows evaluation of the biosphere model sensitivity to this parameter to determine whether any additional work is warranted to develop a more realistic distribution of the parameter values.) This distribution should be used for dissolved solids; it is recommended that for gases, the transferred fraction be equal to 1. The same value is recommended for the future climate.

6.6 EXHALATION OF RADON FROM SOIL

Radon is a radioactive gas formed by decay of radium. When radium isotopes decay in the soil, a fraction of the radon produced is able to escape from soil to the atmosphere. Once radon is released from the soil, it decays through a series of short-lived decay products that interact with atmospheric gases and aerosols to form radioactive aerosol particles. Although radon isotopes are gases, their decay products are metals and commonly exist either as small molecular clusters containing the oxidized metal atom or as larger aerosol particles formed by decay products attaching to initially nonradioactive aerosol particles.

Inhalation of radon decay products is, in many cases, the dominant internal dose contributor when radium isotopes are present in the soil (Yu et al. 2001 [DIRS 159465], p. C-15). The most common radon isotope, and usually the most important dose contributor, is ^{222}Rn. It is produced by decay of ^{226}Ra.

6.6.1 Radon Concentration in Outdoor Air

Concentration of radon in the outdoor air depends on the radon fluxes from soil and on the processes that disperse radon in the atmosphere. Radon exhalation from soil depends in turn on radon emanation from the mineral grains and subsequent transport through pore spaces. Radon generation and transport in soil is a complex process involving solid, liquid, and gas phases in the processes of emanation (release from the solid matrix), diffusion, advection, absorption in the liquid phase, and adsorption in the solid phase (UNSCEAR 2000 [DIRS 158644], p. 97). ^{222}Rn exhalation from soil, represented usually by radon flux density, is proportional to the activity concentration of ^{226}Ra in soil. However, the activity concentration of ^{222}Rn in outdoor air depends not only on the magnitude of exhalation but also on atmospheric mixing processes.

The relationship between ^{222}Rn in air and ^{226}Ra used in the biosphere model (BSC 2004 [DIRS 169460], Section 6.4.2.3) to estimate the concentration of radon in outdoor air is

$$Ca_{g,Rn-222,n=1\&2} = f_{m,Rn-222}\, Cs_{m,Ra-226} \tag{Eq. 6-20}$$

where

$Ca_{g,Rn-222,n=1\&2}$ = activity concentration of ^{222}Rn in outdoor air (Bq/m^3)
n = index of the environments (see below)
$f_{m,\,Rn-222}$ = concentration ratio of ^{222}Rn activity in the air to ^{226}Ra activity in soil (radon release factor) (kg/m^3)
$Cs_{m,Ra-226}$ = activity concentration of ^{226}Ra in surface soil (Bq/kg).

Five environments associated with different human activities are considered in the ERMYN model, four in the contaminated area: active outdoors (n = 1), inactive outdoors (n = 2), active indoors (n = 3), asleep indoors (n = 4), and one outside of the contaminated area (n = 5).

This formula uses a simple relationship between the activity concentration of ^{226}Ra in soil and the ^{222}Rn activity concentration in air in the breathing zone of a person, and it is recommended for the screening models (NCRP 1999 [DIRS 155894], pp. 87 to 88). Such relationships were developed based on the average global levels of ^{222}Rn in the environment. The average activity concentration of ^{226}Ra in soil in the United States is 40 Bq/kg (UNSCEAR 2000 [DIRS 158644], p. 115; NCRP 1999 [DIRS 155894], pp. 87 to 88) and the average global activity concentration of ^{222}Rn in the air is 10 Bq/m^3 (UNSCEAR 2000 [DIRS 158644], p. 103; NCRP 1999 [DIRS 155894], pp. 87 to 88). Based on these values, the conversion factor is equal to 0.25 (Bq/m^3)/(Bq/kg). The information in the reviewed literature is insufficient to determine the uncertainty distribution for this value. A similar approach using a fixed value is also recommended for the screening dose calculations (NCRP 1999 [DIRS 155894], pp. 87 to 88), which are, by design, conservative. Therefore, it is recommended that the fixed value of the radon release factor be used. It is also recommended that the same value of the radon release factor be used for the groundwater exposure scenario for the present day and the future climate.

The conversion factor for radon is based on the global values for ^{226}Ra in soil and ^{222}Rn in air concentrations. Therefore, the applicability of such values to the specific conditions of Amargosa Valley needs to be discussed. Grain size and shape are two important factors that control the emanation of radon from soil into pore space. Generally, the radon emanation factor is inversely proportional to grain size because of radionuclide sorption or coprecipitation with metal oxides or organic compounds on particle surfaces (UNSCEAR 2000 [DIRS 158644], p. 97). Radon emanation factor is defined as the fraction of radon atoms released into rock or soil pore space from radium-bearing grain (UNSCEAR 2000 [DIRS 158644], p. 97).

Considering the texture of the Amargosa Valley soils, which contain a very high fraction of sand, the emanation fraction of naturally occurring radon should be less than average. However, in the case of irrigation with contaminated groundwater, radium will become adsorbed onto the surfaces of the grains. The presence of radium in increased concentration in surface coatings of the grains increases the emanation fraction (fraction of radon that escapes from the solid matrix) relative to that in which radium is uniformly distributed throughout the grain. However, even for naturally occurring radionuclides in soils, there is evidence of activity concentration being preferentially distributed on smaller grains. This could be evidence of increased activity concentration of natural radionuclides in surface coatings relative to their average concentration in the soil.

If the ^{222}Rn flux density is known, rather than the activity concentration in soil, a relationship analogous to that represented by Equation 6-20 can be developed based on the ratio of the ^{222}Rn concentration in air and the average global levels of ^{222}Rn flux density from soil, $CF_{Rn\text{-}222}$ as

$$Ca_{g,\ Rn-222} = CF_{Rn-222}\ J_{outdoor} \qquad \text{(Eq. 6-21)}$$

where

$Ca_{g,Rn\text{-}222}$ = ^{222}Rn activity concentration in the air (Bq/m^3)
$CF_{Rn\text{-}222}$ = ratio of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil (s/m)
$J_{outdoor}$ = radon flux density from contaminated soil [Bq/(m^2 s)].

The global average flux density is estimated to be about 16 mBq/m^2/s (UNSCEAR 2000 [DIRS 158644], p. 99). For dry soil, calculations of radon flux density produce a higher value of 33 mBq/m^2/s (UNSCEAR 2000 [DIRS 158644], p. 99), which also agrees with measured values. Modeling of global radon fluxes also yields the higher value of 34 ± 9 mBq/m^2/s (Schery and Wasiolek 1998 [DIRS 160686], p. 207). Because the average activity concentration of ^{226}Ra in air is 10 Bq/m^3 (as noted in the previous paragraph) the value of $CF_{Rn\text{-}222}$ can be calculated to be about 300 s/m for the flux density equal to 33 to 34 mBq/m^2/s. Accordingly, the best estimate of the ratio of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil is 300 s/m. This value agrees with the approach presented in the RESRAD code manual (Yu et al. 2001 [DIRS 159465], p. C-9), where 500 s/m is given as the upper limit for very large areas of contamination. The value used in RESRAD model is also based on radon levels in the natural environment, but it is likely that it was developed using the lower (older) levels of radon flux density from soil. Because the information in the reviewed literature is insufficient to determine the uncertainty distribution for the value of this conversion factor, it is recommended that the fixed value of 300 s/m be used. This value should also be used for the groundwater exposure scenario for the present day and future climates.

As noted before, radon exhalation from soil depends on the radon release from the mineral grains, which is quantified by the emanation factor, and the subsequent transport through the pore spaces. For the volcanic ash exposure scenario, the ^{222}Rn flux density for a surface source of unit surface activity concentration (1 Bq/m^2) can be estimated by assuming that only the emanation process limits radon release from soil. Because of the source geometry (thin layer), it is assumed that there are no losses due to radon transport through the pore spaces. The value of the emanation factor varies from 0.05 to 0.7 for rocks and soils (UNSCEAR 2000 [DIRS 158644], p. 97). The contaminated tephra released from a volcano is highly porous and may have microscopic fractures and fissures because of the high temperature at which it was formed and released. Such fractures may significantly enhance emanation of radon from the grains, especially if the tephra is dry. Because it is not possible to evaluate the magnitude of this effect, it is recommended that the emanation factor for the volcanic scenario be equal to 1.

6.6.2 Radon Concentration in Indoor Air

Radon produced in soil can enter the indoor air through the air exchange with the outside air, and also through cracks in floors and walls, construction joints, gaps in suspended floors, gaps around service pipes, cavities inside walls, and through the domestic water supply. Where a house is present, soil air containing radon often flows toward its foundation because of differences in air pressure between the soil and the house, the presence of openings in the house foundations, and increased permeability around the basement. There is evidence that a large part of indoor radon comes from the soil below and around buildings (Wilkening 1985 [DIRS 160427], p. 219). The mechanisms of radon entry directly from the soil include diffusion and advection. The diffusion is driven by the concentration gradient of radon in soil gas and in indoor air. The advection is caused by the pressure differential between the building shell and the ground around the foundation (UNSCEAR 2000 [DIRS 158644], pp. 99 and 102). For a reference masonry house, diffusive and advective radon entry each contribute about 40 percent, and the outdoor air contributes about 20 percent of indoor radon, however, the actual contributions vary depending on the house. For example, considering the high percentage of manufactured homes in Amargosa Valley, one may expect that, on average, the contribution from the advective flow of radon into the building will be less than for a typical house because of the lack of direct contact between the building and the soil.

The indoor radon concentration is represented in the biosphere model (BSC 2004 [DIRS 169460], Section 6.4.2.3) as the sum of the indoor and outdoor components, such that

$$Ca_{g,\ Rn-222,n=3\&4} = \frac{J_{indoor}}{v\ H} + Ca_{g,\,Rn-222,n=1\&2} \qquad \text{(Eq. 6-22)}$$

where

$Ca_{g,Rn-222,n=3\&4}$ = activity concentration of ^{222}Rn in indoor air (n = 3 and 4 for active indoor and asleep indoor (Bq/m^3)
J_{indoor} = radon flux density from the house floor (Bq/(m^2 s))
H = interior wall height of the house (meters)
v = house ventilation rate, or air exchange rate (/s). This parameter has two values, a normal rate (v_n) and a higher rate used when evaporative coolers are in operation (v_e)
$Ca_{g\ Rn-222,n=1\&2}$ = ^{222}Rn activity concentration in outdoor air (n = 1 and 2) (Bq/m^3).

The house ventilation rate, v, has two values: a normal rate, v_n, and a higher rate used when evaporative coolers are in operation, v_e. These two values are developed further in this section.

The radon flux density from the floor of the house can be expressed as a proportion of the total radon flux density from contaminated outdoor soil, when soil beneath the house is also considered contaminated (BSC 2004 [DIRS 169460], Section 6.4.2.3), as

$$J_{indoor} = f_{house} \times J_{outdoor} \qquad \text{(Eq. 6-23)}$$

where

$J_{outdoor}$ = radon flux density from outdoor contaminated soil (Bq/(m^2 s))
f_{house} = fraction of radon released into a house from soil beneath the house (dimensionless).

Indoor radon concentration is calculated in the biosphere model (BSC 2004 [DIRS 169460], Section 6.4.2.3) as

$$\begin{aligned} Ca_{g,\ Rn-222,n=3\&4} &= Ca_{g,\ Rn-222,n=1\&2}\left(\frac{f_{house}}{v\ H}\frac{J_{outdoor}}{Ca_{g,\,Rn-222,n=1\&2}}+1\right) \\ &= Ca_{g,\ Rn-222,n=1\&2}\left(\frac{f_{house}}{CF_{Rn-222}\ v\ H}+1\right) \end{aligned} \qquad \text{(Eq. 6-24)}$$

where

CF_{Rn-222} = ratio of radon concentration in outdoor air to radon flux density from soil (s/m).

This analysis develops the values of the fraction of radon that is exhaled from the bare soil that enters into the building, f_{house}, the house ventilation rate, ν, and the interior wall height of the house, H. CF_{Rn-222} was developed in Section 6.6.1.

The average interior wall height was developed in Section 6.5.2 and its value is 7.4 feet (2.3 m). The minimum ceiling height for the habitable rooms and bathrooms is taken at 7 feet (2.1 m). This value represents the minimum ceiling height for a minimum of 50 percent of the room's floor area with the remaining area having a ceiling with a minimum height of 5 feet (24 CFR 3280.104 [DIRS 160555]). As the maximum height according to the NAHB data (NAHB Research Center 1998 [DIRS 160428], p. 38) did not exceed 9 feet (2.7 m), it is recommended that the ceiling height be represented by the piece wise cumulative distribution with the following properties: (2.1 m, 0 percent), (2.3 m, 50 percent), (2.7 m, 100 percent).

According to the *Manufactured Home Construction and Safety Standards* (24 CFR 3280 [DIRS 160555]), the whole house ventilation rate for the manufactured homes should be at minimum 0.35 air exchanges per hour (24 CFR 3280.103(b) [DIRS 160555]). However, the Home Ventilating Institute recommends that standard room ventilation rate is 6 exchanges per hour and ventilation rate for kitchens is 15 exchanges per hour (HVI 2001 [DIRS 160557], p. 24). The nationwide survey of approximately 3,000 households for air exchange rates provided the best available experimental data for residential structures in the United States (Murray and Burmaster 1995 [DIRS 160554], p. 459). The data were grouped into four geographic regions based on heating degree-day isopleths and four seasons. The data for the region encompassing Arizona, Southern California, Texas, and Florida are shown in Table 6-69.

Table 6-69. Empirical Distributions for Air Exchange Rate in U.S. Residences in the Warm Region

Season	Sample size	Air Exchange Rate, 1/h		
		Mean	**Standard deviation**	**Maximum**
Winter	454	0.63	0.52	4.76
Spring	589	0.77	0.62	6.57
Summer	488	1.57	1.56	11.77
Fall	18	0.72	1.43	6.42
All	1549	0.98	1.09	11.77

Source: Murray and Burmaster 1995 [DIRS 160554], pp. 459 and 462 to 463.

The experimental data on air exchange rates are fitted best with lognormal distributions (Murray and Burmaster 1995 [DIRS 160554], pp. 463 to 464). It is recommended that the same distribution be used for the biosphere model. This distribution is characteristic of the annual average conditions. The arithmetic mean is equal to 1.0 air exchanges per hour, and the arithmetic standard deviation is 1.1 air exchanges per hour. The distribution should be truncated at 0.35 air exchanges per hour, which represents the minimum ventilation rate for manufactured homes. To preserve the arithmetic mean, the upper truncation value should be set at 2.9 air exchanges per hour. This value was calculated using the log-transformed values of the arithmetic mean and the lower truncation value. The mean should be equidistant from both truncation values (e.g., the upper truncation is $e^{|\ln(AM)-\ln(LT)|} = e^{|\ln(1)-\ln(0.35)|} = 2.9$, where AM is the arithmetic mean and LT is the lower truncation value). This ventilation rate represents the average conditions and applies to the fraction of time when evaporative coolers are not used.

For houses with evaporative coolers, the ventilation rate of 1.0/hr significantly underestimates the actual air exchange rates. Assuming the average volume of the house of 9800 ft^3 and the average flow rate for an evaporative cooler of 4,900 CFM (Section 6.5.2), the ventilation rate while the unit is in operation is about 30 air exchanges per hour. The average air exchange rate is lower because it includes the time the unit is off. The regional survey data collected in Amargosa Valley (DOE 1997 [DIRS 100332]) include the information on the number of months the respondents used evaporative coolers. As there is no specific information available on the duty cycle (time on divided by time on plus time off) of the evaporative coolers used in Amargosa Valley. It is therefore recommended that the annual average ventilation rate for the fraction of a year in which the evaporative coolers are used be represented by the uniform distribution, with a minimum value of 1 air exchange per hour (this corresponds to the mean value of the exchange rate developed in the preceding paragraph) and a maximum value of 30 air exchanges per hour.

The fraction of radon released into the house from soil, f_{house}, can be evaluated based on the predictions of the radon diffusion into a house through cracks in the concrete slab (UNSCEAR 2000 [DIRS 158644], pp. 99 to 102; United Nations 1988 [DIRS 159566], pp. 64 to 70). For typical conditions, the fraction of radon exhaled from soil that diffuses through an uncracked slab of concrete of 0.2-m thickness into the house, is less than 10 percent. This value was calculated based on the radon flux density from the concrete slab of 1.2×10^{-3} Bq/m^2/s (United Nations 1988 [DIRS 159566], p. 65) and the radon flux density from uncovered soil of 1.7×10^{-2} Bq/m^2/s (United Nations 1988 [DIRS 159566], p. 63). The presence of cracks in the slab may considerably increase the transmission of the diffusive flux from the soil. The predicted fraction of diffusive flux from soil that transports through a slab, if a gap of 1 cm existed for every meter of slab, is about 25 percent (United Nations 1988 [DIRS 159566], p. 65; Landman 1982 [DIRS 160425], p. 71). This quantity may increase if there is a pressure difference across the concrete slab, which causes the advective flow of radon into the house. Most of the dwellings in Amargosa Valley are of the manufactured house type (nearly 90 percent [see Section 6.5.2]) and have a gap between the house and the ground. The gap decreases the direct entry of radon into the house by reducing the radon concentration gradient between the outdoor and indoor air. It is unlikely, therefore, that the fraction of radon diffusing into such a house is greater than 0.25. Predicated upon this information, it is believed that the fraction of the outdoor radon flux density from soil entering the house be represented by a uniform distribution with a minimum of 0.1 and the maximum of 0.25. This adequately represents the infiltration of radon into these houses in Amargosa Valley.

Also of importance is that 73 percent of the houses in Amargosa Valley use evaporative cooling as the means of air conditioning (DOE 1997 [DIRS 100332], p. 22). When the evaporative cooling unit is in operation, the air is blown into the house at a rate of about 30 air exchanges per hour. The increased indoor air pressure will further reduce the seepage of the soil gas into the house and one could assume that virtually all radon entering the home originates from the outdoor air rather than from the soil gas.

6.6.3 Equilibrium Factors

To calculate the dose from short-lived decay products of radon, the degree of equilibrium between the parent radionuclide and its short-lived decay products must be considered. The equilibrium factor, EF_{Rn-222}, is a quantity that permits exposure to be estimated in terms of the potential alpha energy concentration (PAEC) or the equilibrium equivalent radon concentration (EEC), $Ca_{eq,Rn-222}$, from the measurements of radon gas concentration. The equilibrium factor is defined as the ratio of the actual PAEC in air to the PAEC that would prevail if all decay products in the series were in equilibrium with the parent radon. The alternative definition is the ratio of the EEC to the actual radon concentration in air (UNSCEAR 2000 [DIRS 158644], p. 103). The EEC can be calculated as

$$Ca_{eq,\,Rn-222} = EF_{Rn-222}\ Ca_{g,\,Rn-222} \qquad \text{(Eq. 6-25)}$$

where

$Ca_{eq,Rn-222}$ = EEC for ^{222}Rn in air (Bq/m^3)
EF_{Rn-222} = equilibrium factor (dimensionless)
$Ca_{g,Rn-222}$ = ^{222}Rn activity concentration in air (Bq/m^3).

EEC can then be converted to PAEC in working levels (WL) (UNSCEAR 2000 [DIRS 158644], p. 103) using the following conversion:

1 Bq/m^3 of EEC of ^{222}Rn is equivalent to 0.27 mWL of PAEC.

Extensive measurements of the equilibrium factor indicate that typical outdoor ^{222}Rn equilibrium factors are between 0.5 and 0.7 (UNSCEAR 2000 [DIRS 158644], p. 103). The values of the equilibrium factors for outdoor radon obtained in individual measurements range from 0.2 to 1.0, which indicates a relatively high degree of uncertainty in the application of a typical value of the equilibrium factor to derive PAEC from the measurement of radon gas concentration. A summary of the measurements of the outdoor equilibrium factor outdoors in the United States and abroad was given in NCRP Report No. 97 (NCRP 1988 [DIRS 153691], p. 24). The measured values were in the range of 0.43 to 0.87, and the NCRP recommended using the average value of 0.7 (NCRP 1988 [DIRS 153691], p. 24). More recent measurements indicate that a value of 0.6 might be more appropriate for outdoor environments (UNSCEAR 2000 [DIRS 158644], p. 103). Measurements of radon and PAEC at many sites in the southwestern and southeastern United States yielded an average value of equilibrium factor of 0.63 (Wasiolek and James 1995 [DIRS 163507], Table 2), which is within the range of typical values from UNSCEAR (2000 [DIRS 158644]). Table 6-70 shows values for the equilibrium factor from six rural sites in New Mexico (Wasiolek and James 1995 [DIRS 163507]). The average of these six equilibrium factors is 0.61, which agrees well with the values summarized by UNSCEAR (2000 [DIRS 158644], p. 103).

Table 6-70. Average Values of Equilibrium Factor from Measurements at Rural Southwestern Sites

Site	Equilibrium Factor (dimensionless)
Socorro, NM	0.66
Bernardo, NM	0.66
Estancia, NM	0.74
Water Canyon, NM	0.38
White Sands, NM	0.72
Logan, NM	0.51
Average	0.61

Source: Wasiolek and James 1995 [DIRS 163507], Table 2.

For the Yucca Mountain region, the average outdoor equilibrium factor may be even lower than the average obtained at other southwestern sites because of the high insulation and relatively high winds that cause increased deposition (removal) of radon decay products to the earth surface by the process of turbulent diffusion (Schery 2001 [DIRS 159478], p. 267). However, the range of average equilibrium factor values from 0.5 to 0.7 is appropriate for the biosphere model. It is recommended that the average outdoor equilibrium factor be represented by a uniform distribution with a minimum of 0.5 and a maximum of 0.7.

For indoor conditions, recent determinations of the equilibrium factor indoors generally confirm a typical value of 0.4 (UNSCEAR 2000 [DIRS 158644], p. 104; United Nations 1988 [DIRS 159566], p. 75). Indoor measurements range from 0.1 to 0.9, but most are within 30 percent of 0.4 (UNSCEAR 2000 [DIRS 158644], p. 104), that is, in the range of about 0.3 to 0.5. The 1998 report (United Nations 1988 [DIRS 159566], p. 105) includes a summary of the equilibrium factor measurements from thousands of dwellings in North America and Europe. The average equilibrium factor ranged from 0.3 to 0.8, with the range for individual measurements of 0.1 to 0.82. Almost 80 percent of the average values were in the range of 0.3 to

0.5 (when rounded to one significant digit) (United Nations 1988 [DIRS 159566], p. 105), which agrees with the UNSCEAR (2000 [DIRS 158644]) conclusions. The same range of indoor equilibrium factor values is recommended for the biosphere model. It is also recommended that a uniform distribution be used for this parameter. Higher average values for the Yucca Mountain region are unlikely because of the warm climate, construction of the typical houses in the region (manufactured homes), and the use of evaporative coolers in the summer, all of which result in higher home ventilation rates. When evaporative coolers are used, most of the radon decay products attached to the outdoor aerosols will be removed by deposition on the evaporative cooler pads. The high air exchange rate will then effectively prevent buildup of the decay products in the indoor air.

Equilibrium factor values described above apply for the present day and the future climate and for both exposure scenarios.

6.7 CARBON-14 TRANSPORT IN THE ENVIRONMENT

Carbon is highly mobile and readily disperses throughout the environment; therefore, the modeling of its environmental transport and subsequent doses requires a special model. The biosphere model includes such a submodel for the treatment of the ^{14}C introduced into the biosphere. ^{14}C is initially introduced into the soil through the use of contaminated irrigation water. (^{14}C has not been identified as a radionuclide of interest for the extrusive igneous release of radionuclides, consequences of which in the biosphere are modeled using the volcanic ash exposure scenario.) Subsequently, a fraction of ^{14}C is released to the atmosphere by the process of emission of gaseous carbon compounds. Once released into the atmosphere, $^{14}CO_2$ is incorporated into crops via photosynthesis, leading to enhanced levels of ^{14}C in crops. The predominant transport pathway is foliar uptake into the leaf via stomata (pores in the leaf surface). ^{14}C uptake may also occur via the root system, however, root uptake plays a smaller role than foliar uptake (BIOMASS 2001 [DIRS 159468] 2001, T3FM/WD01, p. 48). CO_2, and thus $^{14}CO_2$, may be lost from plants due to respiration. The development of the parameter values supporting the ^{14}C model is described in this section.

6.7.1 Carbon-14 in Soil

Calculation of ^{14}C concentration in soil is based on the assumption of equilibrium conditions between the ^{14}C gains and losses in the topsoil. Mathematically, the concentration of ^{14}C in surface soil can be expressed as (BSC 2004 [DIRS 169460], Section 6.4.6.1):

$$Cs_{C-14,j} = \frac{Cw_{C-14}\ IR_j}{\lambda_{d,C-14} + \lambda_{l,C-14} + \lambda_e + \lambda_{a,C-14}} \qquad \text{(Eq. 6-26)}$$

where

$Cs_{C\text{-}14,,j}$ = activity concentration of ^{14}C in surface soil for the crop type or exposure pathway j (Bq/m^2)

j = crop-type or pathway index; j = 1 for leafy vegetables, 2 for other vegetables, 3 for fruit, 4 for grain, and 5 for fresh forage; j = 0 for the pathways including inhalation, soil ingestion, and external exposure

$Cw_{C\text{-}14}$ = activity concentration of ^{14}C in irrigation water (Bq/m^3)
$IR_{,j}$ = crop irrigation rate; j = 1 to 5 for individual crop types (IRD_j) and j = 0 for the average annual irrigation rate (m/yr)
$\lambda_{d,C\text{-}14}$ = radioactive decay constant for ^{14}C (per year)
$\lambda_{l,C\text{-}14}$ = leaching removal constant for ^{14}C (per year)
λ_e = the surface soil erosion removal constant (per year)
$\lambda_{a,C\text{-}14}$ = emission rate constant of ^{14}C from the soil to the air (per year).

The only parameter supporting Equation 6-26 that is developed in this analysis is the ^{14}C emission rate constant, $\lambda_{a,C\text{-}14}$. The emission rate constant is the fraction of a gaseous radionuclide inventory in the upper (root zone) portion of the soil that is lost to the atmosphere per unit time (usually in one year). The emission rate constant depends to a large extent on the chemical form of carbon, that is, whether it is present as bicarbonates, trapped in organic matter, or in the form of carbonate species dissolved in soil pore water (Sheppard et al. 1991 [DIRS 159545], p. 491). The emission rate of carbon from soil does not depend very strongly on soil type (Davis et al. 1993 [DIRS 103767], p. 156). Information on emission rates of carbon that is not of organic origin is very limited (Davis et al. 1993 [DIRS 103767], p. 156). The average value for sandy soils obtained from lysimeter experiments on Canadian soils was 21/yr to 22/yr (Davis et al. 1993 [DIRS 103767], p. 156; Yu et al. 2001 [DIRS 159465], p. L-16). The values for other soils were lower by a factor of about 2. The default value of the emission rate constant adopted for the RESRAD model was 22/yr (Yu et al. 2001 [DIRS 159465], p. L-16). For the BIOTRAC model, a lognormal distribution of emission rate constant for carbon with the GM of 8.8/yr and a GSD of 10 was chosen (Davis et al. 1993 [DIRS 103767], p. 156). However, this distribution was assumed, rather than derived from the available data, because the only experimental data set used by Davis et al. (1993 [DIRS 103767]), p. 156) to support the value of the emission rate constant is the same as the data that were used by Yu et al. (2001 [DIRS 159465], p. L-16). Therefore, it is believed that the experimental data are insufficient to develop a distribution, and the fixed value of 22/yr measured for sandy soil is appropriate for use in the biosphere model. This value does not result in underestimation of risk to the receptor because the higher carbon emission rate constants from soil lead to higher concentrations of ^{14}C in air where this radionuclide is available for uptake by plants via photosynthesis (see additional discussion of carbon uptake by crops in Section 6.7.3).

6.7.2 Carbon-14 in Air

Inorganic and organic reactions convert most forms of soil carbon to carbon dioxide, CO_2 (Yu et al. 2001 [DIRS 159465], p. L-15). Due to the volatility of CO_2, carbon is lost from the soil to the air. The flux density for gaseous ^{14}C release from soil to air can be estimated (BSC 2004 [DIRS 169460], Section 6.4.6.2) as

$$EVSN_j = Cs_{C-14,j} \ \ \lambda_{a,C-14} \qquad \text{(Eq. 6-27)}$$

where

$EVSN_j$ = average flux density of gaseous ^{14}C from contaminated soil for the crop exposure pathway j (Bq/(m^2 yr))
$Cs_{C\text{-}14,\,j}$ = ^{14}C activity concentration in surface soil for crop or exposure pathway j (Bq/m^2).

The ^{14}C flux density calculated using Eq. 6-24 applies to irrigated land only. Once released into the air, ^{14}C will be diluted by mixing with uncontaminated air. The ^{14}C activity concentration in air can be estimated (BSC 2004 [DIRS 169460], Section 6.4.6.2) as

$$Ca_{g,C-14,j} = \frac{EVSN_j \times \sqrt{\mathrm{A}}}{3.16 \times 10^7 \; H_{mix} \, U} \tag{Eq. 6-28}$$

where

$Ca_{g,C\text{-}14,j}$ = activity concentration of ^{14}C in the air for the crop type or exposure pathway j (Bq/m^3)
A = surface area of land irrigated with contaminated water (m^2)
H_{mix} = mixing height of gaseous ^{14}C (CO$_2$) (meters)
U = annual average wind speed (m/s)
3.16×10^7 = unit conversion factor based on 1 year = 365.25 d (s/yr).

This analysis develops the values of A, H_{mix}, and U used in Equation 6-28.

To determine the surface area of land irrigated with contaminated water, A, it is necessary to determine the average irrigation rate and to make an assumption about the amount of contaminated water that is available for irrigation. This is the amount of water that a community represented by the reasonably maximally exposed individual (RMEI) would use. It was estimated that the annual water demand for such a farming community could range from a few thousand to as much as ten thousand acre-feet (66 FR 55732 [DIRS 156671], p. 55754) and that the water demand of 3,000 acre-feet is a conservative choice of value. In this analysis the volume of water of 3,000 acre-feet (about 3,714,450,000 L = 3,714,450 m^3), reflective of a farming community (66 FR 55732 [DIRS 156671], p. 55754) is used (10 CFR 63.312(c) [DIRS 156605]).

The average irrigation rate for agricultural land is a parameter that is developed elsewhere for the biosphere model (BSC 2004 [DIRS 169673]). The average annual irrigation rate for the present day climate is 0.95 m/yr, with a standard error of 0.08 m/yr, a minimum of 0.73 m/yr, and a maximum of 1.15 m/yr. For the future climate the average annual irrigation rate is 0.50 m/yr, standard error is 0.04 m/yr, a minimum is 0.40 m/yr, and a maximum is 0.60 m/yr (BSC 2004 [DIRS 169673], Section 7). Both distributions are normal. The resulting surface area of land irrigated with contaminated water is then equal to about 3.5×10^6 m^2 for the present day climate and about 7.4×10^6 m^2 for the future climate. The actual surface area of the land that is currently irrigated in Amargosa Valley is around 2,100 acres (8.5×10^6 m^2) (CRWMS M&O 1997 [DIRS 101090], pp. 3-18 to 3-19; YMP 1999 [DIRS 158212], pp. 17 to 18).

For the biosphere model, it is recommended that the surface area of irrigated land for a given climate be calculated as the ratio of the representative volume of 3,000 acre-feet to the average annual irrigation rate.

The height to which the gaseous ^{14}C (CO_2) is uniformly mixed, H_{mix}, depends on the specific application of the parameter. The default values recommended for use in the computer code RESRAD are 2 m for the human inhalation pathway and 1 m for the carbon uptake by crops for human and animal consumption (Yu et al. 2001 [DIRS 159465], p. L-16). The same values of H_{mix} are considered appropriate for application in the biosphere model. The values of A and H_{mix} are arbitrary for the stylized exposure scenario adopted for calculation of concentration of ^{14}C in the air.

The annual average wind speed for the area of interest, based on the meteorological data collected by the Yucca Mountain Project in the vicinity of Yucca Mountain, exceeds 4 m/s. The annual average wind speed for the Meteorological Monitoring Site 9 (Gate 510) is 4.4 m/s (DTN: MO04019SUM9397.000 [DIRS 167054]). Site 9 is the southern most station within the network of meteorological stations operated by the Yucca Mountain Project in the direction of Amargosa Valley (CRWMS M&O 1999 [DIRS 102877], p. 5). The wind at Site 9 is measured at a height of 10 m. However, the annual average wind speed, U, in Equation 6-28 is used to calculate the mixing and dilution of ^{14}C activity released from the farmland covered with crops. For the fully-grown crops, the aerodynamic surface length is around 14 cm (NCRP 1984 [DIRS 103784], p. 48) or higher (Stull 2001 [DIRS 159533], p. 380). (The aerodynamic surface length is defined as the height where the wind speed becomes zero.) The vertical wind profile above the ground is a function of the friction velocity and the aerodynamic surface length. The function is approximately logarithmic, and can be expressed (Stull 2001 [DIRS 159533], p. 377; Randerson 1984 [DIRS 109153], p. 169) as

$$U = \frac{u^*}{k} \ln\left(\frac{z}{z_0}\right) \qquad \text{(Eq. 6-29)}$$

where

U = average wind speed at height z (m/s)
u^* = friction velocity (m/s)
k = von Karman constant (dimensionless)
z = height above ground (meters)
z_0 = aerodynamic surface length (meters) (height at which $U = 0$).

This equation applies to the surface boundary layer for neutral atmospheric conditions, and is appropriate for representing long-term behavior of the system. Neutral atmospheric stability class (class D in the Pasquill-Gifford classification) represents conditions of moderate turbulence. Neutral conditions are associated with relatively strong wind speeds and moderate solar radiation.

Equation 6-29 can be used to obtain the surface-layer wind profile from the observed wind speed and the aerodynamic surface roughness characteristic of the area of interest. As noted before, the average wind speed at 10 m at the Meteorological Monitoring Site 9 is 4.4 m/s. The aerodynamic surface length for the vegetated terrain varies from about 1 cm for short grass to about 10 cm for long grass and crops (Stull 2001 [DIRS 159533], Figure 9.6, p.380; Sehmel 1984 [DIRS 158693], p. 562). The value of k is in the range of 0.35 to 0.4 (Stull 2001 [DIRS 159533], p. 377). The wind profiles for various values of z_0, $u*$ (calculated for a given z_0 using Equation 6-29) and k are shown in Table 6-71. Varying k does not change wind profiles, because $u*$ also changes by the same factor.

The average wind speed, $\overline{U}$, in the atmospheric layer limited from the bottom by the surface roughness length, z_0, and from the top by the height of the mixing cell, H_{mix}, can be calculated as

$$\overline{U} = \frac{\int_{z_0}^{H_{mix}} \frac{u*}{k}\ln\frac{z}{z_0}\,dz}{H_{mix}-z_0} = \frac{\frac{u*}{k}\left[H_{mix}\left(\ln\frac{H_{mix}}{z_0}-1\right)+z_0\right]}{H_{mix}-z_0} \qquad \text{(Eq. 6-30)}$$

The average values of wind speed in the mixing cells for two mixing heights of gaseous $^{14}CO_2$, 1 m and 2 m, calculated using Equation 6-30 are also listed in Table 6-71. The values shown in Table 6-71 were calculated using Excel spreadsheet, as explained in Appendix A.

Table 6-71. Wind Profile in the Surface Boundary Layer

Parameter values for Equation 6-29					
k = 0.35		k = 0.35		k = 0.35	
$u*$ = 0.223		$u*$ = 0.248		$u*$ = 0.334	
z_o = 0.01		z_o = 0.02		z_o = 0.1	
Wind profiles					
z (m)	U (m/s)	z (m)	U (m/s)	z (m)	U (m/s)
0.05	1.03	0.05	0.65	less than z_0	
0.2	1.91	0.2	1.63	0.2	0.66
0.5	2.49	0.5	2.28	0.5	1.54
1	2.93	1	2.77	1	2.20
1.5	3.19	1.5	3.06	1.5	2.59
2	3.37	2	3.26	2	2.86
3	3.63	3	3.55	3	3.25
5	3.96	5	3.91	5	3.74
9	4.33	9	4.33	9	4.30
10	4.40	10	4.40	10	4.40
Average from $z = z_o$ to $z = 1$ m	2.33	Average from $z = z_o$ to $z = 1$ m	2.12	Average from $z = z_o$ to $z = 1$ m	1.49
Average from $z = z_o$ to $z = 2$ m	2.75	Average from $z = z_o$ to $z = 2$ m	2.59	Average from $z = z_o$ to $z = 2$ m	2.06

NOTE: Calculated in Excel spreadsheet using Equations 6-29 and 6-30 (Appendix A).

As can be seen from Table 6-71, the wind velocity changes with height above the ground surface and the wind speed close to the ground is less than the value measured at 10 m. The average wind speed within the mixing cell depends on the aerodynamic surface length and varies between about 1.5 and 2.3 m/s for the mixing height H_{mix} = 1 m and between 2.1 and 2.8 m/s for the mixing height H_{mix} = 2 m.

Based on the vertical wind profile and the average wind speed within the mixing cell, it is recommended that for calculation of ^{14}C uptake by crops (H_{mix} = 1 m), the wind velocity be represented by a uniform distribution over the range of 1.5 m/s to 2.3 m/s. For the human inhalation pathway (H_{mix} = 2 m), it is recommended that the wind speed velocity be represented by the uniform distribution from 2.1 to 2.8 m/s.

6.7.3 Carbon-14 in Crops

The ^{14}C transport in the environment follows that of stable carbon. Two separate transport pathways are considered for ^{14}C uptake by plants: direct root uptake and leaf uptake of CO_2 released from soil to the atmosphere by emission of gaseous compounds of carbon. The latter pathway is dominant because vegetation incorporates most of its carbon from the atmosphere during photosynthesis (Napier et al. 1988 [DIRS 157927], p. 4.86). The activity concentration of ^{14}C in crops resulting from root and leaf uptake is calculated in the biosphere model (BSC 2004 [DIRS 169460], Section 6.4.6.3) as

$$Cp_{C-14,j} = fc_{plant,j}\left[\left(Fa\,\frac{Ca_{g,C-14,j}}{fc_{air}}\right)+\left(Fs\,\frac{Cs_{C-14,j}}{\rho_s\;fc_{soil}}\right)\right] \qquad \text{(Eq. 6-31)}$$

where

$Cp_{C\text{-}14,j}$ = activity concentration of ^{14}C in edible parts of crop type j (Bq/kg $_{\text{wet weight}}$)
$fc_{plant,j}$ = fraction of stable carbon in crop type j (dimensionless, based on kg $_{\text{carbon}}$ /kg $_{\text{wet crop}}$)
Fa = fraction of air-derived carbon in plants, dimensionless
$Ca_{g,C\text{-}14,j}$ = activity concentration of ^{14}C in the air for the crop type or exposure pathway j (Bq/m^3)
fc_{air} = concentration of stable carbon in air, kg/m^3
Fs = fraction of soil-derived carbon in plants, dimensionless
$Cs_{C\text{-}14,j}$ = activity concentration of ^{14}C in surface soil for the crop type or exposure pathway j (Bq/m^2)
fc_{soil} = fraction of stable carbon in soil, dimensionless
ρ_s = surface soil density, kg/m^2.

This analysis develops the values of $fc_{plant,j}$, Fa, fc_{air}, Fs, and fc_{soil} for use in Eq. 6-31.

The fraction of stable carbon in plants, $fc_{plant,j}$, is a plant-specific parameter. It describes the mass fraction of carbon in the wet-weight (fresh) of a plant. The default values used for the GENII and the GENII-S code were 0.09 for fresh fruits, vegetables, and fresh animal feed; and 0.40 for grain and stored animal feed (Napier et al. 1988 [DIRS 157927], p. 4.88). The same values were adopted for the RESRAD model (Yu et al. 2001 [DIRS 159465], p. L-20). It is recommended that the biosphere model also use these values. Using fixed values for carbon content of crop types used in the biosphere model is appropriate because it is unlikely that this parameter would significantly vary within a given crop type and also considering other sources of uncertainty in the modeling of ^{14}C transport in the environment. The biosphere models that were a source of data for fraction of carbon in plants also used fixed values for these parameters.

The fraction of carbon in plants that is derived from carbon in air, *Fa*, represents that portion of total carbon in a plant that was transferred to a plant via the atmosphere. This fraction is dependent on soil organic matter and moisture content, soil pH and microbial characteristics (Sheppard et al. 1991 [DIRS 159545], p. 482). The experimental evidence indicates that much of the transfer of carbon from soil to plants is by way of the atmosphere rather than directly through the roots (Sheppard et al. 1991 [DIRS 159545], p. 491). The researchers estimated that almost 2 percent of the plant carbon originated in the soil, which was in agreement with some earlier estimates (Sheppard et al. 1991 [DIRS 159545], pp. 490 to 491). It is recommended that the fraction of carbon derived from soil, *Fs*, be set at 0.02 for the biosphere model, which implies that the fraction of carbon derived from air, *Fa*, is equal to 0.98. The same values are used as defaults for the RESRAD model (Yu et al. 2001 [DIRS 159465], p. L-20).

An additional finding from the experiment referred to in the previous paragraph was that the soil retained about 2 percent of the inorganic carbon as the result of trapping carbon by natural carbonates present in the soil and organic matter (Sheppard et al. 1991 [DIRS 159545], p. 491). Because the carbonate content of Amargosa Valley soils and their organic matter content are lower than those for the soils used in the experiment, the fraction of carbon retained in the soil may be even lower than 2 percent. This would reduce potential for long-term accumulation of ^{14}C in soil.

The concentration of stable carbon in air, fc_{air}, should be set to 1.8×10^{-4} kg/m^3 for the biosphere model. This value is recommended as a default value for the RESRAD model (Yu et al. 2001 [DIRS 159465], p. L-17). It is also used in the recently published methods for assessing the impact of radionuclides released to the environment (IAEA 2001 [DIRS 158519], p. 144), and it agrees well with the default value of 1.6×10^{-4} kg/m^3 used in the GENII and GENII-S models (Napier et al. 1988 [DIRS 157927], p. 4.88).

It is recommended that the value of 0.03 be used for the fraction of stable carbon in soil, fc_{soil}, in the biosphere model. The same value was selected as a default for the RESRAD model (Yu et al. 2001 [DIRS 159465], p. L-17) as well as the for the GENII and GENII-S models (Napier et al. 1988 [DIRS 157927], p. 4.88).

6.7.4 Carbon-14 in Animal Products

The transfer of ^{14}C from the animal diet to the animal product follows the same route as that of stable carbon. The ^{14}C activity concentration in an animal product is calculated in the biosphere model using the following formula (BSC 2004 [DIRS 169460], Section 6.4.6.4):

$$Cd_{C-14,k} = \frac{(Cp_{C-14,j} \times Qf_k) + (Cw_{C-14} \times Qw_k) + (Cs_{C-14} \times Qs_k)}{(fc_{plant,j} \times Qf_k) + (fc_{water} \times Qw_k) + (fc_{soil} \times Qs_k)} \times fc_{anim,k} \qquad \text{(Eq. 6-32)}$$

where

$Cd_{C\text{-}14,k}$ = activity concentration of ^{14}C in animal product k (Bq/kg)
$Cw_{C\text{-}14}$ = activity concentration of ^{14}C in groundwater (Bq/L)
fc_{water} = concentration of stable carbon in farm animal water, kg/L
$fc_{anim,\,k}$ = fraction of stable carbon in animal product k (dimensionless, based on kg $_{\text{carbon}}$/kg $_{\text{animal product}}$).

The other parameters were defined in Equations 6-9 to 6-11 and 6-31.

In this analysis, the values of the concentration of carbon in water, fc_{water}, and the fraction of stable carbon in animal products, $fc_{anim,\,k}$, are developed.

The GENII, GENII-S, and the RESRAD models use the value of 2.0×10^{-5} kg/L for the concentration of stable carbon in livestock water (Napier et al. 1988 [DIRS 157927], p. 4.88; Yu et al. 2001 [DIRS 159465], p. L-21). The BIOTRAC model uses a triangular distribution ranging from 2.0×10^{-5} kg/L to 6.8×10^{-5} kg/L, with a peak at 4.0×10^{-5} kg/L (Davis et al. 1993 [DIRS 103767], p. 262). The average concentration of carbon in the Nye County well water was measured at 56 mg/L (5.6×10^{-5} kg/L) (Section 6.4.4) with the minimum of six samples of 4.4×10^{-5} kg/L and the maximum of 6.5×10^{-5} kg/L (DTN: GS030908312322.002 [DIRS 170051]). Because this parameter appears in the denominator of Equation 6-32, the greater values are less conservative. Since the values from the local wells are based on low number of samples, the value used by the GENII and RESRAD models, which also constitutes the lower bound of the distribution used in the BIOTRAC model, is recommended for use in the biosphere model.

The fraction of stable carbon in animal products, $fc_{anim,\,k}$, is animal product–dependent. The GENII and GENII-S models use the following values: 0.24 for beef, 0.2 for poultry, 0.07 for milk, and 0.15 for eggs (Napier et al. 1988 [DIRS 157927], p. 4.88). The RESRAD model uses the same values as the GENII model (Yu et al. 2001 [DIRS 159465], p. L-22). For the biosphere model used in the performance assessment for the Canadian waste disposal program, the carbon content of animal tissues (mammals, birds, fish) was represented by a uniform probability distribution function ranging from 0.12 to 0.25 (Zach et al. 1996 [DIRS 103831], p. 51). It is recommended that the values that are used in the GENII and RESRAD models be used in the biosphere modeling for the TSPA-LA. Using fixed values for carbon content of animal products used in the biosphere model is appropriate because it is unlikely that this parameter would significantly vary within a given animal product. The biosphere models that were a source of data for fraction of carbon in plants also used fixed values for these parameters.

6.8 CRITICAL THICKNESS

The critical thickness is the parameter that is used only for the volcanic ash exposure scenario to predict contaminant concentration in the air for the inhalation pathway. The function of this parameter is to allow for mixing of the contaminant deposited on the ground surface with the surface soil for thin sources, and to allow for partial resuspension of deposited activity for thick sources.

In the biosphere model, radionuclide concentrations in the resuspended material (i.e., in the mass of mixed ash and soil or the undiluted original ash) would depend on the ash thickness, d_a, and the critical thickness, d_c. Ash thickness will be calculated in the TSPA-LA model. The mass activity concentration for uncultivated land is calculated as (BSC 2004 [DIRS 169460], Section 6.5.1.2)

$$Cs_{mc,i}(d_a) = \begin{cases} \dfrac{Cs_i}{\rho_a \times d_c} = Cs_{mc,i} & \text{when } d_a < d_c \\ \dfrac{Cs_i}{\rho_a \times d_a} = \dfrac{Cs_i}{\rho_a \times d_c}\dfrac{d_c}{d_a} = Cs_{mc,i}\dfrac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \qquad \text{(Eq. 6-33)}$$

where

$Cs_{mc,i}(d_a)$ = activity concentration of radionuclide i in volcanic ash or in the mix of ash and dust of uncultivated land (Bq/kg)
Cs_i = activity concentration of radionuclide i in ash deposited on the ground surface (Bq/m^2)
ρ_a = bulk density of volcanic ash (kg/m^3)
d_c = critical thickness for resuspension on uncultivated lands (meters)
d_a = thickness of ash deposited on the ground (meters)
$Cs_{mc,i}$ = activity concentration of radionuclide i in the mass of resuspendable ash or in the mix of ash and dust (Bq/kg).

The bulk density of volcanic ash, ρ_a, is lower than the soil bulk density (BSC 2004 [169459], Section 7.1).

Equation 6-33 was rewritten as

$$Cs_{mc,i}(d_a) = Cs_{mc,i} \times g(d_a) \qquad \text{(Eq. 6-34)}$$

where $g(d_a)$, a function of volcanic ash thickness (dimensionless), can be expressed as

$$g(d_a) = \begin{cases} 1 & \text{when } d_a < d_c \\ \dfrac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \qquad \text{(Eq. 6-35)}$$

where other parameters were defined in Equation 6-33.

If the thickness of the material deposited on the ground surface is less than the critical thickness, the entire amount of deposited activity would be resuspended ($g(d_a) = 1$) and the resuspended particulates could include a fraction of uncontaminated material. If the deposit of ash were equal to or greater than the critical thickness, all resuspended particles would be ash because the clean soil would be covered by too much ash to be resuspended, and only a portion of all ash would be available for resuspension. For thin ash deposits, the more conservative results (the radionuclide concentrations in the material available for resuspension) are obtained for the lower values of the critical thickness.

For the relatively thick ash deposits, the parameter of critical thickness controls the fraction of the total activity deposited per unit area that is available for resuspension ($g(d_a) = \frac{d_c}{d_a}$). When the ash thickness is greater than the critical thickness, the volume of resuspended ash will not contain all of the activity that is initially deposited because the entire volume of ash (and all of the activity) will not be available for resuspension. The greater values of the critical thickness will result in the greater fraction of activity deposited per unit area that is available for resuspension and thus higher activity concentration in the resuspended material.

Resuspension can be caused by wind or by mechanical disturbance of the soil, such as that induced by farm equipment, vehicles, or pedestrians. Resuspension caused by the wind relates only to the material the wind stress can act upon, which might be within the top millimeter or so of a soil surface (Sehmel 1980 [163178], p. 110). Mechanical disturbance can affect greater soil thickness. In general, the range of surface soil thickness that may be used for characterizing the resuspension source strength is from about 1 mm to 1 cm (Sehmel 1984 [DIRS 158693], p. 574).

The concept of the thickness of the resuspendable layer was used in the *Preliminary Performance-Based Analyses Relevant to Dose-Based Performance Measures for a Proposed Geologic Repository at Yucca Mountain* (NUREG-1538) (McCartin and Lee 2001 [DIRS 160672]). The value of the resuspendable layer thickness was 0.3 cm (3 mm) (McCartin and Lee 2001 [DIRS 160672], p. 5-4).

The value of the critical thickness selected for the biosphere model has to be evaluated in the context of the expected thickness of volcanic ash deposited at the receptor location. As noted in Section 6.2.1.3, ash depths 18 km downwind from Yucca Mountain were predicted to range from 0.07 to 55 cm (based on 100 realizations of the ASHPLUME model). About 35 percent of predicted depths were less than 1 cm, 75 percent were less than 5 cm, and 90 percent were less than 15 cm (BSC 2004 [DIRS 170026], Table 6-4). Ash depths at the location of the RMEI (18 km south of Yucca Mountain) would be about 2 orders of magnitude or more lower under normal, variable wind conditions (CRWMS M&O 2000 [DIRS 153246], Section 3.10.5.1 and Figure 3.10-14) because the wind at Yucca Mountain blows to the south infrequently (BSC 2004 [DIRS 170026], Figure 8-1).

Because of the relatively thin tephra deposit expected at the receptor location, the values of the critical thickness in the lower region of the range reported in the literature (on the order of 1 mm) will lead to more conservative results. At the same time one needs to take into consideration the contribution of resuspension caused by mechanical disturbance, which is more readily produced than the wind-caused resuspension (Sehmel 1980 [163178], p. 114). In such a case the depth of the layer of soil from which resuspension occurs is greater than that for the wind resuspension. However, for the expected tephra thickness, the dilution with the clean soil would also be greater.

To account for these processes, it is recommended that the critical thickness for the biosphere model be represented by a uniform distribution with a minimum of 1 mm and a maximum of 3 mm.

It has been observed that a decrease of resuspension of a contaminant occurs with time (Anspaugh et al. 1975 [DIRS 151548], p. 571). This decrease is due to processes, which alter the physical and chemical state of contaminant, attachment to host soil particles, downward migration through the soil profile and mixing with the host soil particles, as well as loss from the site (Anspaugh et al. 1975 [DIRS 151548], pp. 571 and 576). Data indicate that the downward migration of radionuclides deposited on the soil surface occurs relatively quickly and that contaminants penetrate to a depth of more than 1 cm within a few months (Anspaugh et al. 1975 [DIRS 151548], pp. 577 and 579). This process will produce further dilution of activity concentration in the resuspendable layer of ash–soil mixture.

7. CONCLUSIONS

This section contains the summary of recommendations concerning environmental transport input parameters for the biosphere model (Section 7.1) and the description of how the applicable Yucca Mountain Review Plan Acceptance Criteria listed in Section 4.2 were satisfied (Section 7.2). The recommendations for the parameter values are included in the data set titled *Environmental Transport Input Parameters for the Biosphere Model*, DTN: MO0406SPAETPBM.002.

The values of environmental transport parameters were developed specifically for use in the biosphere model and may not be appropriate for other applications. Uncertainties in the parameter values are addressed in the appropriate subsections of Section 6.

7.1 RECOMMENDED ENVIRONMENTAL TRANSPORT PARAMETER VALUES

7.1.1 Radionuclide Transport to Crops

7.1.1.1 Soil-to-Plant Transfer Factors for Leafy Vegetables

The soil-to-plant TFs for leafy vegetables in the present day climate, groundwater exposure scenario are listed in Table 7-1.

Table 7-1. Soil-to-plant Transfer Factors for Leafy Vegetables, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	6.4E+01	2.0	1.1E+01	3.8E+02
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
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

NOTE: Uncertainty distribution of TF is lognormal. The values of TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

It is recommended that the same set of soil-to-plant TFs for leafy vegetables be used for the future climate and for the volcanic ash exposure scenario.

7.1.1.2 Soil-to-Plant Transfer Factors for Other Vegetables

The soil-to-plant TFs for other vegetables in the present day climate, groundwater exposure scenario are listed in Table 7-2.

Table 7-2. Soil-to-plant Transfer Factors for Other Vegetables, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	6.4E+01	2.0	1.1E+01	3.8E+02
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

NOTE: Uncertainty distribution of TF is lognormal. The values of TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

It is recommended that the same set of soil-to-plant TFs for other vegetables be used for the future climate and for the volcanic ash exposure scenario.

7.1.1.3 Soil-to-Plant Transfer Factors for Fruit

The soil-to-plant TFs for fruit in the present day climate, groundwater exposure scenario are listed in Table 7-3.

Table 7-3. Soil-to-plant Transfer Factors for Fruit, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	6.4E+01	2.0	1.1E+01	3.8E+02
Selenium	4.6E-02	3.8	1.4E-03	1.4E+00
Strontium	2.9E-01	2.3	3.6E-02	2.4E+00
Technetium	4.3E+00	4.6	8.7E-02	2.1E+02
Tin	1.5E-02	3.6	5.3E-04	4.0E-01
Iodine	5.7E-02	2.8	4.1E-03	7.9E-01
Cesium	5.6E-02	2.8	3.8E-03	8.1E-01
Lead	1.2E-02	3.3	5.8E-04	2.6E-01
Radium	7.3E-03	4.3	1.6E-04	3.2E-01
Actinium	8.5E-04	3.4	3.7E-05	2.0E-02
Thorium	2.9E-04	4.9	4.8E-06	1.7E-02
Protactinium	1.1E-03	10.0	3.0E-06	4.3E-01
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

NOTE: Uncertainty distribution of TF is lognormal. The values of TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

It is recommended that the same set of soil-to-plant TFs for fruit be used for the future climate and for the volcanic ash exposure scenario.

7.1.1.4 Soil-to-Plant Transfer Factors for Grain

The soil-to-plant TFs for grain in the present day climate, groundwater exposure scenario are listed in Table 7-4.

Table 7-4. Soil-to-plant Transfer Factors for Grain, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	2.4E+01	8.4	1.0E-01	5.8E+03
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

NOTE: Uncertainty distribution of TF is lognormal. The values of TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

It is recommended that the same set of soil-to-plant TFs for grain be used for the future climate and for the volcanic ash exposure scenario.

7.1.1.5 Soil-to-Plant Transfer Factors for Forage Crops

The soil-to-plant TFs for forage crops in the present day climate, groundwater exposure scenario are listed in Table 7-5.

Table 7-5. Soil-to-plant Transfer Factors for Forage Crops, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	7.5E+01	2.0	1.3E+01	4.5E+02
Selenium	1.5E-01	5.5	1.9E-03	1.3E+01
Strontium	2.1E+00	2.1	3.2E-01	1.3E+01
Technetium	2.7E+01	2.7	2.1E+00	3.5E+02
Tin	1.6E-01	5.8	1.7E-03	1.5E+01
Iodine	4.0E-02	10.0	1.1E-04	1.5E+01
Cesium	1.3E-01	3.3	6.3E-03	2.8E+00
Lead	1.8E-02	7.0	1.2E-04	2.8E+00
Radium	8.2E-02	3.0	4.9E-03	1.4E+00
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

NOTE: Uncertainty distribution of TF is lognormal. The values of TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

It is recommended that the same set of soil-to-plant TFs for forage crops be used for the future climate and for the volcanic ash exposure scenario.

7.1.1.6 Correlation of Transfer Factors with Partition Coefficients

It is recommended that the TFs be correlated with the corresponding partition coefficients using the value of correlation coefficient of −0.8. The correlation coefficient should be between log-transformed values of TFs and the corresponding partition coefficients. The same value of the correlation coefficient should be used for the present day climate and future climate under the groundwater exposure scenario, and for the volcanic ash exposure scenario.

7.1.1.7 Dry Deposition Velocity

Deposition velocity for the present day and future climates, under the groundwater and the volcanic ash exposure scenarios, is represented by the piece-wise linear distribution with the following values and their cumulative probabilities: (3×10^{-4} m/s, 0 percent), (1×10^{-3} m/s, 16 percent), (8×10^{-3} m/s, 50 percent), (3×10^{-2} m/s, 84 percent), (3×10^{-1} m/s, 100 percent). These data pairs correspond to particle diameters of 0.06, 0.8, 4, 20, and 250 μm respectively.

7.1.1.8 Translocation Factor

It is recommended that the translocation factor for the present day and future climates under the groundwater and the volcanic ash exposure scenarios be represented by the distributions shown in Table 7-6.

Table 7-6. Values of Translocation Factor for the Biosphere Model

Crop type	Translocation factor (value/distribution)
Leafy vegetables	1.0
Other vegetables	Piece-wise linear: (0.05, 0%), (0.1, 50%), (0.3, 100%)
Fruit	Piece-wise linear: (0.05, 0%), (0.1, 50%), (0.3, 100%)
Grain	Piece-wise linear: (0.05, 0%), (0.1, 50%), (0.3, 100%)
Fresh forage for beef cattle and diary cows	1.0

7.1.1.9 Weathering Half-Time

The weathering half-time (called the weathering half-life in the biosphere model) for present day and future climates under the groundwater exposure scenario and for the volcanic ash exposure scenario, is represented by a piece-wise linear distribution with the following values:

(5 days; 0 percent), (14 days; 50 percent), (30 days; 100 percent).

7.1.2 Radionuclide Transport to Animal Products

7.1.2.1 Animal Consumption Rates of Water, Feed, and Soil

The animal consumption rates of water, feed, and soil for the present day climate, groundwater exposure scenarios are shown in Table 7-7. It is recommended that the probability distribution functions for the feed and soil consumption rates be uniform and that the consumption rate of water be represented by a fixed value, except for water consumption by diary cows, which should be represented by a uniform distribution. The same values also apply for the future climate and the volcanic ash exposure scenario.

Table 7-7. Animal Consumption Rates for Water, Feed, and Soil

Animal Type		**Consumption rate**		
		Feed (kg wet/d)	**Water (L/d)**	**Soil (kg/d)**
Beef cattle	Minimum	29 (fresh)	60	0.4
	Maximum	68 (fresh)		1.0
Diary cow	Minimum	50 (fresh)	60	0.8
	Maximum	73 (fresh)	100	1.1
Poultry	Minimum	0.12	0.5	0.01
	Maximum	0.4		0.03
Laying hen	Minimum	0.12	0.5	0.01
	Maximum	0.4		0.03

7.1.2.2 Transfer Coefficients for Meat

The animal intake–to–animal product TCs for meat in the present day climate, groundwater exposure scenario are listed in Table 7-8.

Table 7-8. Transfer Coefficients for Meat, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	4.6E-02	2.0	7.7E-03	2.7E-01
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

NOTE: Uncertainty distribution of TC is lognormal. The values of TCs are in units of d/kg.

It is recommended that the same set of TCs for meat be used for the future climate and for the volcanic ash exposure scenario.

7.1.2.3 Transfer Coefficients for Poultry

The animal intake–to–animal products TCs for poultry in the present day climate, groundwater exposure scenario are listed in Table 7-9.

Table 7-9. Transfer Coefficients for Poultry, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	3.0E-02	2.0	5.0E-03	1.8E-01
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

NOTE: Uncertainty distribution of TC is lognormal. The values of TCs are in units of d/kg.

It is recommended that the same set of TCs for poultry be used for the future climate and for the volcanic ash exposure scenario.

7.1.2.4 Transfer Coefficients for Milk

The animal intake–to–animal products TCs for milk in the present day climate, groundwater exposure scenario are listed in Table 7-10.

Table 7-10. Transfer Coefficients for Milk, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	1.8E-02	2.0	2.9E-03	1.0E-01
Selenium	5.7E-03	2.5	5.5E-04	6.0E-02
Strontium	1.7E-03	2.0	2.8E-04	1.0E-02
Technetium	2.1E-03	6.0	2.0E-05	2.1E-01
Tin	1.1E-03	2.0	1.8E-04	6.3E-03
Iodine	9.1E-03	2.0	1.5E-03	5.4E-02
Cesium	7.7E-03	2.0	1.3E-03	4.6E-02
Lead	1.7E-04	3.0	1.0E-05	2.9E-03
Radium	5.8E-04	2.0	1.0E-04	3.4E-03
Actinium	7.6E-06	4.1	2.0E-07	2.9E-04
Thorium	4.4E-06	2.0	7.4E-07	2.6E-05
Protactinium	4.4E-06	2.0	7.4E-07	2.6E-05
Uranium	4.9E-04	2.0	8.1E-05	2.9E-03
Neptunium	6.3E-06	2.0	1.0E-06	3.9E-05
Plutonium	2.3E-07	7.7	1.2E-09	4.4E-05
Americium	1.6E-06	4.2	3.9E-08	6.3E-05

NOTE: Uncertainty distribution of TC is lognormal. The values of TCs are in units of d/L or in d/kg.

It is recommended that the same set of animal intake–to–animal product TCs for milk be used for the future climate and for the volcanic ash exposure scenario.

7.1.2.5 Transfer Coefficients for Eggs

The animal intake–to–animal product TCs for eggs in the present day climate, groundwater exposure scenario are listed in Table 7-11.

Table 7-11. Transfer Coefficients for Eggs, Present Day Climate, Groundwater Exposure Scenario

Element	GM	GSD	Lower Truncation Limit	Upper Truncation Limit
Chlorine	4.4E-02	10.0	1.2E-04	1.7E+01
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
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

NOTE: Uncertainty distribution of TC is lognormal. The values of TCs are in units of d/kg.

It is recommended that the same set of animal intake–to–animal product TCs for eggs be used for the future climate and for the volcanic ash exposure scenario.

7.1.3 Radionuclide Transport to Aquatic Food

The bioaccumulation factors for freshwater fish, as well as the modifying factors for radionuclide concentration in fishpond water for the present day and future climates, are summarized in Table 7-12. The bioaccumulation factors are represented by lognormal distributions. The values apply to the groundwater exposure scenario; the freshwater fish ingestion pathway is not included in the volcanic ash exposure scenario because under that scenario there is no groundwater release of radionuclides.

Table 7-12. Bioaccumulation Factor and Modifying Factor for Element Concentration in Fishpond Water

Element	Bioaccumulation Factor				Modifying Factor	
	Geometric Mean L/kg	Geometric Standard Deviation	Lower Truncation Limit L/kg	Upper Truncation Limit L/kg	Present Day Climate	Future Climate
Carbon	4.6E+03	3.2	2.3E+02	9.2E+04	1	1
Chlorine	2.2E+02	5.6	2.6E+00	1.9E+04	Uniform distribution min = 2.2 max = 6.1	Uniform distribution min = 1.5 max = 3.3
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		
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		

7.1.4 Radionuclide Transport via Evaporative Coolers

The following parameter values were developed to support modeling of radionuclide transport via evaporative coolers. These parameter values should be used for present day and future climates in the groundwater exposure scenario. For the volcanic ash exposure scenario, the inhalation exposure pathway associated with evaporative coolers is not included because under that scenario there is no groundwater release of radionuclides (i.e., the water is not contaminated). The following parameter values are recommended.

7.1.4.1 Airflow Rate

Airflow rate for evaporative coolers is represented by a piece-wise linear cumulative distribution represented by the following points:

(1,700 m^3/h; 0 percent), (8,300 m^3/h; 50 percent), (10,200 m^3/h; 100 percent).

7.1.4.2 Evaporative Cooler Water Use Rate

Evaporative cooler water evaporation rate is represented by a lognormal distribution with a GM of 17 L/hr and a GSD of 1.7.

The correlation coefficient between the water evaporation rate and the airflow rate for evaporative coolers is equal to 0.8.

7.1.4.3 Evaporative Cooler Water Transfer Fraction

The fraction of radionuclides present in the water in the form of dissolved solids that can be transferred into the air stream as a result of the evaporative cooling (evaporative cooler water transfer fraction) is represented by a uniform distribution ranging from 0 to 1. For contaminants present in the water as gaseous species, this fraction is equal to 1.

7.1.5 Exhalation of Radon from Soil

7.1.5.1 Radon-222 Release Factor

The recommended value of the radon release factor (activity concentration ratio of ^{222}Rn air to ^{226}Ra in surface soil) for the groundwater exposure scenario is 0.25 (Bq/m^3)/(Bq/kg) = 0.25 kg/m^3. This value is appropriate for the groundwater exposure scenario for the present day and future climates. This parameter is not used for the volcanic ash exposure scenario.

7.1.5.2 Ratio of Radon-222 Concentration in Air to Flux Density from Soil

The recommended value of the ratio of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil is 300 (Bq/m^3)/(Bq/(m^2 s) = 300 s/m. This value is appropriate for the volcanic ash exposure scenario for the present day and future climates. This parameter is not used for the groundwater exposure scenario.

7.1.5.3 Fraction of Radon-222 from Soil Entering the House

The fraction of radon released into the house from soil is represented by a uniform distribution with a minimum of 0.1 and a maximum of 0.25. This distribution is appropriate for the present day and future climates and for the groundwater and volcanic ash exposure scenarios.

7.1.5.4 House Ventilation Rate

The ventilation rate for houses that do not use evaporative coolers, and for the fraction of a year when evaporative coolers are not used, is represented by a truncated lognormal distribution with arithmetic mean of 1.0 air exchanges per hour (hr^{-1}) and arithmetic standard deviation of 1.1 air exchanges per hour. The lower truncation limit is 0.35 air exchanges per hour and the upper truncation limit is 2.9 air exchanges per hour. For houses using evaporative coolers, when an evaporative cooler is in operation, the ventilation rate is represented by a uniform distribution with a minimum of 1 air exchange per hour and a maximum of 30 air exchanges per hour. These distributions are appropriate for the present day and future climates and for the groundwater and volcanic ash exposure scenarios.

7.1.5.5 Interior Wall Height

It is recommended that the interior wall (or ceiling) height be represented by a piece-wise linear distribution with the following properties:

(2.1 m; 0 percent), (2.3 m; 50 percent), (2.7 m; 100 percent).

This distribution is appropriate for the present day and future climates and for the groundwater and volcanic ash exposure scenarios.

7.1.5.6 Equilibrium Factor for Radon-222 Decay Products

The outdoor equilibrium factor for radon decay products is represented by a uniform distribution with a minimum of 0.5 and a maximum of 0.7.

The distribution of the indoor equilibrium factor for radon decay products is uniform with a minimum of 0.3 and a maximum of 0.5.

These distributions are appropriate for the present day and future climates and for the groundwater and volcanic ash exposure scenarios.

7.1.6 Carbon-14 Transport in the Environment

Parameter values for the ^{14}C submodel developed in this analysis apply only to the groundwater exposure scenario because ^{14}C has not been identified as a radionuclide of interest for the extrusive igneous release.

7.1.6.1 Carbon Emission Rate from Soil

A fixed value of 22/yr is recommended for the emission rate of carbon from soil for the present day and future climates.

7.1.6.2 Surface Area of Irrigated Land

It is recommended that the surface area of irrigated land for a given climate be calculated as the ratio of the representative volume of 3,000 acre-feet (3,714,450 m^3) to the average annual irrigation rate for the present day and future climates.

7.1.6.3 Carbon Mixing Height

The carbon mixing height for the human inhalation pathway is equal to 2 m, and the mixing height for the carbon uptake by crops for human and animal consumption is equal to 1 m.

7.1.6.4 Annual Average Wind Speed

It is recommended that the wind speed in the 1-m layer above the surface, corresponding to the mixing height for the carbon uptake by crops, be represented by a uniform distribution over the range of 1.5 m/s to 2.3 m/s.

For the calculation of human inhalation dose (mixing height of 2 m), it is recommended that the wind speed velocity be represented by the uniform distribution from 2.1 to 2.8 m/s.

7.1.6.5 Parameters Related to Stable Carbon Concentration in Environmental Media

The values of parameters related to stable carbon concentration in environmental media are given in Table 7-13. The values apply to the present day and future climates.

Table 7-13. Parameters Related to Stable Carbon Concentration in Various Environmental Media

Parameter	Value and Unit
Fraction of stable carbon in leafy vegetables	0.09
Fraction of stable carbon in other vegetables	0.09
Fraction of stable carbon in fruit	0.09
Fraction of stable carbon in grain	0.40
Fraction of stable carbon in forage plants	0.09
Fraction of air-derived carbon in plants	0.98
Fraction of soil-derived carbon in plants	0.02
Concentration of stable carbon in air	1.8E-04 kg/m^3
Fraction of stable carbon in soil	0.03
Concentration of stable carbon in water	2.0E-5 kg/L
Fraction of stable carbon in beef	0.24
Fraction of stable carbon in poultry	0.2
Fraction of stable carbon in milk	0.07
Fraction of stable carbon in eggs	0.15

7.1.7 Critical Thickness

Critical thickness for the resuspension of particulate matter is represented by a uniform distribution with a minimum of 1 mm and a maximum of 3 mm (0.001 to 0.003 m).

7.2 HOW ACCEPTANCE CRITERIA WERE ADDRESSED

The following information (Table 7-14) describes how this analysis addresses the acceptance criteria in the *Yucca Mountain Review Plan* (NRC 2003 [DIRS 163274], Section 2.2.1.3.14, Biosphere Characteristics). Only those acceptance criteria that are applicable to this report (see Section 4.2) are discussed.

This analysis report is one of ten reports (Figure 1-1) that support biosphere modeling and describe how the acceptance criteria have been addressed by the biosphere model. A consideration of all ten reports is required in order to understand how all applicable acceptance criteria are satisfied by the biosphere model.

Table 7-14. Satisfaction of Acceptance Criteria from Section 2.2.1.3.14.3 of the Yucca Mountain Review Plan

Acceptance Criterion	How Acceptance Criterion was Addressed in the Analysis
Acceptance Criterion 14. 1 – System Description and Model Integration are Adequate.	
14.1(3) Assumptions are consistent between the biosphere characteristics modeling and other abstractions. For example, the U.S. Department of Energy should ensure that the modeling of features, events, and processes, such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumption in other total system performance assessment abstractions.	This analysis considers information and assumptions about FEPs shared by other TSPA abstractions. These FEPs are treated in a manner that is consistent with that used in the other abstractions. Most environmental transport parameter values developed in this analysis are unaffected by climate change. For the parameters that are, the treatment of climate change is consistent with the other TSPA modeling abstractions. Section 6.4.3 includes development of the climate-dependent biosphere model parameter that is within a scope of this analysis. Properties of volcanic ash and their effect on selected model input parameters are discussed in Section 6.2.1.3. Soil types are considered primarily for the development of transfer factors in Section 6.2.1 and the subsections.
Acceptance Criterion 14.2 – Data are Sufficient for Model Justification.	
14.2(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.	The justification for the parameter distributions developed in this report, and the consistency of those distributions with the conditions in the Yucca Mountain region, are described in Section 6 and summarized in Section 7.1. The data identified in Section 4.1 were used, interpreted, and appropriately synthesized into the parameter distributions as described in Section 6. Justification is provided for those parameter values that are developed based on the generic data, rather than the site-specific data.

Table 7-14. Satisfaction of Acceptance Criteria from Section 2.2.1.3.14.3 of the Yucca Mountain Review Plan (Continued)

Acceptance Criterion	How Acceptance Criterion was Addressed in the Analysis
Acceptance Criterion 14.2 – Data are Sufficient for Model Justification.	
14.2(2) Data are sufficient to assess the degree to which features, events, and processes related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63, the U.S. Department of Energy should demonstrate that features, events, and processes, which describe the biosphere, are consistent with present knowledge of conditions in the region, surrounding Yucca Mountain. As appropriate, the U.S. Department of Energy sensitivity and uncertainty analyses (including consideration of alternative conceptual models) are adequate for determining additional data needs, and evaluating whether additional data would provide new information that could invalidate prior modeling results and affect the sensitivity of the performance of the system to the parameter value or model.	The sufficiency of data used to develop parameter distributions used in the modeling of features, events, and processes related to biosphere characteristics modeling is described in Sections 4.1 and 6. Demonstration that the parameter distributions are consistent with present knowledge of the conditions in the Yucca Mountain region is in Section 6. Sensitivity and uncertainty analyses are addressed in other biosphere modeling reports listed in Figure 1-1.
Acceptance Criterion 14.3 – Data Uncertainty is Characterized and Propagated through the Model Abstraction	
14.3(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.	The technical justification for bounding assumptions used in this analysis is included in Section 5. The technical defensibility of the probability distribution developed for each parameter is demonstrated in Section 6. The identification of uncertainties and variabilities, and how those uncertainties and variabilities were accounted for in the development of parameter ranges that do not under-represent risk, is also described in Section 6. Although this analysis concerns primarily the characteristics of the environment, it also uses some characteristics of the receptor to develop parameter values for the model. For example, the parameters related to ventilation and air conditioning are based on the living styles of the reasonably maximally exposed individual.
14.3(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.	The technical defensibility of the technical bases for the parameter distributions for plant and animal uptake factors is described in Section 6. The consistency of the data and the distributions of parameters related to environmental transport of radionuclides with site characterization data is described in Sections 4.1 and 6.
14.3(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.	The bounding values of the parameter distributions developed in this analysis were selected to adequately represent uncertainty, as described in Sections 5 and 6. Correlations among biosphere model input parameters are identified in Section 6.

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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

24 CFR 3280. Housing and Urban Development: Manufactured Home Construction and Safety Standards. Readily available. 160555

66 FR 55732. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, NV, Final Rule. 10 CFR Parts 2, 19, 20, 21, 30, 40, 51, 60, 61, 63, 70, 72, 73, and 75. Readily available. 156671

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AP-2.27Q, Rev. 1, ICN 4. *Planning for Science Activities.* 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.

8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

GS030908312322.002. Field and Chemical Data for Spring and Well Samples Collected between 2/26/03 and 5/22/03 in the Yucca Mountain Area. Submittal date: 10/15/2003. 170051

LA0407DK831811.001. Physical Parameters of Basaltic Magma and Eruption Phenomena. Submittal date: 07/15/2004 170768

MO0211SPADIMEN.005. Dimensions of Catfish Ponds in Amargosa Valley. Submittal date: 11/05/2002. 160653

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

MO04019SUM9397.000. Summary of 1993−1997 Site 9 Meteorological Data. Submittal date: 01/20/2004. 167054

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

8.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

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

APPENDIX A
DESCRIPTION OF FILES ACCOMPANYING THIS ANALYSIS

A1. CALCULATION OF TRANSFER FACTORS, TRANSFER COEFFICIENTS, AND BIOACCUMULATION FACTORS

File Name: ***Calculation of TFs TCs and BFs.xls***

Hardware Used to Conduct Calculations–Dell Precision Workstation 530, Microsoft Windows 2000, CPU# 151554.

Description of the File–The Microsoft Excel 2000 workbook *Calculation of TFs TCs and BFs.xls* consists of 10 worksheets, containing information presented in Table A-1.

Table A-1. Description of the *Calculation of TFs TCs and BFs.xls* Workbook

Worksheet Name	Contents	Associated Tables
Leafy Vegetables	Calculation of GMs and GSDs for TFs for leafy vegetables for elements of interest, based on values from references; Generation of plots of TFs based on the data from the references as well as developed data for technetium, iodine, neptunium, plutonium, and americium.	6-2 to 6-7
Other Vegetables	Calculation of GMs and GSDs for TFs for other vegetables for elements of interest, based on values from references; Generation of plots of TFs based on the data from the references as well as developed data for technetium, iodine, neptunium, plutonium, and americium.	6-8 to 6-13
Fruit	Calculation of GMs and GSDs for TFs for fruit for elements of interest, based on values from references; Generation of plots of TFs based on the data from the references as well as developed data for technetium, iodine, neptunium, plutonium, and americium.	6-14 to 6-19
Grain	Calculation of GMs and GSDs for TFs for grain for elements of interest, based on values from references; Generation of plots of TFs based on the data from the references as well as developed data for technetium, iodine, neptunium, plutonium, and americium.	6-20 to 6-25
Pasture	Calculation of GMs and GSDs for TFs for forage plants for elements of interest, based on values from references; Generation of plots of TFs based on the data from the references as well as developed data for technetium, iodine, neptunium, plutonium, and americium.	6-26 to 6-31
Meat	Calculation of GM and GSD for TCs for meat for elements of interest, based on values from references; Generation of plots of TCs based on the data from the references as well as the developed data for technetium, iodine, neptunium, plutonium, and americium.	6-39 to 6-44
Poultry	Calculation of GM and GSD for TCs for poultry for elements of interest, based on values from references; Generation of plots of TCs based on the data from the references as well as the developed data for technetium, iodine, neptunium, plutonium, and americium.	6-46 to 6-51

Table A-1. Description of the *Calculation of TFs TCs and BFs.xls* Workbook (Continued)

Worksheet Name	Contents	Associated Tables
Milk	Calculation of GM and GSD for TCs for milk for elements of interest, based on values from references; Generation of plots of TCs based on the data from the references as well as the developed data for technetium, iodine, neptunium, plutonium, and americium.	6-52 to 6-57
Eggs	Calculation of GM and GSD for TCs for eggs for elements of interest, based on values from references; Generation of plots of TCs based on the data from the references as well as the developed data for technetium, iodine, neptunium, plutonium, and americium.	6-58 to 6-63
Fish	Calculation of GM and GSD for bioaccumulation factors for freshwater fish based on values from references.	6-64 to 6-65

Description of the Calculations–In each worksheet, calculations of the GM and GSD of the reference data were performed as:

– GM of a set of values x_1, x_2, …, x_n was calculated by using the built-in Excel function GEOMEAN for the specified range of values.

– GSD of a set of values x_1, x_2, …, x_n, GSD, was calculated in the Excel spreadsheet using the following formula:

$$GSD = e^{STDEV\left(LN(x_1),\, LN(x_2),\ldots,\, LN(x_n)\right)} \qquad \text{(Eq. A-1)}$$

where

$STDEV$ = Excel function which calculates standard deviation for a specified range of values

$LN(x_i)$ = Excel function that calculates natural logarithm of a specified value x_i.

The upper and lower truncation limits are calculated using:

$$\begin{aligned} lower\ truncation &= \frac{GM}{GSD^{2.576}} \\ upper\ truncation &= GM \times GSD^{2.576} \end{aligned} \qquad \text{(Eq. A-2)}$$

where

GM = geometric mean

GSD = geometric standard deviation.

As explained in Section 6.2.1.1.5, when the GSD of the published values was less than 2, it was assumed to be 2, and if it was greater than 10, it was assumed to be 10.

A2. CALCULATION OF THE VERTICAL WIND PROFILE

File Name: ***Vertical wind profile.xls***

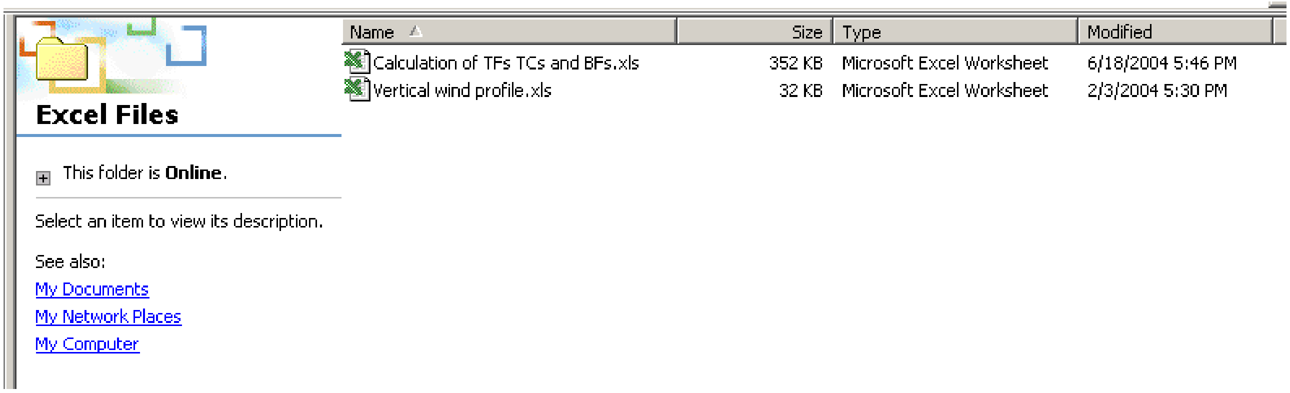
Hardware Used to Conduct Calculations–Dell Precision Workstation 530, Microsoft Windows 2000, CPU# 151554

Description of the File–The Microsoft Excel 2000 workbook *Vertical wind profile.xls* consists of a worksheet, containing the calculations of the vertical wind profile in the boundary layer, described in Section 6.7.2. The results of these calculations are summarized in Table 6-71.

Description of the Calculations–The calculations were based on Equations 6-29 and 6-30 described in Section 6.7.2.

A.3 LIST OF FILES INCLUDED ON CD-ROM

List of files generated in this analysis, including files names, sizes, and dates, is shown in Figure A-1.



Excel Files

This folder is **Online**.

Select an item to view its description.

See also:
My Documents
My Network Places
My Computer

Name	Size	Type	Modified
Calculation of TFs TCs and BFs.xls	352 KB	Microsoft Excel Worksheet	6/18/2004 5:46 PM
Vertical wind profile.xls	32 KB	Microsoft Excel Worksheet	2/3/2004 5:30 PM

Figure A-1. Excel Files Generated in Analysis

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