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REV 01	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

Addendum 1

Case. In addition, eliminated one parameter, absolute humidity, since it is not used in the BDCF calculations.

Addendum 2

documentation was revised.

CONTENTS

	Page
1. PURPOSE	13
2. QUALITY ASSURANCE	19
3. USE OF SOFTWARE	20
4. INPUTS.....	21
4.1 DATA AND PARAMETERS	21
4.1.1 Soil-to-plant Transfer Factors	22
4.1.2 Parameters Pertaining to the Behavior of Particulates and Gases in Near- surface Atmospheric Boundary Layer.....	38
4.1.3 Data Reported in the Engineering Design Climatology and Regional Meteorology Conditions Report.....	40
4.1.4 Translocation Factors	40
4.1.5 Weathering Half Life (Weathering Rate Constant).....	43
4.1.6 Animal Consumption Rates for Water, Feed, and Soil	44
4.1.7 Transfer Coefficients for Animal Products	47
4.1.8 Bioaccumulation Factors for Freshwater Fish.....	60
4.1.9 Dimensions of Catfish Ponds in Amargosa Valley	63
4.1.10 Average Annual Free Water Surface Evaporation (Shallow Lake)	64
4.1.11 Characteristics of Homes and Indoor Air Exchange	64
4.1.12 Parameters Related to Radon in Indoor and Outdoor Air	66
4.1.13 Technical Information Pertaining to Carbon-14 Transport in the Environment	66
4.1.14 Other Sources of Technical Information Used in this Analysis	68
4.2 CRITERIA	68
4.3 CODES AND STANDARDS	70
5. ASSUMPTIONS.....	71
6. ANALYSIS.....	73
6.1 GENERAL CONSIDERATIONS	73
6.1.1 Sources of Information	74
6.1.2 Parameter Value Development Methods.....	74
6.1.3 Site Specificity	75
6.1.4 Radionuclides and Elements Included in Analysis	76
6.1.5 Consideration of Exposure Scenarios and Climate Change	79
6.2 RADIONUCLIDE TRANSPORT TO CROPS	80
6.2.1 Radionuclide Transfer to Crops by Root Uptake	81
6.2.2 Radionuclide Transfer to Crops by External Surface Contamination	123
6.3 RADIONUCLIDE TRANSPORT TO ANIMAL PRODUCTS.....	131
6.3.1 Description of the Animal Product Submodel	131
6.3.2 Animal Consumption Rates for Water, Feed, and Soil	132

CONTENTS (Continued)

	Page
6.3.3 Transfer Coefficients	137
6.4 RADIONUCLIDE TRANSPORT TO AQUATIC FOOD	167
6.4.1 Basic Model for Aquatic Food Chain Transport	167
6.4.2 Fish Farming in Amargosa Valley	167
6.4.3 Application of the Model Based on Concentration Ratios to the Amargosa Valley Context	168
6.4.4 Carbon Transfer through Aquatic Food Chain	173
6.4.5 Consideration of Climate Change	174
6.5 RADIONUCLIDE TRANSPORT VIA EVAPORATIVE COOLERS	174
6.5.1 Evaporative Cooler Operation	174
6.5.2 Evaluation of Exposure from Evaporative Cooler Operation	176
6.6 EXHALATION OF RADON FROM SOIL	183
6.6.1 Radon Concentration in Outdoor Air	183
6.6.2 Radon Concentration in Indoor Air	185
6.6.3 Equilibrium Factors	189
6.7 CARBON-14 TRANSPORT IN THE ENVIRONMENT	191
6.7.1 Carbon-14 in Soil	191
6.7.2 Carbon-14 in Air	192
6.7.3 Carbon-14 in Crops	195
6.7.4 Carbon-14 in Animal Products	197
6.8 CRITICAL THICKNESS	198
7. CONCLUSIONS	201
7.1 RADIONUCLIDE TRANSPORT TO CROPS	201
7.1.1 Soil-to-plant Transfer Factors for Leafy Vegetables	201
7.1.2 Soil-to-plant Transfer Factors for Other Vegetables	202
7.1.3 Soil-to-plant Transfer Factors for Fruit	203
7.1.4 Soil-to-plant Transfer Factors for Grain (Chicken Feed)	204
7.1.5 Soil-to-plant Transfer Factors for Forage Crops	205
7.1.6 Correlation of Transfer Factors with Partition Coefficients	206
7.1.7 Dry Deposition Velocity	206
7.1.8 Translocation Factor	206
7.1.9 Weathering Half-Time	206
7.2 RADIONUCLIDE TRANSPORT TO ANIMAL PRODUCTS	206
7.2.1 Animal Consumption Rates of Water, Feed, and Soil	206
7.2.2 Transfer Coefficients for Meat	207
7.2.3 Transfer Coefficients for Poultry	208
7.2.4 Transfer Coefficients for Milk	209
7.2.5 Transfer Coefficients for Eggs	210
7.3 RADIONUCLIDE TRANSPORT TO AQUATIC FOOD	210
7.4 RADIONUCLIDE TRANSPORT VIA EVAPORATIVE COOLERS	211
7.4.1 Airflow Rate	211
7.4.2 Evaporative Cooler Water Use Rate	211
7.4.3 Evaporative Cooler Water Transfer Fraction	212

CONTENTS (Continued)

	Page
7.5 EXHALATION OF RADON FROM SOIL	212
7.5.1 Radon-222 Release Factor.....	212
7.5.2 Ratio of Radon-222 Concentration in Air to Flux Density from Soil	212
7.5.3 Fraction of Radon-222 from Soil Entering the House	212
7.5.4 House Ventilation Rate	212
7.5.5 Interior Wall Height	213
7.5.6 Equilibrium Factor for Radon-222 Decay Products.....	213
7.6 CARBON-14 TRANSPORT IN THE ENVIRONMENT	213
7.6.1 Carbon Emission Rate from Soil.....	213
7.6.2 Surface Area of Irrigated Land.....	213
7.6.3 Carbon Mixing Height.....	213
7.6.4 Annual Average Wind Speed.....	213
7.6.5 Parameters Related to Stable Carbon Concentration in Environmental Media.....	214
7.7 CRITICAL THICKNESS	214
8. INPUTS AND REFERENCES.....	215
8.1 DOCUMENTS CITED.....	215
8.2 DATA TRACKING NUMBERS CITED.....	225
8.3 CODES, STANDARDS, AND REGULATIONS.....	225
8.4 CITED PROCEDURES.....	226
8.5 ANALYSIS OUTPUT	226
ATTACHMENT I - CALCULATION OF SOIL-TO-PLANT TRANSFER FACTORS, ANIMAL INTAKE-TO-ANIMAL PRODUCT TRANSFER COEFFICIENTS, AND BIOACCUMULATION FACTORS FOR AQUATIC FOOD.....	I-1
ATTACHMENT II - CALCULATION OF THE VERTICAL WIND PROFILE	II-1
ATTACHMENT III - LIST OF FILES AND CD-ROM.....	III-1

FIGURES

	Page
1-1. Overview of the Yucca Mountain Biosphere Model Documentation	14
6-1. Distribution of Measured Water Evaporation Rate for Evaporative Coolers	178
I-1a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Leafy Vegetables	I-5
I-1b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Leafy Vegetables (Part 1)	I-6
I-1c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Leafy Vegetables (Part 2)	I-7
I-2a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Other Vegetables	I-8
I-2b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Other Vegetables (Part 1)	I-9
I-2c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Other Vegetables (Part 2)	I-10
I-3a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Fruit for the BIOMASS Data	I-11
I-3b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Fruit for the BIOMASS Data	I-12
I-3c. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Fruit	I-13
I-3d. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Fruit (Part 1)	I-14
I-3e. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Fruit (Part 2)	I-15
I-4a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Grain	I-16
I-4b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Grain (Part 1)	I-17
I-4c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Grain (Part 2)	I-18
I-5a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Forage Crops	I-19
I-5b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Forage Crops (Part 1)	I-20
I-5c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Forage Crops (Part 2)	I-21
I-6a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Meat	I-22
I-6b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Meat (Part 1)	I-23
I-6c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Meat (Part 2)	I-24

FIGURES (Continued)

	Page
I-7a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Poultry.....	I-25
I-7b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Poultry (Part 1)	I-26
I-7c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Poultry (Part 2)	I-27
I-8a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Milk.....	I-28
I-8b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Milk (Part 1)	I-29
I-8c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Milk (Part 2)	I-30
I-9a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Eggs.....	I-31
I-9b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Eggs (Part 1)	I-32
I-9c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Eggs (Part 2)	I-33
I-10a. Image of the Excel Spreadsheet Showing Calculation of Bioaccumulation Factor for Fish (Part 1).....	I-34
I-10b. Image of the Excel Spreadsheet Showing Calculation of Bioaccumulation Factor for Fish (Part 2).....	I-35
I-10c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Bioaccumulation Factor for Fish (Part 1)	I-36
I-10d. Image of the Excel Spreadsheet Showing Formulas for Calculation of Bioaccumulation Factor for Fish (Part 2)	I-37
II-1a. Image of the Excel Spreadsheet Showing Calculation of the Vertical Wind Profile.....	II-3
II-1b. Image of the Excel Spreadsheet Showing the Formulas Used to Calculate of the Vertical Wind Profile (Part 1).....	II-4
II-1c. Image of the Excel Spreadsheet Showing the Formulas Used to Calculate of the Vertical Wind Profile (Part 2).....	II-5
III-1. List of Files Included on the CD-ROM Accompanying Attachment III.	III-2

TABLES

	Page
1-1. Parameters and Related Features, Events, and Processes.....	15
4-1. Biosphere Model Input Parameters.....	21
4-2. Sources of Technical Information for the Development of the Soil-to-plant Transfer Factor Values.....	23
4-3. Sources of Technical Information Used for Development of Near-surface Atmospheric Transport Parameter Values.....	38
4-4. Sources of Technical Information Used for Development of Translocation Factor Values	40
4-5. Sources of Technical Information Used for Development of Weathering Half Life.....	43
4-6. Sources of Technical Information Used for Development of Animal Consumption Rates	45
4-7. Sources of Technical Information Used for Development of Transfer Coefficients for Animal Products	47
4-8. Technical Information Used for Development of Bioaccumulation Factors for Freshwater Fish.....	60
4-9. Sources of Technical Information Used for Developing Characteristics of Homes and Indoor Air Exchange.....	64
4-10. Technical Information Used for Development of Parameters Pertaining to Carbon Transport in the Environment	67
4-11. Requirements Applicable to this Analysis.....	68
6-1. Primary Radionuclides and Decay Products Included in the Biosphere Model	76
6-2. Technetium Soil-to-Plant Transfer Factors for Leafy Vegetables.....	87
6-3. Iodine Soil-to-Plant Transfer Factors for Leafy Vegetables.....	88
6-4. Neptunium Soil-to-Plant Transfer Factors for Leafy Vegetables.....	89
6-5. Plutonium Soil-to-Plant Transfer Factors for Leafy Vegetables	90
6-6. Americium Soil-to-Plant Transfer Factors for Leafy Vegetables.....	91
6-7. Soil-to-Plant Transfer Factors for Leafy Vegetables for Other Elements	92
6-8. Technetium Soil-to-Plant Transfer Factors for Other Vegetables	93
6-9. Iodine Soil-to-Plant Transfer Factors for Other Vegetables.....	94
6-10. Neptunium Soil-to-Plant Transfer Factors for Other Vegetables	95
6-11. Plutonium Soil-to-Plant Transfer Factors for Other Vegetables.....	96
6-12. Americium Soil-to-Plant Transfer Factors for Other Vegetables.....	97
6-13. Soil-to-Plant Transfer Factors for Other Vegetables for Other Elements.....	98
6-14. Technetium Soil-to-Plant Transfer Factors for Fruit	100
6-15. Iodine Soil-to-Plant Transfer Factors for Fruit	101
6-16. Neptunium Soil-to-Plant Transfer Factors for Fruit	102
6-17. Plutonium Soil-to-Plant Transfer Factors for Fruit.....	103
6-18. Americium Soil-to-Crop Transfer Factors for Fruit	104
6-19. Soil-to-Plant Transfer Factors for Fruit for Other Elements.....	105
6-20. Technetium Soil-to-Plant Transfer Factors for Grain.....	106
6-21. Iodine Soil-to-Plant Transfer Factors for Grain.....	107

TABLES (Continued)

	Page
6-22. Neptunium Soil-to-Plant Transfer Factors for Grain	108
6-23. Plutonium Soil-to-Plant Transfer Factors for Grain	109
6-24. Americium Soil-to-Crop Transfer Factors for Grain	110
6-25. Soil-to-Plant Transfer Factors for Grain for Other Elements	111
6-26. Technetium Soil-to-Plant Transfer Factors for Forage Plants	113
6-27. Iodine Soil-to-Plant Transfer Factors for Forage Plants	114
6-28. Neptunium Soil-to-Plant Transfer Factors for Forage Plants	115
6-29. Plutonium Soil-to-Plant Transfer Factors for Forage Plants	116
6-30. Americium Soil-to-Crop Transfer Factors for Forage Plants	117
6-31. Soil-to-Plant Transfer Factors for Forage Plants for Other Elements	118
6-32. Plutonium Transfer Factors for Plants Grown in Pot Cultures Using Nevada Test Site Soil	119
6-33. Americium Transfer Factors for Plants Grown in Pot Cultures Using Nevada Test Site Soil	119
6-34. Transfer Factors for Plutonium and Americium to Edible Parts of Crops Grown in Contaminated Soil at Nevada Test Site.	119
6-35. Dry Deposition Velocities Used in Biosphere Modeling	124
6-36. Translocation Factors from Various Sources and the Selected Values	128
6-37. Values of Weathering Half-Time from Various Sources	130
6-38. Animal Feed and Water and Soil Consumption Rates from Various Sources and the Selected Values	134
6-39. Technetium Transfer Coefficients for Meat	139
6-40. Iodine Transfer Coefficients for Meat	140
6-41. Neptunium Transfer Coefficients for Meat	141
6-42. Plutonium Transfer Coefficients for Meat	142
6-43. Americium Transfer Coefficients for Meat	143
6-44. Transfer Coefficients for Meat for Other Elements	144
6-45. Calculation of Transfer Coefficients for Cattle Grazing on Contaminated Land in Nevada	147
6-46. Technetium Transfer Coefficients for Poultry	148
6-47. Iodine Transfer Coefficients for Poultry	149
6-48. Neptunium Transfer Coefficients for Poultry	150
6-49. Plutonium Transfer Coefficients for Poultry	151
6-50. Americium Transfer Coefficients for Poultry	152
6-51. Transfer Coefficients for Poultry for Other Elements	153
6-52. Technetium Transfer Coefficients for Milk	155
6-53. Iodine Transfer Coefficients for Milk	156
6-54. Neptunium Transfer Coefficients for Milk	157
6-55. Plutonium Transfer Coefficients for Milk	158
6-56. Americium Transfer Coefficients for Milk	159
6-57. Transfer Coefficients for Milk for Other Elements	160
6-58. Technetium Transfer Coefficients for Eggs	161
6-59. Iodine Transfer Coefficients for Eggs	162
6-60. Neptunium Transfer Coefficients for Eggs	163

TABLES (Continued)

	Page
6-61. Plutonium Transfer Coefficients for Eggs	164
6-62. Americium Transfer Coefficients for Eggs.....	165
6-63. Transfer Coefficients for Eggs for Other Elements	166
6-64. Bioaccumulation Factors for Fresh Water Fish from Various Sources (L/kg).....	170
6-65. Bioaccumulation Factors and Truncation Limits for Element Concentrations in Fishpond Water	171
6-66. Dimensions of the Grow-out Ponds	172
6-67. Wall Height in Manufactured Homes	177
6-68. Evaporative Cooler Water Use	180
6-69. Empirical Distributions for Air Exchange Rate in U.S. Residences in the Warm Region	187
6-70. Average Values of Equilibrium Factor from Measurements at Rural Southwestern Sites	190
6-71. Wind Profile in the Surface Boundary Layer	195
7-1. Soil-to-plant Transfer Factors for Leafy Vegetables, Modern Climate, Groundwater Exposure Scenario	201
7-2. Soil-to-plant Transfer Factors for Other Vegetables, Modern Climate, Groundwater Exposure Scenario	202
7-3. Soil-to-plant Transfer Factors for Fruit, Modern Climate, Groundwater Exposure Scenario	203
7-4. Soil-to-plant Transfer Factors for Grain (Chicken Feed), Modern Climate, Groundwater Exposure Scenario	204
7-5. Soil-to-plant Transfer Factors for Forage Crops, Modern Climate, Groundwater Exposure Scenario	205
7-6. Values of Translocation Factor for the Biosphere Model.....	206
7-7. Animal Consumption Rates for Water, Feed, and Soil.....	207
7-8. Transfer Coefficients for Meat, Modern Climate, Groundwater Exposure Scenario	207
7-9. Transfer Coefficients for Poultry, Modern Climate, Groundwater Exposure Scenario	208
7-10. Transfer Coefficients for Milk, Modern Climate, Groundwater Exposure Scenario	209
7-11. Transfer Coefficients for Eggs, Modern Climate, Groundwater Exposure Scenario	210
7-12. The Values of Bioaccumulation Factor and the Modifying Factor for Element Concentration in Fishpond Water	211
7-13. Parameters Related to Stable Carbon Concentration in Various Environmental Media	214
I-1. Description of the <i>Calculation of TFs TCs and BFs.xls</i> Workbook	I-2

ACRONYMS AND ABBREVIATIONS

BDCF	biosphere dose conversion factor
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
TC	transfer coefficient
TF	transfer factor
TSPA	total system performance assessment
TSPA-LA	total system performance assessment for the license application

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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 (TSPA) 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, as identified in the *Technical Work Plan: for Biosphere Modeling and Expert Support* (TWP) (BSC 2003 [163602]). Some documents in Figure 1-1 may be under development and not available when this report is issued. This figure provides an understanding of how this report contributes to biosphere modeling in support of the license application (LA), but access to the listed documents is not required to understand the contents of this report. This report is one of the reports that develops input parameter values for the biosphere model. The *Biosphere Model Report* (BSC 2003 [160699]) describes the conceptual model, the mathematical model, and the input parameters.

The purpose of this analysis is 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 volcanic ash). The analysis was performed in accordance with the TWP (BSC 2003 [163602]).

This analysis develops values of parameters associated with many features, events, and processes (FEPs) applicable to the reference biosphere (DTN: M00303SEPFEPS2.000 [162452]), which are addressed in the biosphere model (BSC 2003 [160699]). The treatment of these FEPs is described in BSC (2003 [160699], Section 6.2). Parameter values developed in this report, and the related 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 BSC (2003 [160699], Section 6.2). The parameter values developed in this report support the biosphere model and are reflected in the TSPA through the biosphere dose conversion factors (BDCFs).

Biosphere modeling focuses on radionuclides screened for the TSPA-LA (BSC 2002 [160059]). 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).

This analysis combines and revises two previous reports, *Transfer Coefficient Analysis* (CRWMS M&O 2000 [152435]) and *Environmental Transport Parameter Analysis* (CRWMS M&O 2001 [152434]), because the new ERMYN biosphere model requires a redefined set of input parameters. The scope of this analysis includes providing a technical basis for the selection of radionuclide- and element-specific biosphere parameters (except for K_d) that are important for calculating BDCFs based on the available radionuclide inventory abstraction data. The environmental transport parameter values were developed specifically for use in the biosphere model and may not be appropriate for other applications.

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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)	Reference ^b
Soil-to-plant transfer factor (TF)	Plant uptake	3.3.02.01.0A	Plant Uptake	The treatment of this parameter is described in Section 6.2.1.2
	Ashfall	1.2.04.07.0A		
Dry deposition velocity	Soil and sediment transport	2.3.02.03.0A	Plant Uptake	The treatment of this parameter is described in 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	The treatment of this parameter is described in Section 6.2.2.2
Weathering rate constant	Plant uptake	3.3.02.01.0A	Plant Uptake	The treatment of this parameter is described in Section 6.2.2.3
Animal diet-to-animal product transfer coefficient	Animal uptake	3.3.02.02.0A	Animal Uptake	The treatment of this parameter is described in Section 6.3.3
Animal consumption rate of feed	Animal farms and fisheries	2.4.09.02.0A	Animal Uptake, Carbon-14	The treatment of this parameter is described in 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	The treatment of this parameter is described in 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	The treatment of this parameter is described in Section 6.3.2
	Animal uptake	3.3.02.02.0A		
Bioaccumulation factor for aquatic food (by element and climate)	Bioaccumulation	3.3.02.03.0A	Fish Uptake	The treatment of this parameter is described in Section 6.4.3 and 6.4.4
Water concentration modifying factor for fishpond water	Agricultural land use and irrigation	2.4.09.01.0B	Fish Uptake	The treatment of this parameter is described in Section 6.4.3 and 6.4.5
	Climate change, global	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		
	Bioaccumulation	3.3.02.03.0A		

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 evaporative cooler water that is transferred into the air	Atmospheric transport of contaminants	3.2.10.00.0A	Air	The treatment of this parameter is described in Section 6.5.2
	Radon and radon daughter exposure	3.3.08.00.0A		
Water evaporation rate for an evaporative cooler	Dwellings	2.4.07.00.0A	Air	The treatment of this parameter is described in 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	The treatment of this parameter is described in 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	The treatment of this parameter is described in Section 6.6.1
	Radon and radon daughter exposures	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	The treatment of this parameter is described in Section 6.6.1
	Radon and radon daughter exposures	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	The treatment of this parameter is described in Section 6.6.2
	Radon and radon daughter exposures	3.3.08.00.0A		
Equilibrium factor for radon decay products indoors	Radon and radon daughter exposures	3.3.08.00.0A	Inhalation	The treatment of this parameter is described in Section 6.6.3
	Inhalation	3.3.04.02.0A		
Equilibrium factor for radon decay products in outdoor air	Radon and radon daughter exposures	3.3.08.00.0A	Inhalation	The treatment of this parameter is described in Section 6.6.3
	Inhalation	3.3.04.02.0A		

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
Interior wall height	Dwellings	2.4.07.00.0A	Air	The treatment of this parameter is described in Section 6.6.2
	Radon and radon daughter exposures	3.3.08.00.0A		
	Atmospheric transport of contaminants	3.2.10.00.0A		
House ventilation rate	Dwellings	2.4.07.00.0A	Air	The treatment of this parameter is described in Section 6.6.2
	Atmospheric transport of contaminants	3.2.10.00.0A		
	Radon and radon daughter exposures	3.3.08.00.0A		
Surface area of Irrigated land	Agricultural land use and irrigation	2.4.09.01.0B	Carbon-14	The treatment of this parameter is described in Section 6.7.2
	Atmospheric transport of contaminants	3.2.10.00.0A		
	Climate change, global	1.3.01.00.0A		
Carbon emission rate constant for soil	Soil type	2.3.02.01.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.1
	Atmospheric transport of contaminants	3.2.10.00.0A		
Mixing height of gaseous ¹⁴ C (CO ₂)	Atmospheric transport of contaminants	3.2.10.00.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.2
Annual average wind speed	Biosphere characteristics	2.3.13.01.0A	Carbon-14	The treatment of this parameter is described in 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	The treatment of this parameter is described in Section 6.7.3
Fraction of stable carbon in animal product	Animal uptake	3.3.02.02.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.4
Fraction of air-derived carbon in plants	Plant uptake	3.3.02.01.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.3
	Animal Uptake	3.3.02.02.0A		
Fraction of soil-derived carbon in plants	Plant uptake	3.3.02.01.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.3
	Animal Uptake	3.3.02.02.0A		

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 stable carbon in soil	Plant uptake	3.3.02.01.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.3
Concentration of stable carbon in air	Atmospheric transport of contaminants	3.2.10.00.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.3
	Plant uptake	3.3.02.01.0A		
Concentration of stable carbon in water	Animal Uptake	3.3.02.02.0A	Carbon-14	The treatment of this parameter is described in Section 6.7.4
Critical thickness of soil for resuspension	Radionuclide accumulation in soils	2.3.02.02.0A	Soil	The treatment of this parameter is described in Section 6.8
	Soil and sediment transport in the biosphere	2.3.02.03.0A		
	Inhalation	3.3.04.02.0A		

NOTES: YMP = Yucca Mountain Project

^a FEPs are listed in DTN: MO0303SEPFEPS2.000 [162452].

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

2. QUALITY ASSURANCE

Development of this report involves analysis of data to support performance assessment, as identified in the TWP (BSC 2003 [163602]), and thus, it is a quality affecting activity in accordance with AP-2.27Q, *Planning for Science Activities* [159604]. Approved quality assurance procedures identified in the TWP (BSC 2003 [163602], Section 4) have been used to conduct and document the activities described in this report. Electronic data used in this analysis were controlled in accordance with the methods specified in the TWP (BSC 2003 [163602], Section 8).

The natural barriers and items identified in the *Q-List* (YMP 2001 [154817]) are not pertinent to this analysis.

3. USE OF SOFTWARE

The only software used during this analysis was the commercial, off-the-shelf product Microsoft EXCEL (Version 97 SR-2). 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 Attachments I and II.

4. INPUTS

4.1 DATA AND PARAMETERS

The list of 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

Parameter	Sources of Direct Input
Soil-to-plant TFs by crop type and element	See Section 4.1.1
Dry deposition velocity	See Section 4.1.2
	DTN: MO9811DEDCRMCR.000 [148887] Data Reported in the Engineering Design Climatology and Regional Meteorology Conditions Report (see Section 4.1.3)
Translocation factor by crop type	See Section 4.1.4
Weathering half-time (weathering rate constant)	See Section 4.1.5
Animal consumption rates of water, feed, and soil by animal type	See Section 4.1.6
Transfer coefficients by animal product and element	See Section 4.1.7
Bioaccumulation factors for freshwater fish by element	See Section 4.1.8
Water concentration modifying factor for fishpond water by element	DTN: MO0211SPADIMEN.005 [160653] Dimensions of Catfish Ponds in Amargosa Valley (see Section 4.1.9)
	See Section 4.1.10
Water evaporation rate for evaporative cooler	See Section 4.1.11
Airflow rate for evaporative cooler	See Section 4.1.11
Radon release factor (concentration ratio of ^{222}Rn in air to ^{226}Ra in surface soil)	See Section 4.1.12
	See Section 4.1.12
Ratio (conversion factor) of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil	See Section 4.1.12
Interior wall height	See Section 4.1.11
House ventilation rate	See Section 4.1.11
Fraction of ^{222}Rn flux from soil entering the house	See Section 4.1.12

Table 4-1. Biosphere Model Input Parameters (Continued)

Parameter	Sources of Direct Input
Equilibrium factor for ^{222}Rn decay products in indoor air	See Section 4.1.12
Equilibrium factor for ^{222}Rn decay products in outdoor air	See Section 4.1.12
^{14}C emission rate constant for soil	See Section 4.1.13
Mixing height of gaseous ^{14}C (CO_2)	See Section 4.1.13
Annual average wind speed	See Section 4.1.2
	DTN: MO9811DEDCRMCR.000 [148887] Data Reported in the Engineering Design Climatology and Regional Meteorology Conditions Report (see Section 4.1.3)
Fraction of stable carbon in crops by crop type	See Section 4.1.13
Fraction of air-derived carbon in plants	See Section 4.1.13
Concentration of stable carbon in air	See Section 4.1.13
Fraction of soil-derived carbon in plants	See Section 4.1.13
Fraction of stable carbon in soil	See Section 4.1.13
Concentration of stable carbon in water	See Section 4.1.13
Fraction of stable carbon in animal products by animal product	See Section 4.1.13
Critical thickness of soil	See Section 4.1.2

4.1.1 Soil-to-plant Transfer Factors

Values for soil-to-plant transfer factors (TFs) were developed based on technical information from the references presented in Table 4-2. This table lists the parameters, identifies specific sources of information used to develop the parameter values, and provides the section within this report where the analysis is presented. Additional information on the use of this technical information is provided in Sections 6.2.1.1 and 6.2.1.2.

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Chlorine soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 Kennedy and Streng 1992 [103776], p. 6.25 to 6.27 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
2	Selenium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
3	Strontium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
4	Technetium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
5	Tin soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 Kennedy and Streng 1992 [103776], pp. 25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
6	Iodine soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
7	Cesium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
8	Lead soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
9	Radium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
10	Actinium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
11	Thorium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
12	Protactinium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
13	Uranium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
14	Neptunium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
15	Plutonium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1
16	Americium soil-to-plant TF for leafy vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.1

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
17	Chlorine soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
18	Selenium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
19	Strontium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
20	Technetium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
21	Tin soil-to-plant TF for other vegetables	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
22	Iodine soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
23	Cesium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
24	Lead soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
25	Radium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
26	Actinium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
27	Thorium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
28	Protactinium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
29	Uranium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
30	Neptunium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
31	Plutonium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
32	Americium soil-to-plant TF for other vegetables, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.2
33	Chlorine soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
34	Selenium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
35	Strontium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 BIOMASS 2001 [159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
36	Technetium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
37	Tin soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
38	Iodine soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 BIOMASS 2001 [159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
39	Cesium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 BIOMASS 2001 [159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
40	Lead soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
41	Radium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
42	Actinium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
43	Thorium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
44	Protactinium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
45	Uranium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 BIOMASS 2001 [159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
46	Neptunium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
47	Plutonium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 BIOMASS 2001 [159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3
48	Americium soil-to-plant TF for fruit, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 BIOMASS 2001 [159468]/T3FM/WD01, pp. 82 to 92 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
49	Chlorine soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
50	Selenium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
51	Strontium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
52	Technetium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
53	Tin soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
54	Iodine soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
55	Cesium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
56	Lead soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
57	Radium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
58	Actinium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
59	Thorium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
60	Protactinium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
61	Uranium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
62	Neptunium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
63	Plutonium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
64	Americium soil-to-plant TF for grain, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 11 IAEA 1994 [100458], pp. 17 to 25 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.4
65	Chlorine soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
66	Selenium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
67	Strontium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1984 [103784], p. 75 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
68	Technetium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
69	Tin soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
70	Iodine soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
71	Cesium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1984 [103784], p. 75 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
72	Lead soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
72	Radium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
74	Actinium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
75	Thorium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
76	Protactinium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
77	Uranium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
78	Neptunium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
79	Plutonium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1984 [103784], p. 75 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
80	Americium soil-to-plant TF for forage plants, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 10 IAEA 1994 [100458], pp. 17 to 25 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27 LaPlante and Poor 1997 [101079], p. 2-13 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Sheppard 1995 [103789], pp. 55 to 57 Till and Meyer 1983 [101895], pp. 5-50 to 5-51 Wang et al. 1993 [103839], pp. 25 to 26	6.2.1.2.5
81	Correlation factor for soil-to-plant TF s and partition coefficients (K_{ds})	Davis et al. 1993 [103767], p. 234 Karlsson et al. 2001 [159470], p. 37 Sheppard and Sheppard 1989 [160644], p. 653	6.2.1.5

The documents that were used as sources of information 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 these reports are presented below. References were published by professional organizations producing technically defensible products pertinent to this analysis as indicated in the following discussion. The technical information from these reports is considered appropriate for the intended use (i.e., to develop the values of TFs for the biosphere model).

Baes et al. 1984 [103766]—*A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*. This report 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 towards 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, and 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 [159468]—This reference contains a collection of the working documents entitled *Biosphere Modelling and Assessment* 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 [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 inter-comparisons, 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 [100458]—IAEA Technical Reports Series No. 364, *Handbook of Parameter Values for 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, much of which was collected 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 IAEA (2001 [158519]) described below (p. 1).

IAEA 2001 [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 generally are conservative and not likely to lead to underestimates of the doses. The primary source of the TF information presented in this report is the International Union of Radioecologists database compiled in the 1980s and early 1990s.

Karlsson et al. 2001 [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 Streng 1992 [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 [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 [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.

NCRP 1996 [101882] and **NCRP 1996 [101883]**—These documents are volumes I and II of *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water and Ground*, and describe simple models that can be used for assessing doses from radionuclides released to the environment, and includes 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.

Rittmann 1993 [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 [100464], p. 1-1).

Sheppard 1995 [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 [103767]) described previously.

Till and Meyer 1983 [101895]—*Radiological Assessment, A Textbook on Environmental Dose Analysis*, 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 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 (p. xvi).

Wang et al. 1993 [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).

This list of publications constitutes a comprehensive set of reports that include recommended parameter values for radiological assessments. These reports provide an appropriate technical basis for developing parameters for the ERMYN biosphere model. 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. However, it is believed that the combined technical information presented in these reports forms a solid foundation for developing input parameter values for the ERMYN biosphere model.

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 near-surface atmospheric boundary layer were developed based on the references listed in Table 4-3. The technical information from these references is used to develop the values of dry deposition velocity, the annual average wind speed, and the 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 parameters, identifies specific sources of information used to develop the parameter values, and provides the section within this report that contains the analysis. Additional discussions on the use of this technical information is provided in Sections 6.2.2.1, 6.7.3, and 6.8.

Table 4-3. Sources of Technical Information Used for Development of Near-surface Atmospheric Transport Parameter Values

Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
Dry deposition velocity	Dorrian 1997 [159476], pp. 117 and 129 NCRP 1984 [103784], p. 48 NCRP 1999 [155894], p. 68 Sehmel 1984 [158693], pp. 547 to 551, 553, 558 to 561 Schery 2001 [159478], p. 268	6.2.2.1
Annual average wind speed	NCRP 1984 [103784], p. 48 Randerson 1984 [109153], p. 169 Sehmel 1984 [158693], p. 562 Stull 2001 [159533], pp. 377 and 380	6.7.3
Critical thickness	Sehmel 1984 [158693], p. 574 McCartin and Lee [160672], p. 5-4	6.8

The sources of technical information on deposition velocity, wind speed, and the critical thickness consist of review articles, recommendations of the 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. References were published by professional organizations producing technically defensible products pertinent to this analysis as indicated in the following discussion. The technical information from these reports are considered appropriate for the intended use. The list provided below gives brief descriptions of the reports that served as sources of information for the development of deposition velocity and the wind speed.

Dorrian 1997 [[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 1997 [[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 [[103784](#)]*– See Section 4.1.1*

NCRP 1999 [[155894](#)]*– This 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 screening. The description of the methods and the pertinent parameters are useful for developing parameter values for the ERMYN biosphere model.

Randerson 1984 [[109153](#)]; **Sehmel 1984** [[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 [159478]—This textbook, *Understanding Radioactive Aerosols and Their Measurement*, deals with radioactivity and aerosols in indoor and outdoor atmospheres, and 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.

Stull 2001 [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.

4.1.3 Data Reported in the Engineering Design Climatology and Regional Meteorology Conditions Report

The dataset, Data Reported in the Engineering Design Climatology and Regional Meteorology Conditions Report (DTN: MO9811DEDCRMCR.000 [148887]), consists of meteorological data collected by the Yucca Mountain Project. The data are reported in CRWMS M&O (1997 [100117]). For the ERMYN biosphere model, the average wind speed at Meteorological Monitoring Site 9 was used to development the 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.

4.1.4 Translocation Factors

The values of crop type-dependent translocation factor were developed based on technical information 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 this technical information is provided in Section 6.2.2.2.

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

	Parameter	References used to Develop Parameter Value of Reach Conclusion	Section No.
1	Translocation factor for leafy vegetables, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2
2	Translocation factor for other vegetables, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2

Table 4-4. Sources of Technical Information Used for Development of Translocation Factor Value (Continued)

	Parameter	References used to Develop Parameter Value of Reach Conclusion	Section No.
3	Translocation factor for fruit, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2
4	Translocation factor for grain, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2
5	Translocation factor for forage plants consumed by beef cattle, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2
6	Translocation factor for grain consumed by poultry, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2
7	Translocation factor for forage plants consumed by dairy cows, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2
8	Translocation factor for grain consumed by laying hens, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 135 Napier et al. 1988 [157927], p. 4.67 NCRP 1984 [103784], p. 70 Yu et al. 2001 [159465], p. D-12	6.2.2.2

The sources of technical information 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 technical information from these reports is 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.

Kennedy and Streng 1992 [103776]–See Section 4.1.1.

LaPlante and Poor 1997 [101079]–See Section 4.1.1.

Leigh et al 1993 [100464]–This report, *User's 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 to calculate radionuclide transport in the environment and the resulting radiation doses to the human receptor. The manual includes a list of values, which are 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 [100953], Volume 3, Section 5.2) and subsequently updated, as documented in Rittmann (1993 [107744]).

Mills et al. 1983 [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 parameters 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 [100953], p. 1.2).

Napier et al. 1988 [100953] and **Napier et al. 1988** [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 [100953], Volume 1, Section 1.2 and Volume 2, Section 5.0).

NCRP 1984 [103784]–See Section 4.1.1.

Yu et al. 2001 [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 code has been used widely by the DOE, DOE contractors, NRC, EPA, U.S. Army Corps of Engineers,

industrial firms, universities, foreign agencies, and foreign institutions (Yu et al. 2001 [159465], p. xi), including assessments to demonstrate compliance. The input parameters incorporated into RESRAD were chosen to be realistic but reasonably conservative (Yu et al. 2001 [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 [160561]) and in Yu et al. (2001 [159465], pp. 1-6 and 1-7).

4.1.5 Weathering Half Life (Weathering Rate Constant)

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

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

Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
Weathering half time (weathering rate constant)	Baes et al. 1984 [103766], p. 124 IAEA 2001 [158519], p. 64 LaPlante and Poor 1997 [101079], p. B-7 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 137 NCRP 1984 [103784], p. 70 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-69 Smith et al. 1996 [101085], p. 5-30 Till and Meyer 1983 [101895], pp. 5-36 to 5-37 Yu et al. 2001 [159465], p. D-12	6.2.2.3

The sources of technical information related to weathering consist of reports providing summaries of measurements of weathering half time (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 parameters related to weathering.

Baes et al. 1984 [103766]—See Section 4.1.1 for the description of the publication.

IAEA 2001 [158519]—See Section 4.1.1 for the description of the publication.

LaPlante and Poor 1997 [101079]—See Section 4.1.1 for the description of the publication.

Leigh et al 1993 [100464]—See Section 4.1.3 for the description of the publication.

Mills et al. 1983 [103781]—See Section 4.1.3 for the description of the publication.

NCRP 1984 [[103784](#)]-See Section 4.1.1 for the description of the publication.

Regulatory Guide 1.109 1977 [[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 [[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 [[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 [[101085](#)]). This model constitutes an alternative approach to biosphere modeling that is based on the BIOMASS (2001 [[159468](#)]) methodology.

Till and Meyer 1983 [[101895](#)]-See Section 4.1.1 for the description of the publication.

Yu et al. 2001 [[159465](#)]-See Section 4.1.3 for the description of the publication.

4.1.6 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 section within this report that contains the analysis. Additional information on the development of these parameters can be found in Section 6.3.2.

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

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

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
6	Diary cow consumption rate of soil, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 253 IAEA 1994 [100458], p. 33 Kennedy and Streng 1992 [103776], p. 6.19 Smith et al. 1996 [101085], p. 5-24 Yu et al. 2001 [159465], p. D-15	6.3.2
7	Poultry consumption rate of feed, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 253 IAEA 1994 [100458], p. 33 Kennedy and Streng 1992 [103776], p. 6.19 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Mills et al. 1983 [103781], p. 143 Napier et al. 1988 [157927], p. 4-72 NCRP 1984 [103784], p. 70-71 Smith et al. 1996 [101085], p. 5-24	6.3.2
8	Poultry consumption rate of water, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 253 IAEA 1994 [100458], p. 33 Kennedy and Streng 1992 [103776], p. 6.19 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Napier et al. 1988 [157927], p. 4-72 NCRP 1984 [103784], p. 70-71 Smith et al. 1996 [101085], p. 5-24	6.3.2
9	Poultry consumption rate of soil, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 253 Kennedy and Streng 1992 [103776], p. 6.19 Smith et al. 1996 [101085], p. 5-24	6.3.2
10	Laying hen consumption rate of feed, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 253 IAEA 1994 [100458], p. 33 Kennedy and Streng 1992 [103776], p. 6.19 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Napier et al. 1988 [157927], p. 4-72 NCRP 1984 [103784], p. 70-71 Smith et al. 1996 [101085], p. 5-24	6.3.2
11	Laying hen consumption rate of water, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 253 IAEA 1994 [100458], p. 33 Kennedy and Streng 1992 [103776], p. 6.19 LaPlante and Poor 1997 [101079], p. B-8 Leigh et al. 1993 [100464], p. 5-63 Napier et al. 1988 [157927], p. 4-72 NCRP 1984 [103784], p. 70-71 Smith et al. 1996 [101085], p. 5-24	6.3.2
12	Laying hen consumption rate of soil, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 253 Kennedy and Streng 1992 [103776], p. 6.19 Smith et al. 1996 [101085], p. 5-24	6.3.2

The sources of technical information 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 information from these reports are appropriate for the intended use. The reports that were chosen as primary sources of information for the development of animal consumption rates of water feed and soil are described in Sections 4.1.1, 4.1.3, and 4.1.5.

4.1.7 Transfer Coefficients for Animal Products

Values of TCs for animal products were developed based of the technical information from references in Table 4-7, which 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 information is presented in Section 6.3.3.

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

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

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
3	Strontium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 85 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 63 Regulatory Guide 1.109, Rev. 1 1997 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
4	Technetium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 85 NCRP 1996 [101882], pp. 52 to 54 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
5	Tin TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
6	Iodine TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 85 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 63 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
7	Cesium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 85 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 63 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
8	Lead TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
9	Radium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 85 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
10	Actinium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
11	Thorium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
12	Protactinium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
13	Uranium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
14	Neptunium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
15	Plutonium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
16	Americium TC for meat, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 51 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 37 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87 Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [159465], p. D-16	6.3.3.1
17	Chlorine TC for poultry, groundwater scenario, modern climate	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 Rittmann 1993 [107744], pp. 35 to 36	6.3.3.2
18	Selenium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
19	Strontium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], p. 5-87	6.3.3.2
20	Technetium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
21	Tin TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36	6.3.3.2

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
22	Iodine TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
23	Cesium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982, p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29 Till and Meyer 1983 [101895], p. 5-87	6.3.3.2
24	Lead TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
25	Radium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
26	Actinium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
27	Thorium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
28	Protactinium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
29	Uranium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
30	Neptunium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
31	Plutonium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
32	Americium TC for poultry, groundwater scenario, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 40 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-29	6.3.3.2
33	Chlorine TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 IAEA 1994 [100458], p. 35 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
34	Selenium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
35	Strontium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 82 to 83 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
36	Technetium TC for milk, groundwater scenario, modern climate	<p>Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16</p>	6.3.3.3
37	Tin TC for milk, groundwater scenario, modern climate	<p>Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Rittmann 1993 [107744], pp. 35 to 36 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16</p>	6.3.3.3
38	Iodine TC for milk, groundwater scenario, modern climate	<p>Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 82 to 83 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16</p>	6.3.3.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
39	Cesium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 82 to 83 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
40	Lead TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
41	Radium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 82 to 83 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
42	Actinium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
43	Thorium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
44	Protactinium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
45	Uranium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 82 to 83 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
46	Neptunium TC for milk, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
47	Plutonium TC for eggs, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1984 [103784], pp. 82 to 83 NCRP 1996 [101882], pp. 52 to 54 Ng 1982 [160322], p. 62 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
48	Americium TC for eggs, groundwater scenario, modern climate	Baes et al. 1984 [103766], p. 50 Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 35 IAEA 2001 [158519], pp. 67 to 68 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 NCRP 1996 [101882], pp. 52 to 54 Ng 1982, p. 62 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-86 Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [159465], p. D-16	6.3.3.3
49	Chlorine TC for eggs, groundwater scenario, modern climate	Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 Rittmann 1993 [107744], pp. 35 to 36	6.3.3.4
50	Selenium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
51	Strontium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Till and Meyer 1983 [101895], p. 5-87	6.3.3.4
52	Technetium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
53	Tin TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36	6.3.3.4
54	Iodine TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
55	Cesium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27 Till and Meyer 1983 [101895], p. 5-87	6.3.3.4
56	Lead TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
57	Radium animal diet-to-animal product TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
58	Actinium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
59	Thorium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
60	Protactinium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
61	Uranium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
62	Neptunium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
63	Plutonium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4
64	Americium TC for eggs, groundwater scenario, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 41 Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30 LaPlante and Poor 1997 [101079], p. 2-13 Mills et al. 1983 [103781], pp. 145 to 146 Ng 1982 [160322], p. 63 Rittmann 1993 [107744], pp. 35 to 36 Smith et al. 1996 [101085], p. 5-27	6.3.3.4

The sources of technical information 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 information from these reports is considered appropriate for the intended use. Descriptions of these reports, except Ng (1982 [160322]), were given in Section 4.1.1, 4.1.3 and 4.1.5. Additional information is presented in Section 6.3.3.

Ng 1982 [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.

4.1.8 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 section within this report that contains the analysis.

Table 4-8. Technical Information Used for Development of Bioaccumulation Factors for Freshwater Fish

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Carbon bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 1994 [100458], p. 45 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], p. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-13 Wang et al. 1993 [103839], p. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3 and 6.4.4
2	Chlorine bioaccumulation factor for freshwater fish, modern climate	Kennedy and Strenge 1992 [103776], p. 6.32 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Wang et al. 1993 [103839], p. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
3	Selenium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], p. 233 to 234 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], p. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Wang et al. 1993 [103839], p. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
4	Strontium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-13 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
5	Technetium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-13 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
6	Tin animal bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 Kennedy and Streng 1992 [103776], p. 6.32 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
7	Iodine bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Streng 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-13 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
8	Cesium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Streng 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-13 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
9	Lead bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Streng 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
10	Radium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Streng 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
11	Actinium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
12	Thorium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
13	Protactinium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
14	Uranium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
15	Neptunium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Strenge 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-13 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
16	Plutonium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Streng 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Till and Meyer 1983 [101895], pp. 5.98 to 5.103 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3
17	Americium bioaccumulation factor for freshwater fish, modern climate	Davis et al. 1993 [103767], pp. 233 to 234 IAEA 1994 [100458], p. 45 IAEA 2001 [158519], p. 73 Kennedy and Streng 1992 [103776], p. 6.32 Mills et al. 1983 [103781], pp. 148 to 149 Napier et al. 1988 [100953], pp. 5.769 to 5.770 NCRP 1996 [101882], pp. 58 to 60 Wang et al. 1993 [103839], pp. 33 to 35 Yu et al. 2001 [159465], p. D-19	6.4.3

Sources of technical information on transfer 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 information from these reports is appropriate for the intended use. The reports were described in Sections 4.1.1, 4.1.3, and 4.1.5. Additional information can be found in Sections 6.4.3 and 6.4.4.

4.1.9 Dimensions of Catfish Ponds in Amargosa Valley

The dataset, Dimensions of Catfish Ponds in Amargosa Valley (DTN: MO0211SPADIMEN.005 [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 were collected to support this analysis and are appropriate for the intended use.

4.1.10 Average Annual Free Water Surface Evaporation (Shallow Lake)

Isoplethes 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 [160564], Map 3). The annual average evaporation rate for a shallow lake is used in Section 6.4.3 and 6.4.5 to develop values for the water concentration modifying factors for fishpond water for the modern and future climates. The technical information on shallow lake evaporation is an appropriate surrogate for estimating evaporation from fishponds and is appropriate for the intended use.

4.1.11 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, identifies specific sources of information used to develop the parameter values, and provides the section within this report that contains the analysis and where the additional information on the parameter use in the analysis can be found.

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

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	Water use rate for an evaporative cooler	Karpiscak et al. 1998 [160563], pp. 122-130 Watt and Brown [159497], p. 24	6.5.2
2	Airflow rate for an evaporative cooler	Karpiscak and Marion 1994 [159501], p. 3 NAHB Research Center 1998 [160428], p. 35 ToolBase Services 2002 [159507] Watt and Brown [159497], Chapter VII and VIII	6.5.2
3	Ceiling height of a home	NAHB Research Center 1998 [160428], p. 38	6.6.2
4	Air exchange (ventilation) rate	HVI 2001 [160557], p. 24 Murray and Burmaster 1995 [160554], pp. 462 to 464	6.6.2

Sources of technical information 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 list provided below gives descriptions of the reports that were chosen as primary sources of information for developing parameters related to characteristics of residential homes and indoor air exchange.

HVI 2001 [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.

Karpiscak and Marion 1994 [159501] and **Karpiscak et al. 1998** [160563]—These authors 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 [159501]) in a publication entitled *Evaporative Cooler Water Use* and as an article (Karpiscak et al. 1998 [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. To our knowledge, 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.

Murray and Burmaster 1995 [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.

NAHB Research Center 1998 [160428] and **ToolBase Services 2002** [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 [159507]) is a technical information 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 [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.

4.1.12 Parameters Related to Radon in Indoor and Outdoor Air

Parameter values related to the behavior of radon in indoor and outdoor air were based on technical information from reports by the United Nations Scientific Committee on the Effects of Atomic Radiation and the NCRP. Four reports were used in this analysis: *Sources, Effects and Risks of Ionizing Radiation, 1988 Report to the General Assembly, with Annexes* (United Nations 1988 [159566]), *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 [158644]), *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies* (NCRP 1999 [155894]), and *Measurement of Radon and Radon Daughters in Air* (NCRP 1988 [153691]). The United Nations Scientific Committee on the Effects of Atomic Radiation is comprised of scientists who report to the General Assembly of the United Nations on sources and effects of ionizing radiation, and their reports are regarded by the scientific community as authoritative and balanced. The NCRP was chartered by the U.S. Congress with a mission of formulating and widely disseminating information, guidance, and recommendations on radiation protection and measurements. The NCRP reports represent the consensus of leading scientists on the subject of protection against radiation and radiation measurements.

Technical information from these four reports is used in Sections 6.6.1 through 6.6.3 to develop values for the radon release factor, the ratio (conversion factor) of ^{222}Rn concentration in outdoor air to ^{222}Rn flux density from soil, the fraction of ^{222}Rn flux from soil entering the house, the equilibrium factor for ^{222}Rn decay products in indoor air, and the equilibrium factor for ^{222}Rn decay products in outdoor air. Information in these four reports concerns the basic properties of radon behavior in the environment and are appropriate for the intended use. In addition, *Outdoor Radon Dose Conversion Coefficient in South-Western and South-Eastern United States* (Wasiulek and James 1998 [160686]), was used to develop the value of equilibrium factor for radon decay products outdoor. This journal article presents the results of outdoor radon measurements from the southwest region of the United States. The article was published in *Radiation Protection Dosimetry*, which is a peer-reviewed journal covering all aspects of personal and environmental dosimetry and monitoring, and maintaining high scientific and technical standards. Another journal article, *Diffusion of Radon Through Cracks in a Concrete Slab* (Landman 1982 [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.

4.1.13 Technical Information Pertaining to Carbon-14 Transport in the Environment

The technical information pertaining to ^{14}C transport in the environment was obtained from the references listed in Table 4-10. The information is 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 C-14, 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, and concentration of stable carbon in water. Table 4-10

lists the parameters, identifies specific sources of information used to develop the parameter values, and provides the section within this report where the analysis is presented.

Table 4-10. Technical Information Used for Development of Parameters Pertaining to Carbon Transport in the Environment

	Parameter	References used to Develop Parameter Value or Reach Conclusion	Section No.
1	C-14 emission rate constant for soil	Davis et al. 1993 [103767], p. 156 Sheppard et al. 1991 [159545], pp. 491 Yu et al. 2001 [159465], p. L-16	6.7.1
2	Mixing height of gaseous C-14	Yu et al. 2001 [159465], p. L-16	6.7.2
3	Fraction of stable carbon in crops,	Napier et al. 1988 [157927], p. 4.88 Yu et al. 2001 [159465], p. L-20	6.7.3
4	Fraction of stable carbon in animal products	Napier et al. 1988 [157927], p. 4.88 Yu et al. 2001 [159465], p. L-22 Zach et al. 1996 [103831], p. 51	6.7.4
5	Fraction of air-derived carbon in plants	Sheppard et al. 1991 [159545], pp. 490 to 491 Yu et al. 2001 [159465], p. L-20	6.7.3
6	Fraction of soil-derived carbon in plants	Sheppard et al. 1991 [159545], pp. 490 to 491 Yu et al. 2001 [159465], p. L-20	6.7.3
7	Concentration of stable carbon in air	IAEA 2001 [158519], p. 144 Napier et al. 1988 [157927], p. 4.88 Yu et al. 2001 [159465], p. L-17	6.7.3
8	Concentration of stable carbon in water	Davis et al. 1993 [103767], p. 262 Napier et al. 1988 [157927], p. 4.88 Yu et al. 2001 [159465], p. L-21	6.7.4
9	Fraction of stable carbon in soil	Napier et al. 1988 [157927], p. 4.88 Yu et al. 2001 [159465], p. L-17	6.7.3

The sources of technical information on transport of carbon in the environment consist of the journal article, the reports containing recommendations 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. Descriptions of most of the reports used as primary sources of information for developing parameter values related to transport of carbon in the environment were given in Sections 4.1.1 and 4.1.3. The additional reports are described below.

Sheppard et al. 1991 [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 Journal*, 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 information from this article is considered appropriate for intended use.

Zach et al. 1996 [103831]—*The Disposal of Canada's Nuclear Fuel Waste: A Study of Postclosure Safety of In-Room Emplacement of Used CANDU Fuel in Copper Containers in Permeable Plutonic Rock*, published by the Atomic Energy of Canada Limited, describes the biosphere model for the study of postclosure safety of emplacement of used CANDU (i.e., Canadian deuterium uranium reactor) fuel in plutonic rock of the Canadian Shield. This biosphere model is based on BIOTRAC (Davis et al. 1993 [103767]) with some modifications and improvements. Model parameters described in this publication are considered appropriate for consideration in the development of parameters for the ERMYN biosphere model.

4.1.14 Other Sources of Technical Information Used in this Analysis

Other sources of technical information used in this analysis include the rules at 10 CFR Part 63 ([156605]), *Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada* (annual water demand used in Section 6.7.2 to develop the value of area of irrigated land), the rules at 24 CFR Part 3280 ([160555]), *Housing and Urban Development: Manufactured Home Construction and Safety Standards* (ceiling height and house ventilation rate used in Section 6.6.2), and established facts (Lide and Frederikse 1997 [103178]), *CRC Handbook of Chemistry and Physics* (statistics for lognormal distribution used in Section 6.2.1.1.5).

4.2 CRITERIA

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

Table 4-11. Requirements Applicable to this Analysis

Requirement Number	Requirement Title	Related Regulation
PRD-002/T-015	Requirements for Performance Assessment	10 CFR 63.114
PRD-002/T-026	Required Characteristics of the Reference Biosphere	10 CFR 63.305
PRD-002/T-028	Required Characteristics of the Reasonably Maximally Exposed Individual	10 CFR 63.312

Source: Canori and Leitner 2003 [161770], Table 2-3.

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

Acceptance Criterion 1—System Description and Model Integration are Adequate.

- The TSPA adequately incorporates important site features, physical phenomena, and couplings, and consistent and appropriate assumptions throughout the biosphere characteristics modeling abstraction process

- The TSPA model abstraction identifies and describes aspects of the biosphere characteristics modeling that are important to repository performance and includes the technical bases for these descriptions. For example, the reference biosphere should be consistent with the arid or semi-arid conditions in the vicinity of Yucca Mountain
- Assumptions are consistent between the biosphere characteristics modeling and other abstractions. For example, the DOE should ensure that the modeling of FEPs such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumptions in other TSPA abstractions

Acceptance Criterion 2—Data are Sufficient for Model Justification.

- The parameter values used in the safety case are adequately justified (e.g., behaviors and characteristics of the residents of the Town of Amargosa Valley, Nevada, and characteristics of the reference biosphere), 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
- Data are sufficient to assess the degree to which FEPs related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63, the DOE should demonstrate that FEPs describing the biosphere are consistent with present knowledge of conditions in the region surrounding Yucca Mountain. As appropriate, the DOE sensitivity and uncertainty analyses (including consideration of alternative conceptual models) are adequate for determining additional data needs, and evaluating whether additional data would provide new information that could invalidate prior modeling results and affect the sensitivity of the performance of the system to the parameter value or model.

Acceptance Criterion 3—Data Uncertainty is Characterized and Propagated through the Model Abstraction.

- Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible and reasonably account for uncertainties and variabilities, and are consistent with the definition of the reasonably maximally exposed individual in 10 CFR Part 63
- The technical bases for the parameter values and ranges in the abstraction, such as consumption rates, plant and animal uptake factors, mass-loading factors, and BDCFs, are consistent with site characterization data and are technically defensible
- Process-level models used to determine parameter values for the biosphere characteristics modeling are consistent with site characterization data, laboratory experiments, field measurements, and natural analog research

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

4.3 CODES AND STANDARDS

No codes and standards, other than those identified the *Project Requirements Document* (Canori and Leitner 2003 [[161770](#)], Table 2-3) and determined to be applicable (Table 4.2-1), were used in this analysis.

5. ASSUMPTIONS

Four assumptions are used in the analysis.

Assumption 1—The translocation factor for other vegetables (see Section 6.2.1.1.2), fruit, grain, and stored feed for laying hens is represented by a piece-wise linear cumulative probability distribution represented by the following 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, used in Section 6.2.2.2.

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 [160674]). Because activity could be transferred from the water or fish to other media such as the sediments, potential activity gains could arise if the ponds were not cleaned between the fish raising cycles. Because the ponds are drained after harvest (Roe 2002 [160674]), it is assumed that they are cleaned and that the sediments removed. 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.

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. This assumed distribution is consistent with the range of uncertainty in reported values of the bioaccumulation factor for carbon (Table 6-65) and will cover the range of possible values when water is the only contaminated medium.

Confirmation Status—This assumption does not require further confirmation because it is unlikely to underestimate ^{14}C transfer to fish and, therefore, is considered bounding.

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

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 [[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.

Confirmation Status—This assumption does not require further confirmation because it is a bounding assumption.

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

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

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 2003 [160699]).

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 2003 [160699], Section 6.3):

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

- Radionuclide deposition on crop surfaces by dry processes (resuspension of contaminated soil and subsequent adhesion of soil particles onto vegetation surfaces)
- Radionuclide deposition on crop surfaces by wet processes resulting from 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
- Post-deposition retention by vegetation (consideration of weathering processes)
- Root uptake of radionuclides by plants
- Release of gaseous radionuclides from the soil
- Absorption of $^{14}\text{CO}_2$ 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 commonly are 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.

6.1.2 Parameter Value Development Methods

The values of parameters for the biosphere model were based on multiple sources of technical information and 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 [159468], T1/WD04, p. 12; IAEA 1994 [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 [103766], p. 7).

Technical judgment often was 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 [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

Most of the environmental transport parameters used in the biosphere model are influenced, to some degree, by local conditions such as the climate and soil types. Ideally, parameters would be obtained through site-specific studies. In most instances, data were not collected in the region surrounding Yucca Mountain. Many parameters, especially those for pathways that contribute a small percentage to the BDCFs (CRWMS M&O 2001 [152539], p. 78; CRWMS M&O 2001 [152536], pp. 73 to 77), can be adequately represented by generic values. The pathway analysis for the new biosphere model has not yet been conducted. The new biosphere model (BSC 2003 [160699]) uses mathematical representations that are similar to those used by the previous model, and the results of the pathway analysis for the previous biosphere model (CRWMS M&O 2001 [152539], p. 78; CRWMS M&O 2001 [152536], pp. 73 to 77) can be used to anticipate the relative importance of pathways.

The selection of parameter values for the ERMYN biosphere model relied heavily on published information. In cases where site-specific data were lacking, it usually was possible to evaluate the basis for applying the literature-derived parameter value to Yucca Mountain conditions.

6.1.4 Radionuclides and Elements Included in Analysis

The following 28 radionuclides were recommended for use in the TSPA-LA 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 2002 [160059], p. 39). This list includes radionuclides that are of importance during the compliance period of 10,000 years (10 CFR 63.305(c) [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 2002 [160059], p. 39). The TSPA-LA will be conducted for the postclosure period of 20,000 years (BSC 2002 [160146], 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 (half-life 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 2003 [160699], Section 6.3.5). The resulting set of radionuclides considered in the biosphere model (Table 6-1) consists of the 30 primary radionuclides and decay products with half-lives less than 180 days. The set includes 17 elements. Table 6-1 includes the half-lives of radionuclides under consideration.

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

Primary Radionuclide	Short-lived Decay Product	Half-life ^a
Carbon-14 (^{14}C)		5730 yr
Chlorine-36 (^{36}Cl)		3.01E+05 yr
Selenium-79 (^{79}Se)		6.50E+04 yr
Strontium-90 (^{90}Sr)		29.12 yr
	Yttrium-90 (^{90}Y)	64.0 h
Technetium-99 (^{99}Tc)		2.13E+05 yr
Tin-126 (^{126}Sn)		1.0E+05 yr
	Antimony-126 m ($^{126\text{m}}\text{Sb}$)	19.0 min
	Antimony-126 (^{126}Sb)	12.4 d
Iodine-129 (^{129}I)		1.57E+07 yr
Cesium-135 (^{135}Cs)		2.3E+06 yr
Cesium-137 (^{137}Cs)		30.0 yr
	Barium-137m ($^{137\text{m}}\text{Ba}$)	2.552 min
Thorium Series (4n)		
Plutonium-240 (^{240}Pu)		6.537E+03 yr
Uranium-236 (^{236}U)		2.3415E+07 yr

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

Primary Radionuclide	Short-lived Decay Product	Half-life ^a
Thorium-232 (²³² Th)		1.405E+10 yr
Radium-228 (²²⁸ Ra)		5.75E+00 yr
	Actinium-228 (²²⁸ Ac)	6.13 hr
Uranium-232 (²³² U)		72 yr
Thorium-228 (²²⁸ Th)		1.9131 yr
	Radium-224 (²²⁴ Ra)	3.66 d
	Radon-220 (²²⁰ Rn)	55.6 s
	Polonium-216 (²¹⁶ Po)	0.15 s
	Lead-212 (²¹² Pb)	10.64 h
	Bismuth-212 (²¹² Bi)	60.55 min
	Polonium-212 (²¹² Po)	0.305 μs
	Thallium-208 (²⁰⁸ Tl)	3.07 min
Neptunium Series (4n + 1)		
Americium-241 (²⁴¹ Am)		432.2 yr
Neptunium-237 (²³⁷ Np)		2.14E+06 yr
	Protactinium-233 (²³³ Pa)	27.0 d
Uranium-233 (²³³ U)		1.585E+05 yr
Thorium-229 (²²⁹ Th)		7340 yr
	Radium-225 (²²⁵ Ra)	14.8 d
	Actinium-225 (²²⁵ Ac)	10.0 d
	Francium-221 (²²¹ Fr)	4.8 min
	Astatine-223 (²²³ At)	32.3 ms
	Bismuth-213 (²¹³ Bi)	45.65 min
	Polonium-213 (²¹³ Po)	4.2 μs
	Thallium-209 (²⁰⁹ Tl)	2.20 min
	Lead-209 (²⁰⁹ Pb)	3.253 h
Uranium Series (4n + 2)		
Plutonium-242 (²⁴² Pu)		3.763E+05 yr
Uranium-238 (²³⁸ U)		4.468E+09 yr
	Thorium-234 (²³⁴ Th)	24.10 d
	Protactinium-234m (^{234m} Pa)	1.17 min
	Protactinium-234 (²³⁴ Pa)	6.70 h
Plutonium-238 (²³⁸ Pu)		87.74E+01 yr
Uranium-234 (²³⁴ U)		2.445E+05 yr
Thorium-230 (²³⁰ Th)		7.7E+04 yr
Radium-226 (²²⁶ Ra)		1600 yr
	Radon-222 (²²² Rn)	3.8235 d
	Polonium-218 (²¹⁸ Po)	3.05 min
	Lead-214 (²¹⁴ Pb)	26.8 min
	Astatine-218 (²¹⁸ At)	2 s
	Bismuth-214 (²¹⁴ Bi)	19.9 min

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

Primary Radionuclide	Short-lived Decay Product	Half-life ^a
	Polonium-214 (²¹⁴ Po)	164.3 μ s
	Thallium-210 (²¹⁰ Tl)	1.3 min ^b
Lead-210 (²¹⁰ Pb)		22.3 yr
	Bismuth-210 (²¹⁰ Bi)	5.012 d
	Polonium-210 (²¹⁰ Po)	138.38 d
Actinium Series (4n + 3)		
Americium-243 (²⁴³ Am)		7380 yr
	Neptunium-239 (²³⁹ Np)	2.355 d
Plutonium-239 (²³⁹ Pu)		2.4065E+04 yr
Uranium-235 (²³⁵ U)	100	703.8E6 yr
	100	25.52 hr
Protactinium-231 (²³¹ Pa)		3.276E+04 yr
Actinium-227 (²²⁷ Ac)		21.773 yr
	Thorium-227 (²²⁷ Th)	18.718 d
	Francium-223 (²²³ Fr)	21.8 min
	Radium-223 (²²³ Ra)	11.434 d
	Radon-219 (²¹⁹ Rn)	3.96 s
	Polonium-215 (²¹⁵ Po)	1.78 ms
	Lead-211 (²¹¹ Pb)	36.1 min
	Bismuth-211 (²¹¹ Bi)	2.14 min
	Thallium-207 (²⁰⁷ Tl)	4.77 min
	Polonium-211 (²¹¹ Po)	0.516 s

Source:

^a Eckerman and Ryman (1993 [107684], Table A.1).^b Lide and Frederikse (1997 [243741], 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 (BSC 2000 [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 (BSC 2000 [153246], Figures 4.2-3 and 4.2-4). The ^{14}C dose for the nominal performance resulted primarily from the aquatic food pathway (CRWMS M&O 2001 [152539], p. 78). 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 radionuclide 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 (i.e., igneous intrusion or human intrusion) may result in the release of radionuclides to groundwater.

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 2002 [160146], pp. 47 to 48), 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, done using the GoldSim software program, for both scenarios 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: modern (present-day) interglacial climate, monsoon climate (about twice the precipitation of the present day climate), and glacial transition (intermediate glacial) climate (colder than monsoon but similar precipitation) (BSC 2002 [160146], p. 75). 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 by Sharpe (2002 [159127]) and USGS (2001 [158378]).

The values of some environmental transport parameters are different for the present day and future climates. The present-day conditions, referred to as the modern climate, are characteristic of the interglacial climate and have hot, dry summers and warm winters with lower annual precipitation and higher annual temperatures than the predicted future climates (Sharpe 2002

[159127], p. 26). The future climate states are represented in this analysis by the upper bound of the glacial transition climate, which is predicted to persist for the majority of the 10,000-yr compliance period (USGS 2001 [158378], p. 66). 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 (Sharpe 2002 [159127], p. 26). Recommended analog weather stations for the upper bound of this climate are Spokane, St. John, and Rosalia, Washington (Sharpe 2002 [159127], Table 6-3). 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 2003 [160699], Section 6.4.3):

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

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 human 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 [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 [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 [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 [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 the 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 post-volcanic 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 2003 [160699], Section 6.4.3.1) as

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

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 dry soil)
$F_{s \rightarrow p\ i,j}$	=	soil-to-plant TF for radionuclide i and crop type j (Bq/kg dry plant per Bq/kg dry soil)
DW_j	=	dry-to-wet weight ratio for edible part of plant (kg dry plant per kg 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 [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 2003 [160699], 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 (CRWMS M&O 2001 [152434], pp. 38 to 39). 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 plant, for example the whole plant and the grain (UNSCEAR 2000 [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 where the leafy parts or the fruits are 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 TFs 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 crop type for animal consumption:

- Leafy vegetables
- Other vegetables (including root vegetables and legumes)
- Fruit
- Grain for human consumption as well as chicken and laying hen feed
- Forage for beef cattle and dairy 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 maize. Crops for animal consumption include fresh pasture (alfalfa and clover) for dairy 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 identified in a food consumption survey (DOE 1997 [100332]).

6.2.1.1.3 Properties of Soils in Amargosa Valley

The TF values partially depend on the characteristics of the soils for 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, and high salt content). Nevertheless, people farm these soils, possibly using careful selection of crops and special management practices (CRWMS M&O 1999 [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 [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 [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 [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 officially released and made available to the members of the IUR. 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 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 wet-

to-dry-weight ratio were 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 (low 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 [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 (e.g., the concentration of a specific mineral) and the organic matter content (e.g., 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 [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 [103766], p. 7; Davis et al. 1993 [103767], p. 232; Sheppard 1995 [103789], p. 2).

Observed TFs values differ, mainly as a result of different soils, vegetation types, and environmental conditions. However, even field-scale measurements are subject to a variability. Measurements of soil partition coefficients (K_{ds}) on a 100 m² by 150 m² study plot produced values differing by a factor of four for some radionuclides (BIOMASS 2001 [159468], T1/WD04, p. 9-11). Because K_{ds} are inversely correlated with TFs (BIOMASS 2001 [159468], T1/WD04, p. 27-31; Karlsson et al. 2001 [159470], p. 37; Davis et al. 1993 [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 [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, and 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 (1996 [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 generally is above 3, with a typical value of about 6. 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 [103767], p. 232). Compared to the IUR data (Sheppard and Evenden 1996 [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 1996 [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 1996 [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 to be 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 ([101079], p. 3-12), as the point where the number of standard deviations is 2.576 (Lide and Frederikse 1997 [103178], p. A-104.), such that the 99 percent confidence interval is

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

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 modern 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 6.1.1.

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. The GM and standard deviation calculations were conducted using Microsoft Excel 97 SR-2; the spreadsheets and a description of the method are included in Attachment I. 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 6.1.1), used wet (fresh) weight-based TFs and were not used.

The values listed by the IAEA (IAEA 1994 [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 [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 towards plant species for which more data were collected, not 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) from Till and Meyer (1983 [101895], 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 [107736], pp. D-4 to D-6). The aerial values of TFs (1983 [101895], 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 where 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 [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 [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	TF, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 10	9.5E+00 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	1.8E+02 ^b	1.0E+01 – 7.8E+03 (95% confidence range)
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	4.4E+01	–
4	LaPlante and Poor 1997 [101079], p. 2-13	7.6E+01 ^c	lognormal, GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E+01 ^d	–
6	Sheppard 1995 [103789], pp. 55 to 57	–	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [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

Technetium

Reference No.	Transfer Factor (Best Estimate)
1	9.5E+00
2	1.8E+02
3	4.4E+01
4	7.6E+01
5	4.0E+01
8	4.0E+01
9	4.0E+01

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 [103766], p. 10	1.5E-01 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	—	—
3	Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27	3.4E-03	—
4	LaPlante and Poor 1997 [101079], p. 2-13	3.4E-03 ^b	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E-01 ^c	—
6	Sheppard 1995 [103789], pp. 55 to 57	3.2E-03 ^d	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	—	—
8	Wang et al. 1993 [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

Iodine

Reference No.	Transfer Factor (Best Estimate)
1	1.5E-01
3	3.4E-03
4	3.4E-03
5	3.4E-03
6	3.2E-03
8	1.5E-01
9	2.6E-02

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 [103766], p. 10	1.0E-01 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	4.6E-02 ^b	2.4E-02 – 1.1E-01 (expected values)
3	Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27	1.3E-02	—
4	LaPlante and Poor 1997 [101079], p. 2-13	6.9E-02 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	1.0E+00 ^d	—
6	Sheppard 1995 [103789], pp. 55 to 57	4.6E-02 ^e	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	—	—
8	Wang et al. 1993 [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 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	Range and Distribution
1	Baes et al. 1984 [103766], p. 10	4.5E-04 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	1.2E-4 ^b	4.1E-05 – 6.4E-04
3	Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27	3.9E-04	–
4	LaPlante and Poor 1997 [101079], p. 2-13	3.4E-4 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E-04 ^d	–
6	Sheppard 1995 [103789], pp. 55 to 57	2.6E-4 ^e	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	1.75E-4	–
8	Wang et al. 1993 [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

Plutonium

Reference No.	Transfer Factor (Best Estimate)
1	4.5E-04
2	1.2E-04
3	3.9E-04
4	3.4E-04
5	4.0E-04
6	2.6E-04
7	1.75E-04
8	3.9E-04
9	2.9E-04 (GM)

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Comments
1	Baes et al. 1984 [103766], p. 10	5.5E-03 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	3.6E-04 ^b	2.0E-04 – 6.6E-04
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	5.8E-04	—
4	LaPlante and Poor 1997 [101079], p. 2-13	1.2E-03 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	2.0E-03 ^d	—
6	Sheppard 1995 [103789], pp. 55 to 57	8.2E-04 ^e	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	—	—
8	Wang et al. 1993 [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

Americium

Transfer factor

Reference No.

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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

No.	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 [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 [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 Streng 1992 [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 [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 [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 [103789], pp. 55 to 57	–	–	2.2E+00	–	1.5E-01	1.5E-02	2.3E-02	–	1.6E-02	–	2.1E-02
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–	2.2E+00	–	2.2E-02	–	4.4E-01	–	–	–	–
8	Wang et al. 1993 [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	1.2E-01	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	1.2E-02	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	1.2E+00	7.7E-01	9.2E-01	2.6E-02	5.9E-02	1.4E-01	6.6E-02

NOTES: ^a The lower bound of the value of 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. Microsoft Excel 97 SR-2 was used to calculate GMs and standard deviations for TFs for other vegetables, as shown in Attachment I.

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 [103766], p. 11	1.5E+00 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	4.3E+00 ^b	2.4E-01 – 7.9E+01
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	1.1E+00	–
4	LaPlante and Poor 1997 [101079], p. 2-13	1.1E+01 ^c	lognormal, GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E+01 ^d	–
6	Sheppard 1995 [103789], pp. 55 to 57	6.6E+00 ^e	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [103839], pp. 25 to 26	1.5E+00	–
9	This analysis - recommendation	–	lognormal; GM = 4.4E+00 ^g ; GSD = 3.7 truncation: low = 1.5E-01; high = 1.2E+02

Technetium

Reference No.	Transfer factor (Best Estimate)
1	1.5E+00
2	4.3E+00
3	1.1E+00
4	1.1E+01
5	4.0E+01
6	6.6E+00
8	1.5E+00
9	4.4E+00

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 [103766], p. 11	5.0E-02 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	2.0E-02 ^b	—
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	5.0E-02	—
4	LaPlante and Poor 1997 [101079], p. 2-13	2.0E-02 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E-01 ^d	—
6	Sheppard 1995 [103789], pp. 55 to 57	1.9E-03 ^e	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	3.0E-02	—
8	Wang et al. 1993 [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

Iodine

Reference No.	Transfer factor (Best Estimate)
1	5.0E-02
2	2.0E-02
3	5.0E-02
4	4.0E-01
5	2.0E-02
6	1.9E-03
7	3.0E-02
8	5.0E-02
9	3.2E-02 (GM)

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 [103766], p. 11	1.0E-02 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	2.1E-02 ^b	6.7E-03 – 3.5E-02
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	9.4E-03	–
4	LaPlante and Poor 1997 [101079], p. 2-13	2.7E-02 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	1.0E+00 ^d	–
6	Sheppard 1995 [103789], pp. 55 to 57	2.8E-02 ^e	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	4.0E-5 ^f	–
8	Wang et al. 1993 [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

Neptunium

Reference No.	Transfer factor
1	1.0E-02
2	2.1E-02
3	9.4E-03
4	2.7E-02
5	1.0E+00
6	2.8E-02
7	4.0E-05
8	1.7E-02
9	3.1E-02

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown as dashed lines

^aThe 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)

^bBest estimate is the GM of the values for individual crops (potato, onion, radish, carrot, and bean)

^cInput values for the GENII-S code used in biosphere modeling for Yucca Mountain.

^dGENII-S default

^eValue for root vegetables, 5 percent clay content in soil.

^fValue for legumes for pH > 7 – not included in the calculations because it was over two orders of magnitude less than the remaining values.

^gRESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

^hFor 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 [103766], p. 11	4.5E-05 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	3.7E-04 ^b	6.1E-05 – 4.4E-03
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	2.0E-04	–
4	LaPlante and Poor 1997 [101079], p. 2-13	2.3E-04 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E-04 ^d	–
6	Sheppard 1995 [103789], pp. 55 to 57	1.6E-04 ^e	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	1.6E-04 ^f	8.1E-06 – 1.4E-03
8	Wang et al. 1993 [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

Plutonium

Reference No.	Transfer factor (Best Estimate)
1	4.5E-05
2	3.7E-04
3	2.0E-04
4	2.3E-04
5	4.0E-04
6	1.6E-04
7	1.6E-04
8	1.9E-04
9	1.9E-04

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 [103766], p. 11	2.5E-04 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	5.2E-04 ^b	1.6E-04 – 2.2E-03
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	4.1E-04	—
4	LaPlante and Poor 1997 [101079], p. 2-13	4.7E-04 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	2.0E-03 ^d	—
6	Sheppard 1995 [103789], pp. 55 to 57	5.0E-04 ^e	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	6.4E-05 ^f	—
8	Wang et al. 1993 [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 as dashed lines

^aThe 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)

^bBest estimate is the GM of the values for individual crops (potato, onion, radish, carrot, and bean)

^cInput values for the GENII-S code used in biosphere modeling for Yucca Mountain.

^dGENII-S default

^eValue for root vegetables, 5 percent clay content in soil

^fValue for legumes

^gRESRAD default value. The TF is a composite of values recommended for root vegetables, fruit, and grain.

^hFor 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

No.	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 [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 [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 Streng 1992 [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 [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 [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 [103789], pp. 55 to 57	–	–	1.3E+00	–	9.1E-02	9.2E-03	1.4E-02	–	1.0E-02	–	1.3E-02
7	Till and Meyer 1983 [101895], 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 [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

NOTES: ^a The lower bound of the value of GSD was used.^b The upper bound of the value of 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 [[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. Calculation of GMs for the soil-to-fruit TFs for the BIOMASS data is shown in Attachment I.

Most of the references used to derive TFs for vegetables, except Sheppard (1995 [[103789](#)]), also contained some fruit-related TF data. TFs for fruit are summarized in Tables 6-14 through 6-19. Calculations of GM and standard deviations were preformed using Microsoft Excel 97 SR-2 and are shown in Attachment I.

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 [103766], p. 11	1.5E+00 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	–	–
3	BIOMASS 2001 [159468], T3FM/WD01, pp. 82 to 92	–	–
4	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	1.5E+00	–
5	LaPlante and Poor 1997 [101079], p. 2-13	1.1E+01 ^b	lognormal; GSD = 2
6	Rittmann 1993 [107744], pp. 35 to 36	4.0E+01 ^c	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [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 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 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 [103766], p. 11	5.0E-02 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	2.0E-02 ^b	–
3	BIOMASS 2001 [159468], T3FM/WD01, pp. 82 to 92	9.3E-02 ^c	GSD = 1.8
4	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	5.0E-02	–
5	LaPlante and Poor 1997 [101079], p. 2-13	2.0E-02 ^d	lognormal; GSD = 2
6	Rittmann 1993 [107744], pp. 35 to 36	4.0E-01 ^e	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [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 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 Best estimate is the GM of the TFs for individual crops (apple, apricot, and watermelon) that could be grown in AV. Subtropical fruits were not included; also TFs for fruit grown in peat soil were not included because of incompatibility with AV 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 [103766], p. 11	1.0E-02 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	—	—
3	BIOMASS 2001 [159468], T3FM/WD01, pp. 82 to 92	—	—
4	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	1.0E-02	—
5	LaPlante and Poor 1997 [101079], p. 2-13	2.7E-02 ^b	lognormal; GSD = 2
6	Rittmann 1993 [107744], pp. 35 to 36	1.0E+00 ^c	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	—	—
8	Wang et al. 1993 [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 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 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 [103766], p. 11	4.5E-05 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	–	–
3	BIOMASS 2001 [159468], T3FM/WD01, pp. 82 to 92	1.0E-03 ^b	GSD = 2.7
4	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	4.5E-05	–
5	LaPlante and Poor 1997 [101079], p. 2-13	2.3E-04 ^c	lognormal; GSD = 2
6	Rittmann 1993 [107744], pp. 35 to 36	4.0E-04 ^d	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [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 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 TFs for individual crops (apple, peach, gooseberry, blackcurrant, strawberry, melon, rhubarb) that could be grown in AV. Subtropical fruits were not included; also TFs for fruit grown in peat soil were not included because of incompatibility with AV 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-Crop Transfer Factors for Fruit

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 11	2.5E-04 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	–	–
3	BIOMASS 2001 [159468], T3FM/WD01, pp. 82 to 92	1.0E-03 ^b	GSD = 3.4
4	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	2.5E-04	–
5	LaPlante and Poor 1997 [101079], p. 2-13	4.7E-04 ^c	lognormal; GSD = 2
6	Rittmann 1993 [107744], pp. 35 to 36	2.0E-03 ^d	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–
8	Wang et al. 1993 [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 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 TFs for individual crops (apple, peach, gooseberry, blackcurrant, strawberry, melon, rhubarb) that could be grown in AV. Subtropical fruits were not included; also TFs for fruit grown in peat soil were not included because of incompatibility with AV 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

No.	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 [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 [100458], pp. 17 to 25	–	–	2.0E-01	–	2.2E-01	–	–	–	–	–	–
3	BIOMASS 2001 [159468], T3FM/WD01, pp. 82 to 92	–	–	1.8E-01	–	1.7E-02	–	–	–	–	–	5.0E-2
4	Kennedy and Streng 1992 [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 [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 [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	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	–	–	2.4E-01	–	2.6E-02	–	3.5E-03	–	–	–	1.7E-03
8	Wang et al. 1993 [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

NOTES: ^a The lower bound of the value of GSD was used.^b The upper bound of the value of GSD was used.

6.2.1.2.4 Grain

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. GMs and standard deviations were calculated using Microsoft Excel 97 SR-2 and are included in Attachment I.

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 [103766], p. 11	1.5E+00 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	7.3E-01	7.3E-02 – 3.7E+00 ^b
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	7.3E-01	—
4	LaPlante and Poor 1997 [101079], p. 2-13	7.3E-01 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E+01 ^d	—
6	Sheppard 1995 [103789], pp. 55 to 57	8.3E-01 ^e	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	—	—
8	Wang et al. 1993 [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

Technetium

Reference No.	Transfer factor (Best Estimate)
1	1.5E+00
2	7.3E-01
3	7.3E-01
4	7.3E-01
5	4.0E+01
6	8.3E-01
7	—
8	1.5E+00
9	1.6E+00 (GM)

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 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 [103766], p. 11	5.0E-02 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	—	—
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	5.0E-02	—
4	LaPlante and Poor 1997 [101079], p. 2-13	2.0E-02 ^b	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E-01 ^c	—
6	Sheppard 1995 [103789], pp. 55 to 57	2.4E-04 ^d	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	—	—
8	Wang et al. 1993 [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

Iodine

Reference No.	Transfer Factor (Best Estimate)
1	5.0E-02
2	—
3	5.0E-02
4	2.0E-02
5	4.0E-01
6	2.4E-04
7	—
8	5.0E-02
9	5.0E-02

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 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 [103766], p. 11	1.0E-02 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	2.7E-03	2.3E-05 – 8.3E-02 ^b
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	2.7E-03	–
4	LaPlante and Poor 1997 [101079], p. 2-13	2.7E-03 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	1.0E-01 ^d	–
6	Sheppard 1995 [103789], pp. 55 to 57	3.5E-03 ^e	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	1.2E-04 ^f	–
8	Wang et al. 1993 [103839], pp. 25 to 26	1.7E-2 ^g	–
9	This analysis - recommendation	–	lognormal; GM = 4.4E-03 ^h ; GSD = 6.9 truncation: low = 3.1E-05; high = 6.3E-01

Neptunium

Reference No.	Transfer factor (Best Estimate)
1	1.0E-02
2	2.7E-03
3	2.7E-03
4	2.7E-03
5	1.0E-01
6	3.5E-03
7	1.2E-04
8	1.7E-02
9	4.4E-03

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 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>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 [103766], p. 11	4.5E-05 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	8.6E-06	3.5E-07 – 4.2E-01 ^b
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	2.6E-05	—
4	LaPlante and Poor 1997 [101079], p. 2-13	8.6E-06 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	4.0E-05 ^d	—
6	Sheppard 1995 [103789], pp. 55 to 57	2.0E-05 ^e	—
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	1.5E-06 ^f	—
8	Wang et al. 1993 [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 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 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-Crop Transfer Factors for Grain

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 11	2.5E-04 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	2.2E-05	1.5E-07 – 7.7E-01 ^b
3	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	5.9E-05	–
4	LaPlante and Poor 1997 [101079], p. 2-13	2.2E-05 ^c	lognormal; GSD = 2
5	Rittmann 1993 [107744], pp. 35 to 36	2.0E-04 ^d	–
6	Sheppard 1995 [103789], pp. 55 to 57	6.0E-05 ^e	–
7	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	2.8E-05 ^f	–
8	Wang et al. 1993 [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 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 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 = 7.5E-05; GSD = 3.2

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

No.	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 [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 [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 Streng 1992 [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 [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 [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 [103789], pp. 55 to 57	–	–	1.7E-01	–	1.2E-02	1.2E-03	1.8E-03	–	1.3E-03	–	1.6E-03
7	Till and Meyer 1983 [101895], 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 [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

NOTES: ^a The lower bound of the value of GSD was used.

6.2.1.2.5 Forage Plants

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 (Till and Meyer 1983 [101895], p. 5-52). TFs for actinide uptake by plants sometimes are an order of magnitude higher for legumes and for other species, such as grasses (Till and Meyer 1983 [101895], p. 5-52). Alfalfa, a leguminous plant, is the major crop grown in the Amargosa Valley (CRWMS M&O 1997 [101090], pp. 3-18 to 3-19; YMP 1999 [158212], pp. 17 to 18). Therefore, a preference was given to TFs for leguminous plants in developing TFs 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. TFs for forage plants are listed in Tables 6-26 to 6-31; calculations of GMs and standard deviations are included in Attachment I.

6.2.1.2.6 Site-specific Studies

Site-specific measurements involving plutonium and americium uptake by plants 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 [160549], pp. 287 to 302; Romney et al. 1977 [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 [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 [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 [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 [103766], p. 10	9.5E+00 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	8.1E+00 ^b	8.1E-01 – 8.1E+01 ^b
3	IAEA 2001 [158519], pp. 67 to 68	8.0E+01 ^c	—
4	Kennedy and Streng 1992 [103776], pp. 6.25 to 6.27	4.4E+01 ^d	—
5	LaPlante and Poor 1997 [101079], p. 2-13	7.6E+01 ^e	lognormal; GSD = 2
6	NCRP 1984 [103784], p. 75	—	—
7	NCRP 1996 [101882], pp. 52 to 54	4.0E+01 ^f	—
8	Rittmann 1993 [107744], pp. 35 to 36	4.0E+01 ^g	—
9	Sheppard 1995 [103789], pp. 55 to 57	5.6E+00 ^h	—
10	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	—	—
11	Wang et al. 1993 [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

Technetium

Reference No.	Transfer Factor (Best Estimate)
1	9.5E+00
2	8.1E+00
3	8.0E+01
4	4.4E+01
5	7.6E+01
7	4.0E+01
8	4.0E+01
9	5.6E+00
11	4.0E+01
12	4.0E+01

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 (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 [103766], p. 10	1.5E-01 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	3.4E-03 ^b	3.4E-04 – 3.4E-02 ^b
3	IAEA 2001 [158519], pp. 67 to 68	1.0E-01 ^c	—
4	Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27	3.4E-03 ^d	
5	LaPlante and Poor 1997 [101079], p. 2-13	3.4E-03 ^e	lognormal; GSD = 2
6	NCRP 1984 [103784], p. 75	—	1.5E-02 – 3.3E+00
7	NCRP 1996 [101882], pp. 52 to 54	1.0E-01 ^f	—
8	Rittmann 1993 [107744], pp. 35 to 36	4.0E-01 ^g	—
9	Sheppard 1995 [103789], pp. 55 to 57	1.6E-03 ^h	—
10	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	1.84E+00 ⁱ	—
11	Wang et al. 1993 [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

Iodine

Reference No.	Transfer Factor (Best Estimate)
1	1.5E-01
2	3.4E-03
3	1.0E-01
4	3.4E-03
5	3.4E-03
7	1.0E-01
8	4.0E-01
9	1.6E-03
10	1.84E+00
11	1.7E-01
12	1.7E-01

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 (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 [103766], p. 10	1.0E-01 ^a	—
2	IAEA 1994 [100458], pp. 17 to 25	8.1E-03 ^b	2.0E-03 – 1.2E-01 ^b
3	IAEA 2001 [158519], pp. 67 to 68	5.0E-01 ^c	—
4	Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27	1.3E-02 ^d	—
5	LaPlante and Poor 1997 [101079], p. 2-13	6.9E-02 ^e	lognormal; GSD = 2
6	NCRP 1984 [103784], p. 75	—	—
7	NCRP 1996 [101882], pp. 52 to 54	1.0E-01 ^f	—
8	Rittmann 1993 [107744], pp. 35 to 36	1.0E+00 ^g	—
9	Sheppard 1995 [103789], pp. 55 to 57	2.4E-02 ^h	—
10	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	4.8E-03 ⁱ	—
11	Wang et al. 1993 [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

Neptunium

Reference No.	Transfer factor (approx.)
1	1.0E-01
2	8.1E-03
3	5.0E-01
4	1.3E-02
5	6.9E-02
6	—
7	1.0E-01
8	1.0E+00
9	2.4E-02
10	4.8E-03
11	1.0E-01
12	1.0E-01
13	—

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 (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>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 [103766], p. 10	4.5E-04 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	8.0E-04 ^b	1.1E-04 – 5.1E-02 ^b
3	IAEA 2001 [158519], pp. 67 to 68	1.0E-01 ^c	–
4	Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27	3.9E-04 ^d	
5	LaPlante and Poor 1997 [101079], p. 2-13	3.4E-04 ^e	lognormal; GSD = 2
6	NCRP 1984 [103784], p. 75	8.5E-04 ^f	9.2E-06 – 8.5E-04
7	NCRP 1996 [101882], pp. 52 to 54	1.0E-01 ^g	–
8	Rittmann 1993 [107744], pp. 35 to 36	4.0E-04 ^h	–
9	Sheppard 1995 [103789], pp. 55 to 57	1.3E-04 ⁱ	–
10	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	2.3E-04 ^j	–
11	Wang et al. 1993 [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

Plutonium

Reference No.	Transfer factor (Best Estimate)
1	4.5E-04
2	8.0E-04
3	1.0E-01
4	3.9E-04
5	3.4E-04
6	8.5E-04
7	1.0E-01
8	4.0E-04
9	1.3E-04
10	2.3E-04
11	2.7E-04
12	1.0E-03 (Recommendation)

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 (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 Value 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-Crop Transfer Factors for Forage Plants

No.	Reference	Transfer Factor, dimensionless	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 10	5.5E-05 ^a	–
2	IAEA 1994 [100458], pp. 17 to 25	7.1E-04 ^b	1.8E-04 – 3.1E-03 ^b
3	IAEA 2001 [158519], pp. 67 to 68	1.0E-01 ^c	–
4	Kennedy and Strenge 1992 [103776], pp. 6.25 to 6.27	5.8E-04 ^d	
5	LaPlante and Poor 1997 [101079], p. 2-13	1.2E-03 ^e	lognormal; GSD = 2
6	NCRP 1984 [103784], p. 75	–	–
7	NCRP 1996 [101882], pp. 52 to 54	1.0E-01 ^f	–
8	Rittmann 1993 [107744], pp. 35 to 36	2.0E-03 ^g	–
9	Sheppard 1995 [103789], pp. 55 to 57	4.2E-04 ^h	–
10	Till and Meyer 1983 [101895], pp. 5-50 to 5-51	1.7E-03 ⁱ	–
11	Wang et al. 1993 [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

Americium

Reference No.	Transfer Factor (Best Estimate)
1	5.5E-05
2	7.1E-04
3	1.0E-01
4	5.8E-04
5	1.2E-03
6	–
7	1.0E-01
8	2.0E-03
9	4.2E-04
10	1.7E-03
11	4.0E-03
12	–

NOTES: TFs are in units of Bq/kg dry-weight crop per Bq/kg dry-weight soil.

Truncation limits shown 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 (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 = 12.1E-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

No.	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 [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 [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 [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 [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 [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 [103784], p. 75	–	–	1.8E+00	–	4.1E-02	–	–	–	–	–	–
7	NCRP 1996 [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 [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 [103789], pp. 55 to 57	–	–	1.1E+00	–	7.7E-02	7.8E-03	1.2E-02	–	8.5E-03	–	1.1E-02
10	Till and Meyer 1983 [101895], 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 [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

NOTES: ^a The lower bound of the value of 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 (1976 [160550], p. 323); Romney et al. (1977 [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 (1976 [160550], p. 324); Romney et al. (1977 [160558], p. 53).

In another study (Au et al. 1977 [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 [160560], p. 1). The experimental results concerning the TFs for plutonium and americium are shown in Table 6-34.

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($^{239-240}\text{Pu}$)	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}

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

Plant	Treatment	Plutonium(²³⁹⁻²⁴⁰ Pu)	Americium (²⁴¹ Am)
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 [160560], pp. 8 to 11).

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 1976 [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 [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.

Measurements of transuranic uptake by plants were reviewed by Schulz (1976 [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 (1×10^{-8} to 1×10^{-3}) and 8 orders of magnitude for americium uptake (1×10^{-7} to 1×10^{-1}) (Schulz 1976 [160550], p. 322). Schultz (1976 [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 for plutonium (on the order of 1×10^{-4}) are appropriate for use in the biosphere model. TFs for americium calculated in experiments involving soil collected on the NTS also are 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 [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 Amargosa Valley soils 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 [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 [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 [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 [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. The ash thickness at the receptor location predicted in the previous TSPA was less than 1 cm in 95 percent of the model realizations and less than 1 mm in 80 percent of realizations (Section 6.8). 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 modern climate, but not substantially different from the modern 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 modern climate (USGS 2001 [158378], p. 76). However, the glacial-transition climate is cooler than the modern climate, so evaporation is lower than during modern times and, consequently, the water content of the soil can be higher (USGS 2001 [158378], p. 77). 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 modern 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_d). 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 [159468] 2001, 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 [103767], p. 234; Karlsson et al. 2001 [159470], p. 37; Sheppard and Sheppard 1989 [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 also is used for the agricultural land model in Karlsson et al. (2001 [159470], p. 37). The correlation coefficient should be between log-transformed values of TFs and K_{ds} (Sheppard and Sheppard 1989 [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 [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 2003 [160699], Sections 6.4.3.2 and 6.4.3.3) as

$$Cp_{water, i, j} = \frac{Dw_{i, j} f_{o, j} R w_j T_j}{\lambda_w Y_j} \left(1 - e^{-\lambda_w t_{g, j}}\right)$$

$$Cp_{dust, i, j} = \frac{Da_i Ra_j T_j}{\lambda_w Y_j} \left(1 - e^{-\lambda_w t_{g, j}}\right)$$

(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 (Bq/kg_{wet weigh})
- $Cp_{dust, i, j}$ = activity concentration of radionuclide i in crop type j contributed from plant leaf uptake due to deposition of resuspended particulates on crop surfaces (Bq/kg_{wet weigh})
- $Dw_{i, j}$ = deposition rate of radionuclide i due to application of irrigation water on crop type j (Bq/(m² d))
- $f_{o, j}$ = fraction of irrigation applied using overhead methods for plant type j (dimensionless)
- $R w_j$ = 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 (kg_{wet weight}/m²).
- Da_i = deposition rate of radionuclide i with resuspended particulates (Bq/(m² 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 2003 [160699], Section 6.4.3.3) as

$$Da_i = 8.64 \times 10^4 Ca_{p, i} V_d$$

(Eq. 6-6)

where

$$\begin{aligned}
 Ca_{p,i} &= \text{activity concentration of radionuclide } i \text{ in the air used for evaluation of} \\
 &\quad \text{activity deposition on crops (Bq/m}^3\text{)} \\
 V_d &= \text{dry deposition velocity for airborne particulates (m/sec)} \\
 8.64 \times 10^4 &= \text{unit conversion factor (sec/d).}
 \end{aligned}$$

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 re-entrained and resuspended into the atmosphere. Suspension describes the subsequent insertion of particles, which were originally deposited on a surface by some non-atmospheric process, such as irrigation with contaminated water, into the atmosphere (Sehmel 1984 [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 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, that 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 [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 [103767], p. 198	lognormal distribution GM = 0.006 m/s, GSD = 2	Values used for the BIOTRAC model
2	IAEA 1982 [103768], p. 17	0.002	Particulates <4 μm deposited on vegetation
3	LaPlante and Poor 1997 [101079], p. B-2	0.001	Value used in dose assessment for Yucca Mountain
4	Leigh et al. 1993 [100464], p. 5-63	0.001	GENII-S default value
6	Yu et al. 2001 [159465], p. D-12	Gaseous elements = 0 Halogens = 0.01 Other elements = 0.001	RESRAD default values

Deposition processes and associated parameters were the subject of a comprehensive review by G.A. Sehmel. Dry deposition velocities for many materials and various deposition surfaces were summarized (Sehmel 1984 [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 (Till and Meyer 1983 [101895], p. 5.19) found deposition velocities to range from 1×10^{-5} to 1×10^{-1} m/s. Sehmel and Hodgson (1978 [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 [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 [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: MO9811DEDCRMCR.000 [148887]; CRWMS M&O 1997 [100117], p. A-11). However, the wind speed in the surface boundary layer decreases towards 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 [103784], p. 48 where the range of friction velocity is given, and Sehmel 1984 [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. 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 five (NCRP 1999 [155894], p. 68). In a review (Dorrian 1997 [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 [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 two (EPA 1996 [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 [155894], p. 67). Based on the reviewed literature (EPA 1996 [160121], Section 3.7.5 to 3.8; Nieuwenhuijsen et al. 1998 [150855]; Pinnick et al. 1993 [160312]; Dorrian 1997 [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} to about 3×10^{-2} m/s (Sehmel 1984 [158693], p. 559), although Schery (2001 [159478], p. 268) shows that deposition velocity values range from about 1×10^{-4} 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 from 2 to 6 μm and a GSD of about five (NCRP 1999 [155894], p. 68). If the median diameter is 4 μm , 68 percent of particles would fall within the range from 0.8 to 20 μm ($4 \mu\text{m}/5$ to $4 \mu\text{m} \times 5$), and 99 percent of particles would be in the range from 0.06 to 250 μm ($4 \mu\text{m}/5^{2.58}$ to $4 \mu\text{m} \times 5^{2.58}$). Deposition velocities corresponding to these particle size ranges are from 1×10^{-3} to 3×10^{-2} m/s for the most likely sizes of resuspended particles, and between 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 [158693], p. 559; Schery 2001 [159478], p. 268). The deposition velocity for 4 μm particles can be estimated at around 8×10^{-3} m/s (Sehmel 1984 [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 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 [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 6-31). 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: SN0006T0502900.002 [150856], data No. 22 and 24), the sizes of airborne particles for the post-volcanic biosphere are expected to be within the range considered for the groundwater exposure scenario and the modern 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, among other things, on 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 [160339], p. 18). Alternatively, it can be defined as the ratio of activity on 1 m² of edible plant parts at harvest (Bq/m²) to the activity retained on 1 m² of foliage at the time of deposition (Bq/m²) (IAEA 1994 [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 and 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 [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). Depending on the radionuclide deposition process, some soil-to-plant TFs are based on concentrations in the edible parts of specific food crops and associated radionuclide concentrations in soil, account for radionuclide translocation within the crop.

Some conservative models, which are used for screening purposes (IAEA 2001 [158519]; Regulatory Guide 1.109, Rev. 1, 1977 [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 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 (Till and Meyer 1983 [101895], p. 5-53, Smith et al. 1996 [101085], p. 5-31).

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.

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 [100464], p. 5-63 Napier et al. 1988 [157927], p. 4.67	Leafy vegetables Root vegetables Fruit Grain Fresh forage for beef cattle Fresh forage for dairy cows Stored feed for beef cattle Stored feed for dairy 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 [157927] uses "other vegetables" category, whereas Leigh et al. 1993 [100464] uses "root vegetables" category for non-leafy vegetables.
2	Mills et al. 1983 [103781], p. 135	Leafy vegetables Other produce Fresh forage	1.0 0.1 1.0	For all non-leafy vegetables
3	NCRP 1984 [103784], p. 70	Leafy vegetables Other produce Fresh forage	1.0 0.1 1.0	For all non-leafy vegetables
4	Kennedy and Strenge 1992 [103776], pp. 6.41 to 6.42	Leafy vegetables Other vegetables Fruit Grain Forage for beef cattle Forage for dairy 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 [159465], p. D-12	Leafy vegetables Root vegetables, Fruit, and Grain Fresh forage	1.0 0.1 1.0	Foliage-to-food radionuclide TCs
6	LaPlante and Poor 1997 [101079], p. B-8	Leafy vegetables Root vegetables Fruit Grain Fresh forage for beef cattle Fresh forage for dairy 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 dairy 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

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 1976 [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, an assumption was made (Assumption 1) that the translocation factor for root (other) vegetables, fruit, grain, and stored feed for laying hens 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 modern climate are 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 [158519], Section 5.1.1.2; also ICRU 2001 [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 [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-time (half-life) of the crop surface-deposited contamination of 14 days. The relationship (ICRU 2001 [160339], p. 15) between any process half-time and the process rate constant is expressed as

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

where

$$\begin{aligned} T &= \text{process half-time, d} \\ \lambda &= \text{process rate constant, d}^{-1}. \end{aligned}$$

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

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

No	Reference	Weathering half-time, days	Comments
1	Baes et al. 1984 [103766], p. 124	14 8 (iodine)	Cited from NRC Regulatory Guide 1.109, Rev. 1 1977 [100067] and other references
2	IAEA 2001 [158519], p. 63	14 (all plant surfaces)	Values given as removal constants, converted using Eq. 3
3	LaPlante and Poor 1997 [101079], p. B-7	14	GENII-S default value
4	Leigh et al. 1993 [100464], p.5-63	14	GENII-S default
5	Mills et al. 1983 [103781], p. 137	14	Cited from NRC Regulatory Guide 1.109, Rev. 1 1977 [100067]
6	NCRP 1984 [103784], p. 70	14	Cited from NRC Regulatory Guide 1.109, Rev. 1 1977 [100067]
7	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-69	14	Based on NRC staff's judgments as stated in the notes
8	Smith et al. 1996 [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	Till and Meyer 1983 [101895], p. 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 [159465], p. D-12	12.7 (13 days)	Calculated from weathering removal constant of 20 yr^{-1} using Equation 6-6 and units conversion
11	Value selected for the biosphere model	Piece-wise cumulative distribution: 5 days, 0 percent 14 days, 50 percent 30 days, 100 percent	

The weathering half-time 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-time 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-time given in Table 6-37, range from 5 to 30 days with 14 days being the mode. Considering this information, it is recommended that the

weathering half-time 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-time corresponds to the crops irrigated using an overhead sprinkler system. The longer weathering half-time is appropriate for contaminant removal from crops irrigated using flood, ditch, drip or other types of irrigation not involving the overhead method and thus not accompanied by the rapid removal of contaminant from the crop surfaces.

It is also recommended that the distribution developed for the groundwater exposure scenario and the modern climate should be used for the volcanic ash exposure scenario and for the future climate. This is because the distribution of the weathering half-time is based on the 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. The 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 2003 [160699], Section 6.4.4) can be estimated as

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

where

$Cd_{i,k}$	=	activity concentration of radionuclide i in animal product k (Bq/kg 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 2003 [160699], Sections 6.4.4.1 through 6.4.4.3) as

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

where

- $Fm_{i, k}$ = animal intake-to-animal product TC for radionuclide i and animal product k (d/kg fresh weight or d/L for milk)
- $Cp_{i, j}$ = activity concentration of radionuclide i in animal feed j (Bq/kg 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 [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 feed but also to the water and soil ingestion.

The intake of food and water by animals depends on animal species, mass, age, growth rate of the animal, the digestibility of feed, and, in the case of lactating animals, the milk yield (IAEA 2001 [158519], p. 69). The type of feed depends on the animal species. Typical feed for the dairy cows includes grass products, maize, clover, alfalfa, and sugar beets, whereas beef cattle are fed a diet of grass products and maize (IAEA 1994 [100458], p. 32). Laying hens and chickens are fed cereals and protein feed. For the biosphere model calculations, grazing animals (beef cattle and dairy cows), are assumed to be on a diet of fresh pasture only. Laying hens and poultry, on the other hand, are 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 the 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 ratios (IAEA 1982 [103768], NCRP 1984 [103784], and IAEA 1994 [100458]) or the fractions of different types of animal feed in an animal diet (Kennedy and Streng 1992 [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 (CRWMS M&O 2001 [152539], p. 78; CRWMS M&O 2001 [152536], pp. 73 to 77). 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 to 68 kg/d for beef cattle, 50 to 73 kg/d for dairy cows and from 0.11 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 to 60 L/d for beef cattle, from 50 to 100 L/d for dairy cows, and from 0.1 to 0.3 L/d for chickens (IAEA 1994 [100458], p. 33). Most of the values listed in other documents (see Table 6-38) fall within these ranges. The dairy cow water consumption rate in Yu et al. (2001 [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 and 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 dairy cows would be about 160 L/d (Yu et al. 1993 [160561], p. 132). This high value was compared with the estimated water requirements for dairy cows, considering the site-specific conditions, as described below.

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

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

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).

Table 6-38. Animal Feed and 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 [100464], p. 5-63 Napier et al. 1988 [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 [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.
2	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-38	Beef cattle Diary cows	50 50	50 60	Not included	
3	IAEA 2001 [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 [100458], p. 15)
4	Mills et al. 1983 [103781], p. 143	Beef cattle Diary cows Poultry	68 55 0.12	50 60 -	Not included	
5	NCRP 1984 [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 [100458], p. 15)
6	Kennedy and Strenge 1992 [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 – 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.
7	Yu et al. 2001 [159465], p. D-15	Beef cattle Diary cows	68 55	50 160	0.5 0.5	RESRAD default values

Table 6-38. Animal Feed and 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 [103767], p. 253	Beef cattle Diary cows Poultry Laying hens	50 60 0.4 0.4	40 60 0.4 0.4	1.0 0.8 0.006 0.006 based on 6-7% of dry-weight feed or forage ingestion	Ingestion rates are assumed to be normally distributed, GSDs are given.
9	IAEA 1994 [100458], p. 33	Beef cattle Diary cows Poultry Laying hen	7.2 (dry-weight) 29 (wet-weight) 16.1 (dry-weight) 64 (wet-weight) 0.07 (dry-weight) 0.1 (dry-weight)	20-60 50-100 0.1-0.3 0.1-0.3	6% of feed for grazing cattle; corresponds to 0.4 – 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 [100458], p. 15). Mean fraction of soil intake expressed as fraction of feed intake
10	Smith et al. 1996 [101085], p. 5-24	Dairy cows and beef cattle Chicken	60 0.3	60 0.5	0.6 0.02	Beef cattle and diary cows are not distinguished; neither are laying hens and poultry.
11	LaPlante and Poor 1997 [101079], p. B-8	Beef cattle Diary cows Poultry Laying hen	33 (fresh/stored) 73 (fresh/stored) 0.08 0.11	60 100 0.3 0.3	Not included	Cited from IAEA (1994) with updated dry-to-wet ratio conversion.
12	Recommended values	Beef cattle Diary cows Poultry Laying hen	29 – 68 (fresh) 50 – 73 (fresh) 0.12 – 0.4 0.12 – 0.4	60 60-100 0.5 0.5	0.4 – 1.0 0.8 – 1.1 0.01 – 0.03 0.01 – 0.03	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.

Dry mass of feed intake can be taken from Table 6-38. Several references listed in that table give the feed consumption rate in terms of dry mass as 16 kg/d. The milk yield per dairy cow can be calculated based on the information from the Amargosa Dairy (Sepulveda 1999 [160413]). In this dairy, in March 1999, 4,503,280 pounds of milk were produced by the average number of lactating cows per day of 2,612. The average daily milk yield per cow is thus 25.3 kg/d. This value may be considered as 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 in Mason (2003 [160415]). The average minimum temperature can be obtained from the data for Meteorological Monitoring Site 9 (Gate 510) (DTN: MO9811DEDCRMCR.000 [148887]; CRWMS M&O 1997 [100117], p. A-11), which is the southern most Yucca Mountain Site station in the direction of Amargosa Valley (CRWMS M&O 1999 [102877], p. 5). The annual average minimum temperature was used instead of the weekly average minimum temperature because the value of water intake by dairy cows in the biosphere model applies to the annual average conditions. The annual average minimum temperature for Site 9 is 10.0°C. Using these values, the estimated daily water intake by dairy cows is about 80 L/d, which is a half of the value in Yu et al. (2001 [159465], p. D-15). This value may also be corroborated by the data from Bernard and Montgomery (2002 [160609], p. 5) presenting the results of the study that evaluated the water intake of dairy cows at a range of temperatures from 68 to 104°F. The corresponding daily water intake (not to be mistaken with the annual average water daily intake) was in the range from 18 gal/d (68 L/d) to 31.7 gal/d (120.0 L/d). The milk yield was 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 dairy cow consumption rate of water of 160 L/d used in Yu et al. (2001 [159465]) is unsubstantiated. The range of values in IAEA (1994 [100458]) of 50 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 dairy cows. Considering the site-specific conditions, especially with regard to the actual milk yield and higher than typical temperatures, the expected value of 80 L/d and the uncertainty represented by the uniform distribution in the range from 60 to 100 L/d is considered appropriate for dairy cow consumption for the biosphere model.

The water consumption rates for chickens in Davis et al. (1993 [103767], p. 253) and Smith (1996, p. 5-24) are greater than the values reported in IAEA (1994 [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 IAEA (1994 [100458], p. 33), Kennedy and Strenge (1992 [103776], p. 6.19), and Davis et al. (1993 [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 dairy 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 0.71 for grain, based on the mid-range values given in IAEA (1994 [100458], p. 15). It is

recommended that the soil consumption rates be represented by uniform distributions based on the calculated ranges.

The ingestion of soil was measured in an experiment conducted at the NTS (Gilbert et al. 1988 [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 rumens of two steers after 24 hour 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 [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 [160559], p. 147). Gilbert et al. (1988 [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 dairy 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

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 [160339], p. 14). TC is the fraction of the animal's daily intake of a radionuclide that is transferred to one 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 [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 [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 be representative of all meat, and cow milk to represent all kinds of milk. For example, IAEA (2001 [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 [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).

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 best representations of the parameter values (BIOMASS 2001 [159468] 2001, T1/WD04, p. 12). The distributions for TCs are considered to be lognormal (LaPlante et al. 1997, p. 2-14; Davis et al. 1993 [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 6-62). There are a variety of reasons for such spread of values. If the TC values are similar from report to report, this means that either 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), for the cases of large data spread ($GSD > 10$) it is recommended 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 modern 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 the 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. GMs and GSDs for TCs for meat were calculated using Microsoft Excel 97 SR-2 (see Attachment I) 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 [103766], p. 51	8.5E-03 ^a	–
2	Davis et al. 1993 [103767], pp. 233 to 234	8.5E-03	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 37	1.0E-04 ^b	1.0E-06 – 1.0E-04
4	IAEA 2001 [158519], pp. 67 to 68	1.0E-03 ^c	–
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	8.5E-03 ^a	–
6	LaPlante and Poor 1997 [101079], p. 2-13	1.0E-04 ^d	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	9.9E-04 ^a	–
8	NCRP 1984 [103784], p. 85	–	–
9	NCRP 1996 [101882], pp. 52 to 54	1.0E-04 ^e	–
10	Ng 1982 [160322], p. 63	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	4.0E-01 ^f	–
12	Rittmann 1993 [107744], pp. 35 to 36	9.9E-04 ^g	–
13	Smith et al. 1996 [101085], p. 5-27	6.0E-03 ^h	–
14	Till and Meyer 1983 [101895], p. 5-87	8.7E-03 ^a	–
15	Wang et al. 1993 [103839], pp. 27 to 29; Yu et al. 2001 [159465], p. D-16	1.0E-04 ⁱ	–
16	This analysis	–	lognormal; GM = 1.1E-03 ^j ; GSD = 7.2 truncation: low = 6.9E-06; high = 1.8E-01

Technetium

NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown 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 Value for beef

^h Value for beef; value used in the biosphere modeling for Yucca Mountain.

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

^j 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 [103766], p. 51	7.0E-03 ^a	–
2	Davis et al. 1993 [103767], pp. 233 to 234	7.0E-03	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 37	4.0E-02 ^a	7.0E-03 – 5.0E-2
4	IAEA 2001 [158519], pp. 67 to 68	5.0E-02 ^b	–
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	7.0E-03 ^a	–
6	LaPlante and Poor 1997 [101079], p. 2-13	4.0E-02 ^c	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	2.0E-02 ^a	–
8	NCRP 1984 [103784], p. 85	7.0E-03 ^a	–
9	NCRP 1996 [101882], pp. 52 to 54	4.0E-02 ^d	–
10	Ng 1982 [160322], p. 63	7.2E-03 ^a	7.2E-03 – 2.0E-02
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	2.9E-03	–
12	Rittmann 1993 [107744], pp. 35 to 36	2.0E-03 ^a	–
13	Smith et al. 1996 [101085], p. 5-27	3.0E-03 ^c	–
14	Till and Meyer 1983 [101895], p. 5-87	7.2E-03 ^a	–
15	Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [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 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 [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 [103766], p. 51	5.5E-05 ^a	—
2	Davis et al. 1993 [103767], pp. 233 to 234	5.5E-05	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 37	1.0E-03 ^a	—
4	IAEA 2001 [158519], pp. 67 to 68	1.0E-02 ^b	—
5	Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30	5.5E-05 ^a	—
6	LaPlante and Poor 1997 [101079], p. 2-13	1.0E-03 ^c	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	5.0E-03 ^a	—
8	NCRP 1984 [103784], p. 85	—	—
9	NCRP 1996 [101882], pp. 52 to 54	1.0E-03 ^d	—
10	Ng 1982 [160322], p. 63	—	—
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	2.0E-04	—
12	Rittmann 1993 [107744], pp. 35 to 36	1.0E-03 ^a	—
13	Smith et al. 1996 [101085], p. 5-27	1.2E-04 ^c	—
14	Till and Meyer 1983 [101895], p. 5-87	3.6E-06 ^e	—
15	Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [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

Neptunium

Reference No.	Transfer factor (d/kg)
1	~6.0E-05
2	~6.0E-05
3	~1.0E-03
4	~1.0E-02
5	~6.0E-05
6	~1.0E-03
7	~5.0E-03
8	—
9	~1.0E-03
10	—
11	~2.0E-04
12	~1.0E-03
13	~1.0E-04
14	~3.6E-06
15	~1.0E-03
16	~5.0E-04

NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown 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 [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 [103766], p. 51	5.0E-07 ^a	–
2	Davis et al. 1993 [103767], pp. 233 to 234	2.0E-06	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 37	1.0E-05 ^a	2.0E-07 – 2.0E-04
4	IAEA 2001 [158519], pp. 67 to 68	2.0E-04 ^b	–
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	5.0E-07 ^a	–
6	LaPlante and Poor 1997 [101079], p. 2-13	1.0E-05 ^c	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	5.0E-03 ^a	–
8	NCRP 1984 [103784], p. 85	–	5.0E-09 – 2.0E-05 ^a
9	NCRP 1996 [101882], pp. 52 to 54	1.0E-04 ^d	–
10	Ng 1982 [160322], p. 63	1.0E-06 ^a	1.3E-07 – 5.8E-06
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	–	–
12	Rittmann 1993 [107744], pp. 35 to 36	2.0E-06 ^a	–
13	Smith et al. 1996 [101085], p. 5-27	2.0E-04 ^c	–
14	Till and Meyer 1983 [101895], p. 5-87	1.0E-06 ^a	–
15	Wang et al. 1993 [103839], pp. 27 to 29 Yu et al. 2001 [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 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 [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 [103766], p. 51	3.5E-06 ^a	–
2	Davis et al. 1993 [103767], pp. 233 to 234	3.5E-06	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 37	4.0E-05 ^a	4.0E-06 – 1.0E-04
4	IAEA 2001 [158519], pp. 67 to 68	1.0E-04 ^b	–
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	3.5E-06 ^a	–
6	LaPlante and Poor 1997 [101079], p. 2-13	4.0E-05 ^c	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	5.0E-03 ^a	–
8	NCRP 1984 [103784], p. 85	–	–
9	NCRP 1996 [101882], pp. 52 to 54	5.0E-05 ^d	–
10	Ng 1982 [160322], p. 63	–	–
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	–	–
12	Rittmann 1993 [107744], pp. 35 to 36	2.0E-05 ^a	–
13	Smith et al. 1996 [101085], p. 5-27	4.0E-04 ^c	–
14	Till and Meyer 1983 [101895], p. 5-87	3.6E-06 ^a	–
15	Wang et al. 1993 [103839], pp. 27 to 29; Yu et al. 2001 [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 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 [103839], pp. 27 to 29.

^f For the references listed in this table, GM = 13.4E-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 [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 [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 [100458], p. 37	2.0E-02	—	8.0E-03	—	5E-02	4.0E-04	9.0E-04	—	—	—	3.0E-04
4	IAEA 2001 [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 [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 [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 [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 [103784], p. 85	—	—	8.0E-04	—	3.0E-02	—	5.0E-04	—	—	—	—
9	NCRP 1996 [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 [160322], p. 63	—	—	3.0E-04	—	2.0E-02	—	—	—	—	—	—
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	—	—	6.0E-04	—	4.0E-03	—	—	—	—	—	—
12	Rittmann 1993 [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 [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	Till and Meyer 1983 [101895], 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 [103839], pp. 27 to 29 Yu et al. 2001 [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
	GSD	1.8	5.8	4.4	4.6	2.6	2.6	2.1	8.2	15.1	21.2	3.0

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
	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

NOTES: ^a The lower bound of the value of GSD was used.

^b The upper bound of the GSD 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 [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 [160553], p. 328) is calculated as

$$r = C f_{sv} I_v + C I_s \quad (\text{Eq. 6-13})$$

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 [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 [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 [160553], p. 329).

The results of the calculation indicate that the TCs for plutonium for meat are in the range from 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 blood (Eckerman et al. 1988 [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 (see 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, [160553], pp. 327 to 329

NOTES: ^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. Calculations of GMs and GSDs for TCs for poultry were done using Microsoft Excel 97 SR-2 spreadsheet and are shown in Attachment I.

Table 6-46. Technetium Transfer Coefficients for Poultry

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Davis et al. 1993 [103767], pp. 233 to 234	1.9E+00 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 40	3.0E-02	3.0E-02 – 2.0E-01
3	Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30	3.0E-02	–
4	Mills et al. 1983 [103781], pp. 145 to 146	9.9E-04	–
5	Ng 1982 [160322], p. 63	–	–
6	Rittmann 1993 [107744], pp. 35 to 36	3.0E-02 ^b	–
7	Smith et al. 1996 [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: Cs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown 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 [103767], pp. 233 to 234	2.8E+00 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 40	1.0E-02	–
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	1.8E-02	–
4	Mills et al. 1983 [103781], pp. 145 to 146	4.0E-03	–
5	Ng 1982 [160322], p. 63	2.0E-01	8.0E-03 – 2.0E-01
6	Rittmann 1993 [107744], pp. 35 to 36	1.8E-02 ^b	–
7	Smith et al. 1996 [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

Iodine

Reference No.	Transfer factor (Best Estimate)
1	2.8E+00
2	1.0E-02
3	1.8E-02
4	4.0E-03
5	2.0E-01
6	1.8E-02
7	2.0E-01
9	~6.0E-02

NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown 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 [103767], pp. 233 to 234	5.5E-03 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 40	—	—
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	4.0E-03	—
4	Mills et al. 1983 [103781], pp. 145 to 146	4.0E-03	—
5	Ng 1982 [160322], p. 63	—	—
6	Rittmann 1993 [107744], pp. 35 to 36	4.0E-03 ^b	—
7	Smith et al. 1996 [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 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 [103767], pp. 233 to 234	7.6E-03 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 40	3.0E-03	2.0E-05 – 3.0E-03
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	1.5E-04	–
4	Mills et al. 1983 [103781], pp. 145 to 146	4.0E-03	–
5	Ng 1982 [160322], p. 63	2.0E-05 ^b	–
6	Rittmann 1993 [107744], pp. 35 to 36	1.5E-04 ^c	–
7	Smith et al. 1996 [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

Plutonium

Reference No.	Transfer factor
1	7.6E-03
2	3.0E-03
3	1.5E-04
4	4.0E-03
5	2.0E-05
6	1.5E-04
7	1.0E-01
8	1.2E-03 (GM)
9	1.0E-03

NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown as dashed lines.

^a Same value was used for poultry and eggs.

^b Value for PuO₂

^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 [103767], pp. 233 to 234	8.5E-03 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 40	6.0E-03	2.0E-05 – 6.0E-03
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	2.0E-04	–
4	Mills et al. 1983 [103781], pp. 145 to 146	4.0E-03	–
5	Ng 1982 [160322], p. 63	7.2E-05	–
6	Rittmann 1993 [107744], pp. 35 to 36	2.0E-04 ^b	–
7	Smith et al. 1996 [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 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 [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 [100458], p. 40	–	9.0E+00	8.0E-02	–	1.0E+01	–	–	–	–	–	1.0E+00
3	Kennedy and Strenge 1992 [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 [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 [160322], p. 63	–	–	3.2E-02	–	4.4E+00	–	–	–	–	–	–
6	Rittmann 1993 [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 [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	Till and Meyer 1983 [101895], 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

NOTES: ^a The lower bound of the value of GSD was used.^b The upper bound of the value of 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 [100458], IAEA 2001 [155188]) indicate that technetium transfer from animal diet to milk tends to be lower than was previously considered (Davis et al. 1993 [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 [103766]), Mills et al. (1983 [103781]), Till and Meyer (1983 [101895]), and Regulatory Guide 1.109, Rev. 1 (1997 [100067]) and compare with data from IAEA (2001 [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 [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 [155188], p. 43). Based on the Eh-pH diagram for technetium, the stability region for TcO_2 is very limited (Brookins 1988 [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 as 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 [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 [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 [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 [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 through 6-57 while the calculations of GM and standard deviation are included in the Microsoft Excel 97 SR-2 spreadsheet shown in Attachment I.

Table 6-52. Technetium Transfer Coefficients for Milk

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 50	1.0E-02	—
2	Davis et al. 1993 [103767], pp. 233 to 234	9.9E-04	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 35	1.4E-04 ^a	2.3E-05 – 1.1E-03
4	IAEA 2001 [158519], pp. 67 to 68	1.0E-03 ^b	—
5	Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30	1.0E-02	—
6	LaPlante and Poor 1997 [101079], p. 2-13	1.4E-04 ^c	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	1.2E-02	—
8	NCRP 1984 [103784], pp. 82 to 83	—	—
9	NCRP 1996 [101882], pp. 52 to 54	1.0E-03 ^b	—
10	Ng 1982 [160322], p. 62	—	—
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	2.5E-02	—
12	Rittmann 1993 [107744], pp. 35 to 36	3.0E-04 ^c	—
13	Smith et al. 1996 [101085], p. 5-27	7.5E-03 ^d	—
14	Till and Meyer 1983 [101895], p. 5-86	9.9E-03	—
15	Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [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

Technetium

NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown 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/kg	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 50	1.0E-02	–
2	Davis et al. 1993 [103767], pp. 233 to 234	9.9E-03	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 35	1.0E-02	1.0E-03 – 3.5E-02
4	IAEA 2001 [158519], pp. 67 to 68	1.0E-02 ^a	–
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	1.0E-02	–
6	LaPlante and Poor 1997 [101079], p. 2-13	1.0E-02 ^b	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	1.0E-02	–
8	NCRP 1984 [103784], pp. 82 to 83	1.2E-02 ^c	2.7E-03 – 3.5E-02
9	NCRP 1996 [101882], pp. 52 to 54	1.0E-02 ^a	–
10	Ng 1982 [160322], p. 62	9.9E-03	–
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	6.0E-03	–
12	Rittmann 1993 [107744], pp. 35 to 36	1.2E-02 ^d	–
13	Smith et al. 1996 [101085], p. 5-27	3.0E-03 ^b	–
14	Till and Meyer 1983 [101895], p. 5-86	9.9E-03	–
15	Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [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/kg 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/kg	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 50	5.0E-06	—
2	Davis et al. 1993 [103767], pp. 233 to 234	5.0E-06	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 35	5.0E-06	—
4	IAEA 2001 [158519], pp. 67 to 68	5.0E-05 ^a	—
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	5.0E-06	—
6	LaPlante and Poor 1997 [101079], p. 2-13	5.0E-06 ^b	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	2.5E-06	—
8	NCRP 1984 [103784], pp. 82 to 83	—	—
9	NCRP 1996 [101882], pp. 52 to 54	1.0E-05 ^a	—
10	Ng 1982 [160322], p. 62	—	—
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	5.0E-06	—
12	Rittmann 1993 [107744], pp. 35 to 36	1.0E-05 ^c	—
13	Smith et al. 1996 [101085], p. 5-27	5.0E-06 ^b	—
14	Till and Meyer 1983 [101895], p. 5-86	5.0E-06	—
15	Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [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/kg 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 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/kg	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 50	1.0E-07	—
2	Davis et al. 1993 [103767], pp. 233 to 234	1.0E-07	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 35	1.1E-06	3.0E-09 – 3.0E-06
4	IAEA 2001 [158519], pp. 67 to 68	3.0E-06 ^a	—
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	1.0E-07	—
6	LaPlante and Poor 1997 [101079], p. 2-13	1.1E-06 ^b	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	2.5E-08	—
8	NCRP 1984 [103784], pp. 82 to 83	1.0E-07 ^c	—
9	NCRP 1996 [101882], pp. 52 to 54	1.0E-06 ^a	—
10	Ng 1982 [160322], p. 62	1.0E-07	—
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	—	—
12	Rittmann 1993 [107744], pp. 35 to 36	1.0E-07 ^d	—
13	Smith et al. 1996 [101085], p. 5-27	5.0E-06 ^b	—
14	Till and Meyer 1983 [101895], p. 5-86	2.7E-09 ^e	—
15	Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [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/kg 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 Value for plutonium citrate

^d GENII default

^e Value for PuO₂

^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/kg	
		Best Estimate	Range and Distribution
1	Baes et al. 1984 [103766], p. 50	4.0E-07	–
2	Davis et al. 1993 [103767], pp. 233 to 234	4.1E-07	lognormal; GSD = 3.2
3	IAEA 1994 [100458], p. 35	1.5E-06	4.0E-07 – 2.0E-05
4	IAEA 2001 [158519], pp. 67 to 68	2.0E-05 ^a	–
5	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	4.0E-07	–
6	LaPlante and Poor 1997 [101079], p. 2-13	1.5E-06 ^b	lognormal; GSD = 2
7	Mills et al. 1983 [103781], pp. 145 to 146	2.5E-06	–
8	NCRP 1984 [103784], pp. 82 to 83	–	–
9	NCRP 1996 [101882], pp. 52 to 54	2.0E-06 ^a	–
10	Ng 1982 [160322], p. 62	4.1E-07	–
11	Regulatory Guide 1.109, Rev. 1 1977 [100067], p. 1.109-37	–	–
12	Rittmann 1993 [107744], pp. 35 to 36	3.0E-07 ^d	GENII-S default
13	Smith et al. 1996 [101085], p. 5-27	5.0E-06 ^b	–
14	Till and Meyer 1983 [101895], p. 5-86	2.0E-05 ^c	–
15	Wang et al. 1993 [103839], pp. 30 to 32 Yu et al. 2001 [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/kg 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 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/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 [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 [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 [100458], p. 35	1.7E-02	–	2.8E-03	–	7.9E-03	–	1.3E-03	–	–	–	4.0E-04
4	IAEA 2001 [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 [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 [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 [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 [103784], p. 83	–	–	1.4E-03	–	7.1E-03	–	4.0E-04	–	–	–	4.0E-04
9	NCRP 1996 [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 [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 [100067], p. 1.109-37	–	–	8.0E-04	–	1.2E-02	–	–	–	–	–	–
12	Rittmann 1993 [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 [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	Till and Meyer 1983 [101895], 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 [103839], pp. 30 to 32; Yu et al. 2001 [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
	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

NOTES:

^a The lower bound of the value of 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 through 6-63. Calculations of GMs and GSDs for TCs for eggs were done using Microsoft Excel 97 SR-2 spreadsheet and are shown in Attachment I.

Table 6-58. Technetium Transfer Coefficients for Eggs

No.	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Davis et al. 1993 [103767], p. 233 to 234	1.9E+00 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 41	3.0E+00	—
3	Kennedy and Strenge 1992 [103776], pp. 6.29 to 6.30	3.0E+00	—
4	LaPlante and Poor 1997 [101079], p. 2-13	3.0E+00 ^b	lognormal; GSD = 2
5	Mills et al. 1983 [103781], pp. 145 to 146	9.9E-04 ^c	—
6	Ng 1982 [160322], p. 63	—	—
7	Rittmann 1993 [107744], pp. 35 to 36	3.0E+00	GENII-S default
8	Smith et al. 1996 [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

Technetium

Reference No.	Transfer factor (Best Estimate)
1	1.9E+00
2	3.0E+00
3	3.0E+00
4	3.0E+00
5	9.9E-04
7	3.0E+00
8	1.2E+00
9	2.4E+00 (GM)

NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown 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

	Reference	Transfer Coefficient, d/kg	
		Best Estimate	Range and Distribution
1	Davis et al. 1993 [103767], p. 233 to 234	2.8E+00 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 41	3.0E+00	2 – 4
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	2.8E+00	–
4	LaPlante and Poor 1997 [101079], p. 2-13	3.0E+00 ^b	lognormal; GSD = 2
5	Mills et al. 1983 [103781], pp. 145 to 146	1.6E+00	–
6	Ng 1982 [160322], p. 63	4.4E+00	3.7E+00 – 5.2E+00
7	Rittmann 1993 [107744], pp. 35 to 36	2.8E+00 ^c	–
8	Smith et al. 1996 [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 as dashed lines.

^a Same value used for poultry and eggs (Davis et al. 1993 [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 [103767], p. 233 to 234	5.5E-03 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 41	–	–
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	2.0E-03	–
4	LaPlante and Poor 1997 [101079], p. 2-13	2.0E-03 ^b	lognormal; GSD = 2
5	Mills et al. 1983 [103781], pp. 145 to 146	2.0E-03	–
6	Ng 1982 [160322], p. 63	–	–
7	Rittmann 1993 [107744], pp. 35 to 36	2.0E-03 ^c	–
8	Smith et al. 1996 [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 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 [103767], p. 233 to 234	7.6E-03 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 41	5.0E-04	3.0E-05 – 8.0E-03
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	8.0E-03	–
4	LaPlante and Poor 1997 [101079], p. 2-13	5.0E-04 ^b	lognormal; GSD = 2
5	Mills et al. 1983 [103781], pp. 145 to 146	2.0E-03	–
6	Ng 1982 [160322], p. 63	3.3E-05	–
7	Rittmann 1993 [107744], pp. 35 to 36	8.0E-03 ^c	–
8	Smith et al. 1996 [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

Plutonium

Reference No.	Transfer factor (Best Estimate)
1	7.6E-03
2	5.0E-04
3	8.0E-03
4	8.0E-03
5	2.0E-03
6	3.3E-05
7	8.0E-03
8	8.0E-03
9	1.7E-03

NOTES: TCs are in units of Bq/kg of animal product per Bq/d of radionuclide intake.

Truncation limits shown 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 [103767], p. 233 to 234	8.5E-03 ^a	lognormal; GSD = 3.2
2	IAEA 1994 [100458], p. 41	4.0E-03	1.0E-03 – 9.0E-03
3	Kennedy and Streng 1992 [103776], pp. 6.29 to 6.30	9.0E-03	–
4	LaPlante and Poor 1997 [101079], p. 2-13	4.0E-03 ^b	lognormal; GSD = 2
5	Mills et al. 1983 [103781], pp. 145 to 146	2.0E-03	–
6	Ng 1982 [160322], p. 63	3.9E-03	–
7	Rittmann 1993 [107744], pp. 35 to 36	9.0E-03 ^c	–
8	Smith et al. 1996 [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 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

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 [103767], p. 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 [100458], p. 41	—	9.0E+00	2.0E-01	—	4.0E-01	—	—	—	—	—	1.0E+00
3	Kennedy and Streng 1992 [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 [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 [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 [160322], p. 63	—	—	2.2E-01	—	4.3E-01	—	—	—	—	—	—
7	Rittmann 1993 [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 [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	Till and Meyer 1983 [101895], p. 5-87	—	—	3.0E-01	—	5.0E-03	—	—	—	—	—	—
	GM	4.4E-02	7.3E+00	2.7E-01	8.7E-02	5.9E-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	2.3	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	2.3	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	7.2E-02	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	4.8E+00	2.1E+01	1.5E-01	2.5E-02	5.9E-01	1.2E-02	6.7E+00

NOTES: ^a The lower bound of the value of GSD equal to 2.0 was used.

^b The upper bound of the value of 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 [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 2003 [160699], Section 6.4.5) as

$$Cf_i = Cw_{f,i} BF_i = Cw_i MF_i BF_i \quad (\text{Eq. 6-14})$$

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 [158519], p. 72). The most important parameter governing the value of a bioaccumulation factor is the trophic level of the organism (IAEA 2001 [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. However, bottom-feeding fish have higher bioaccumulation factors (take up more radioactivity) than the piscivorous (fish eating) fish (IAEA 1994 [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 [101090], pp. 3 to 17, YMP 1999 [158212], pp. 15 to 16). During the period from 1988 to 1998, which included the time of the food consumption survey (DOE

1997 [100332]), the farm was fully operational. The production has since declined, but the farm still remains in operation (Roe 2002 [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 [101090], pp. 3 to 17, YMP 1999 [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 inches (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 [160674]).

The following information about catfish farming, relevant to the biosphere modeling, was obtained from the Mississippi State University Extension Service (2002 [159489]). (Mississippi is the major catfish producer accounting for about $\frac{3}{4}$ of the U.S. catfish production.) It takes about 2 years to grow a catfish and a full-grown fish weighs one to two pounds. The amount of food that is needed to grow the fish is two pounds of feed per one 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 [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 one 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 [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, as well as 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 changes with time because throughout a year, fresh water must be added to the ponds on a continuous 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 estimation 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 [100458], p. 46-47), 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 shown in Attachment I. Additional information on the ranges of bioaccumulation factors can be found in IAEA (1994 [100458], p. 45). The distribution of bioaccumulation factors represents the uncertainty in the upper bound of the parameter value, rather than the uncertainty in the parameter itself. There is an 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 [103767], pp. 233-234	IAEA 1994 [100458], p. 45	IAEA 2001 [158519], p. 73	Kennedy and Streng 1992 [103776], p. 6.32	Mills et al. 1983 [103781], pp. 148-149	Napier et al. 1988 [100953], pp. 5.769-5.770	NCRP 1996 [101882], pp. 58-60	Reg. Guide 1.109 [100067], p. 1.109-13	Till and Meyer 1983 [101895], p. 5-98-5.103	Wang et al. 1993 [103839], p. 33-35; Yu et al. 2001 [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	3E+01	3.0E+01	2.5E+02	1.0E+01	2.5E+03	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

NOTES:

^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

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	1.2E+03
Strontium	4.6E+01	2.0	7.8E+00	2.8E+02
Technetium	2.0E+01	2.0	3.3E+00	1.2E+02
Tin	2.5E+03	2.0	4.2E+02	1.5E+04
Iodine	4.5E+01	2.6	3.8E+00	5.3E+02
Cesium	3.5E+03	2.2	4.7E+02	2.5E+04
Lead	2.9E+02	2.5	2.7E+01	3.1E+03
Radium	6.7E+01	2.2	9.2E+00	5.0E+02
Actinium	2.9E+01	3.0	1.7E+00	5.0E+02
Thorium	1.1E+02	2.5	1.0E+01	1.2E+03
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

NOTES:

^a Calculated using values shown in Table 6-64, see Attachment I

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 [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 [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 ¹⁴C which is discussed later, and that the activity accumulates in the ponds for up to 2 years (Assumption 2). After all fish have been harvested, the ponds are drained and cleaned, and the water is completely replaced.

The water concentration modifying factor can thus be calculated by taking 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.

$$MF_i = \frac{PD + AE \times RC}{PD} \quad (\text{Eq. 6-15})$$

where

PD = pond depth, m
 AE = annual evaporation rate, m/yr
 RC = duration of fish raising cycle, yr.

The fishpond depth, PD , can be determined from the results of the Regional Data Analysis Investigation (Roe 2002 [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 from 0.8 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 [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 [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 inches (for the map isopleths closest to the Amargosa Valley). Based on this information, the value of 80 inches (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 [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 inches. In the Mojave Desert at Silver Lake, California (Blaney 1957 [159504], p. 212), where climate is similar to that in the Amargosa Valley, annual evaporation is about 80 inches (79.46 inches; 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 one and two 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 from 2.2 for the pond depth of 1.7 m and one-year evaporation to 6.1 for the pond depth of 0.8 m and 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 modern 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 [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 [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 [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 [103767], p. 104). Therefore, taking into account the geometry of the fishponds, depths of which 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 ($6,039 \text{ m}^3$) and the volume of water that evaporates from the ponds in one year ($2.03 \text{ m/yr} \times 4,258 \text{ m}^2 = 8,644 \text{ m}^3/\text{yr}$). The annual rate of water (and activity) addition to the ponds is equal to $8,644 \text{ m}^3/\text{yr}$ divided by $6,039 \text{ m}^3$ (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. The catfish at the Deer Catfish Farm are raised using commercial feed, which is not contaminated (Roe 2002 [160674]). Because of this, 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 (Table 6-65; i.e., 4.6×10^3) be used for the biosphere model. 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 (Attachment I) and are shown in Table 6-65.

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 inches (0.76 to 0.89 m) (Farnsworth et al. 1982 [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 needs to be added to the ponds to compensate for the evaporation losses, is between 0.9 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 from 1.5 for the pond depth of 1.7 m and one-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 modern 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 modifying factor for the modern 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 [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 [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 [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 [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 2002 [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:

- Under-powered, 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 2002 [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 inches 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 [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 air flow 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 re-circulates 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 2003 [160699], Section 6.4.2.2) are calculated as

$$Ca_{e,i} = f_{evap} \frac{M_{water}}{F_{air}} Cw_i \quad (\text{Eq. 6-16})$$

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}	=	air flow 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.

The majority of the homes in Amargosa Valley are manufactured homes, accounting for nearly 90 percent of homes. Bureau of the Census (2002 [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 [159728], Table H31) 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 consists of single family houses. The 2000 Census data indicated that 91.3 percent of the total Amargosa Valley population (1043 of 1142 people) lived in manufactured homes (Bureau of the Census 2002

[159728], Table H33). Therefore manufactured homes can be used to represent a typical residential structure in Amargosa Valley.

Most manufactured homes are single- or doublewide. 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 ft² for the single-wide (single-section) homes and 1,629 ft² for double-wide (double-section) homes and 1,955 ft² for multi-section homes (NAHB Research Center 1998 [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 ft². The average size of a conventional single-family home is 2,048 ft² (NAHB Research Center 1998 [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 [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
7-1/2 feet	37.4
8 feet	5.1
8-1/2 feet	1.5
9 feet	7.7

Source: NAHB Research Center 1998 [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 ft³. 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 ft² in hot desert climates (ToolBase Services 2002 [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-ft² 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 [159501], p. 3). In this case, the airflow adequate for a 9,800-ft³ 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 of a few hundred CFM up to about 2,000 CFM (Watt and Brown 1997 [159497], pp. 131, 132, and 135). Window-mounted evaporative coolers may provide the airflow rate between about 1,000 and 2,000 CFM (Watt and Brown 1997 [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 to over 6,000 CFM (Watt and Brown 1997 [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 m³/h), a 50 percent value of 4,900 CFM (8,300 m³/h), and a 100 percent value of 6,000 CFM (10,200 m³/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 [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 whether it evaporated 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 (based on data from Karpiscak et al. 1998 [160563]). Households were selected for the study on the basis of home size and cooler size (4,500 to 6,500 CFM). The airflow rates for the coolers used in the study are 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.

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 bleedoff 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 bleedoff systems, the amount of bleedoff 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 [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 [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 the 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 [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 6-16. 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 a 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). 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.

Table 6-68. Evaporative Cooler Water Use

House No.	System Configuration ^a				Water Use		Bleedoff		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

Table 6-68. Evaporative Cooler Water Use (Continued)

House No.	System Configuration ^a				Water Use		Bleedoff		Operating Hours	Water Use Rate, L/hr ^b	Water Evaporation Rate, L/hr ^c
	BS	NBS	AC	NAC	gallons	liters	gallons	liters			
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
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

Table 6-68. Evaporative Cooler Water Use (Continued)

House No.	System Configuration ^a				Water Use		Bleedoff		Operating Hours	Water Use Rate, L/hr ^b	Water Evaporation Rate, L/hr ^c
	BS	NBS	AC	NAC	gallons	liters	gallons	liters			
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
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 [160563], p. 122

NOTES: The table includes measurements from 1993 and 1994.

^a NBS = no bleedoff system

BS = bleedoff system

AC = air conditioner

NAC = no air conditioner

^b Total water use rate for evaporative coolers equipped with bleedoff 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 bleedoff system. For coolers without bleedoff system it is a ratio of cooler water use to number of operating hours; for coolers with bleedoff system it is equal to cooler water use minus bleedoff divided by operating hours. For coolers without bleedoff, water use rate is the same as water evaporation rate.

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 non-radioactive 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 [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 [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 2003 [160699], Section 6.4.2.3) to estimate the concentration of radon in outdoor air is

$$C_{a,Rn-222,n=1\&2} = f_{m,Rn-222} C_{s_m,Ra-226} \quad (\text{Eq. 6-19})$$

where

$C_{a,Rn-222,n=1\&2}$	=	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)
$C_{s_m,Ra-226}$	=	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 [155894], p. 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 [158644], p. 115; NCRP 1999 [155894], pp. 87 to 88) and the average global activity concentration of ^{222}Rn in the air is 10 Bq/m³ (UNSCEAR 2000 [158644], p. 103; NCRP 1999 [155894], pp. 87 to 88). Based on these values, the conversion factor is equal to 0.25 (Bq/m³)/(Bq/kg). The information in the reviewed literature is insufficient to determine the uncertainty distribution for this value. Similar approach, using a fixed value is also recommended for the screening dose calculations (NCRP 1999 [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 modern 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. Generally, the radon emanation factor is inversely proportional to grain size because of radionuclide sorption or co-precipitation with metal oxides or organic compounds on particle surfaces (UNSCEAR 2000 [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 6-19 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, $CF_{\text{Rn-222}}$ as

$$Ca_{g, \text{Rn-222}} = CF_{\text{Rn-222}} J_{\text{outdoor}} \quad (\text{Eq. 6-20})$$

where

$$\begin{aligned} Ca_{g, \text{Rn-222}} &= {}^{222}\text{Rn activity concentration in the air (Bq/m}^3\text{)} \\ CF_{\text{Rn-222}} &= \text{ratio of } {}^{222}\text{Rn concentration in outdoor air to } {}^{222}\text{Rn flux density from soil} \\ &\quad \text{(s/m)} \\ J_{\text{outdoor}} &= \text{radon flux density from contaminated soil [Bq/(m}^2\text{ s)]}. \end{aligned}$$

The global average flux density is estimated to be about 16 mBq/m²/s (UNSCEAR 2000 [158644], p. 99). For dry soil, calculations of radon flux density produce a higher value of 33 mBq/m²/s (UNSCEAR 2000 [158644], p. 99), which also agrees with measured values. Modeling of global radon fluxes also yields the higher value of 34 ± 9 mBq/m²/s (Schery and Wasiolek 1998 [160686], p. 207). Because the average activity concentration of ^{226}Ra in air is 10 Bq/m³ (as noted in the previous paragraph) the value of $CF_{\text{Rn-222}}$ can be calculated to be about

300 s/m for the flux density equal to 33 to 34 mBq/m²/s. Accordingly, the best estimate of the ratio of ²²²Rn concentration in outdoor air to ²²²Rn flux density from soil is 300 s/m. This value agrees with the approach presented in the RESRAD code manual (Yu et al. 2001 [159465], p. C-9), where 500 s/m is given as the upper limit for the 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 modern 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 fraction, and the subsequent transport through the pore spaces. For the volcanic ash exposure scenario, the ²²²Rn flux density for a surface source of unit surface activity concentration (1 Bq/m²) 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 fraction varies from 0.05 to 0.7 for rocks and soils (UNSCEAR 2000 [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 fraction 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 towards its foundations 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, if present. There is evidence that a large part of indoor radon comes from the soil below and around buildings (Wilkening 1985 [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 [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 no direct contact of the building with the soil.

The indoor radon concentration is represented in the biosphere model (BSC 2003 [160699], Section 6.4.2.3) as the sum of the indoor and outdoor components, such that

$$Ca_{g, Rn-222, n=3\&4} = \frac{J_{indoor}}{v H} + Ca_{g, Rn-222, n=1\&2} \quad (\text{Eq. 6-21})$$

where

$$\begin{aligned} Ca_{g, Rn-222, n=3\&4} &= \text{activity concentration of } ^{222}\text{Rn in indoor air } (n = 3 \text{ and } 4 \text{ for active indoor and asleep indoor; defined in Equation 6.4.2-2) (Bq/m}^3) \\ J_{indoor} &= \text{radon flux density from the house floor (Bq/(m}^2 \text{ sec))} \\ H &= \text{interior wall height of the house (m)} \\ v &= \text{house ventilation rate, or air exchange rate (/sec). This parameter has two values, a normal rate } (v_n) \text{ and a higher rate used when evaporative coolers are in operation } (v_e) \\ Ca_{g, Rn-222, n=1\&2} &= ^{222}\text{Rn activity concentration in outdoor air } (n = 1 \text{ and } 2) (Bq/m}^3). \end{aligned}$$

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 2003 [160699], Section 6.4.2.3), as

$$J_{indoor} = f_{house} \times J_{outdoor} \quad (\text{Eq. 6-22})$$

where

$$\begin{aligned} J_{outdoor} &= \text{radon flux density from outdoor contaminated soil (Bq/(m}^2 \text{ s))} \\ f_{house} &= \text{fraction of radon released into a house from soil beneath the house (dimensionless).} \end{aligned}$$

Indoor radon concentration is calculated in the biosphere model (BSC 2003 [160699], Section 6.4.2.3) as

$$\begin{aligned} Ca_{g, Rn-222, n=3\&4} &= Ca_{g, Rn-222, n=1\&2} \left(\frac{f_{house}}{v H} \frac{J_{outdoor}}{Ca_{g, Rn-222, n=1\&2}} + 1 \right) \\ &= Ca_{g, Rn-222, n=1\&2} \left(\frac{f_{house}}{CF_{Rn-222} v H} + 1 \right) \end{aligned} \quad (\text{Eq. 6-23})$$

where

$$CF_{Rn-222} = \text{ratio of radon concentration in outdoor air to radon flux density from soil (s/m).}$$

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, v , 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 6.6.1 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 [160555]). As the maximum height according to the NAHB data (NAHB Research Center 1998 [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 [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) [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 [160557], p. 24). The nationwide survey of 3,000 households for air exchange rates provided the best available experimental data for residential structures in the United States (Murray and Burmaster 1995 [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 [160554], pp. 459 and 462 to 463

The experimental data on air exchange rates are fitted best with lognormal distributions (Murray and Burmaster 1995 [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 ft³ 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 [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 in Amargosa Valley. It is therefore recommended that the annual average ventilation rate for the fraction of a year when 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 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 [158644], pp. 99 to 102; United Nations 1988 [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/m²/s (United Nations 1988 [159566], p. 65) and the radon flux density from uncovered soil of 1.7×10^{-2} Bq/m²/s (United Nations 1988 [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 [159566], p. 65; Landman 1982 [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 [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, F_{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 [158644], p. 103). The EEC can be calculated as

$$Ca_{eq,Rn-222} = F_{Rn-222} Ca_{g,Rn-222} \quad (\text{Eq. 6-24})$$

where

$$\begin{aligned} Ca_{eq,Rn-222} &= \text{EEC for } ^{222}\text{Rn in air (Bq/m}^3\text{)} \\ F_{Rn-222} &= \text{equilibrium factor (dimensionless)} \\ Ca_{g,Rn-222} &= ^{222}\text{Rn activity concentration in air (Bq/m}^3\text{)}. \end{aligned}$$

EEC can then be converted to PAEC in working levels (WL) (UNSCEAR 2000 [158644], p. 103) using

$$1 \text{ Bq/m}^3 \text{ of EEC of } ^{222}\text{Rn is equivalent to 0.27 mWL of PAEC.}$$

Extensive measurements of the equilibrium factor indicate that typical outdoor ^{222}Rn equilibrium factors are between 0.5 and 0.7 (UNSCEAR 2000 [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 [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 [153691], p. 24). More recent measurements indicate that a value of 0.6 might be more appropriate for outdoor environments (UNSCEAR 2000 [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 [163507], Table 2), which is within the range of typical values from UNSCEAR (2000, [158644]). Table 6-70 shows values for the equilibrium factor from six rural sites in New Mexico (Wasiolek and James 1995 [163507]). The average of these six equilibrium factors is 0.61, which agrees well with the values summarized by UNSCEAR (2000 [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 [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 insolation 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 [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 [158644], p. 104; United Nations 1988 [159566], p. 75). Indoor measurements range from 0.1 to 0.9, but most are within 30 percent of 0.4 (UNSCEAR 2000 [158644], p. 104), that is, in the range of about 0.3 to 0.5. The 1998 report (United Nations 1988 [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 [159566], p. 105), which agrees with the UNSCEAR (2000 [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 modern 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. 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, $^{14}\text{CO}_2$ 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 [159468] 2001, T3FM/WD01, p. 48). CO_2 , and thus $^{14}\text{CO}_2$, 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 2003 [160699], Section 6.4.6.1):

$$C_{S_{C-14},j} = \frac{C_{W_{C-14}} IR_j}{\lambda_{d,C-14} + \lambda_{l,C-14} + \lambda_e + \lambda_{a,C-14}} \quad (\text{Eq. 6-25})$$

where

- $C_{S_{C-14},j}$ = 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
- $C_{W_{C-14}}$ = 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)
- $\lambda_{d,C-14}$ = radioactive decay constant for ^{14}C (per yr)
- $\lambda_{l,C-14}$ = leaching removal constant for ^{14}C (per yr)
- λ_e = the surface soil erosion removal constant (per yr)
- $\lambda_{a,C-14}$ = emission rate constant of ^{14}C from the soil to the air (per yr).

The only parameter supporting Equation 6-25 that is developed in this analysis is the ^{14}C emission rate constant, $\lambda_{a,C-14}$. 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 [159545], p. 491). The emission rate of carbon from soil does not depend very strongly on soil type (Davis et al. 1993 [103767], p. 156). Information on emission rates of carbon that is not of organic

origin is very limited (Davis et al. 1993 [103767], p. 156). The average value for sandy soils obtained from lysimeter experiments on Canadian soils was 21 to 22 y⁻¹ (Davis et al. 1993 [103767], p. 156; Yu et al. 2001 [159465], p. L-16). The values for other soils were lower by about a factor of 2. The default value of the emission rate constant adopted for the RESRAD model was 22 y⁻¹ (Yu et al. 2001 [159465], p. L-16). For the BIOTRAC model, a lognormal distribution of emission rate constant for carbon with the GM of 8.8 y⁻¹ and a GSD of 10 was chosen (Davis et al. 1993 [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 [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 [159465], p. L-16). Therefore, it is believed that the experimental data are insufficient to develop a distribution and the fixed value of 22 y⁻¹ measured for sandy soil is appropriate for use in the biosphere model.

6.7.2 Carbon-14 in Air

Inorganic and organic reactions convert most forms of soil carbon to carbon dioxide, CO₂ (Yu et al. 2001 [159465], p. L-15). Due to the volatility of CO₂, carbon is lost from the soil to the air. The flux density for gaseous ¹⁴C release from soil to air can be estimated (BSC 2003 [160699], Section 6.4.6.2) as

$$EVS N_j = Cs_{C-14,j} \lambda_{a,C-14} \quad (\text{Eq. 6-26})$$

where

$$\begin{aligned} EVS N_j &= \text{average flux density of gaseous } ^{14}\text{C from contaminated soil for the crop} \\ &\quad \text{exposure pathway } j \text{ (Bq/(m}^2 \text{ yr))} \\ Cs_{C-14,j} &= ^{14}\text{C activity concentration in surface soil for crop or exposure pathway } j \\ &\quad \text{(Bq/m}^2\text{)}. \end{aligned}$$

The ¹⁴C flux density calculated using Eq. 6-26 applies to irrigated land only. Once released into the air, ¹⁴C will be diluted by mixing with uncontaminated air. The ¹⁴C activity concentration in air can be estimated (BSC 2003 [160699], Section 6.4.6.2) as

$$Ca_{g,C-14,j} = \frac{EVS N_j \times \sqrt{A}}{3.16 \times 10^7 H_{mix} U} \quad (\text{Eq. 6-27})$$

where

$$\begin{aligned} Ca_{g,C-14,j} &= \text{activity concentration of } ^{14}\text{C in the air for the crop type or exposure} \\ &\quad \text{pathway } j \text{ (Bq/m}^3\text{)} \\ A &= \text{surface area of land irrigated with contaminated water, m}^2 \\ H_{mix} &= \text{mixing height of gaseous } ^{14}\text{C (CO}_2\text{), m} \\ U &= \text{annual average wind speed, m/s} \\ 3.16 \times 10^7 &= \text{unit conversion factor based on } 1 \text{ yr} = 365.25 \text{ d (sec/yr)} \end{aligned}$$

This analysis develops the values of A , H_{mix} , and U used in Equation 6-27.

The surface area of land irrigated with contaminated water, A , can be estimated using the volume of contaminated water based on an annual water demand of 3,000 acre-feet (about $3,714,450,000 \text{ L} = 3,714,450 \text{ m}^3$), as defined by the NRC rule (10 CFR 63.312(c) [156605]), and the average irrigation rate for agricultural land developed for the biosphere model (BSC 2003 [160976]). The average annual irrigation rate for the modern climate is 1.06 m/yr, with a standard error of 0.09 m/yr, a minimum of 0.83 m/yr, and a maximum of 1.29 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 2003 [160976], Section 7). Both distributions are normal. The resulting surface area of land irrigated with contaminated water is then equal to about $3.5 \times 10^6 \text{ m}^2$ for the modern climate and about $7.4 \times 10^6 \text{ m}^2$ for the future climate. The actual surface area of the land that is currently irrigated in Amargosa Valley is around 2,100 acres ($8.5 \times 10^6 \text{ m}^2$) (CRWMS M&O 1997 [101090], pp. 3-18 to 3-19; YMP 1999 [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 [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: MO9811DEDCRMCR.000 [148887]; CRWMS M&O 1997 [100117], p. A-11). 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 [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 6-27 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 [103784], p. 48) or higher (Stull 2001 [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 [159533], p. 377; Randerson 1984 [109153], p. 169) as

$$U = \frac{u^*}{k} \ln \left(\frac{z}{z_0} \right) \quad (\text{Eq. 6-28})$$

where

U	=	average wind speed at height z (m/s)
u^*	=	friction velocity (m/s)
k	=	von Karman constant (dimensionless)
z	=	height above ground (m)
z_0	=	aerodynamic surface length (m) (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 6-28 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 [159533], Figure 9.6, p.380; Sehmel 1984 [158693], p. 562). The value of k is in the range of 0.35 to 0.4 (Stull 2001 [159533], p. 377). The wind profiles for various values of z_0 , u^* (calculated for a given z_0 using Equation 6-28) and k are shown in Table 6-71. Varying k does not change wind profiles, because u^* also changes by same factor.

The average wind speed, $\bar{U}$, 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

$$\bar{U} = \frac{\int_{z_0}^{H_{mix}} \frac{u^*}{k} \ln \frac{z}{z_0} dz}{H_{mix} - z_0} = \frac{u^*}{k} \left[H_{mix} \left(\ln \frac{H_{mix}}{z_0} - 1 \right) + z_0 \right] \quad (\text{Eq. 6-29})$$

The average values of wind speed in the mixing cells for two mixing heights of gaseous $^{14}\text{CO}_2$, 1 m and 2 m, calculated using Equation 6-29 are also listed in Table 6-71. The values shown in Table 6-71 were calculated using Excel spreadsheet, as explained in Attachment II.

Table 6-71. Wind Profile in the Surface Boundary Layer

Parameter values for Equation 6-28					
$k = 0.35$		$k = 0.35$		$k = 0.35$	
$u^* = 0.223$		$u^* = 0.248$		$u^* = 0.334$	
$z_o = 0.01$		$z_o = 0.02$		$z_o = 0.1$	
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_o	
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

NOTES: Calculated in Excel spreadsheet using Equations 6-28 and 6-29, as explained in Attachment II.

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 from 1.5 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 [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 2003 [160699], Section 6.4.6.3) as

$$Cp_{C-14,j} = fc_{plant,j} \left[\left(Fa \frac{Ca_{g,C-14,j}}{fc_{air}} \right) + \left(Fs \frac{Cs_{C-14,j}}{\rho_s fc_{soil}} \right) \right] \quad (\text{Eq. 6-29})$$

where

$Cp_{C-14,j}$	=	activity concentration of ^{14}C in edible parts of crop type j (Bq/kg _{wet weight})
$fc_{plant,j}$	=	fraction of stable carbon in crop type j (dimensionless, based on kg _{carbon} / kg _{wet crop})
Fa	=	fraction of air-derived carbon in plants, dimensionless
$Ca_{g,C-14,j}$	=	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
$Cs_{C-14,j}$	=	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. 6-29.

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 (fresh) weight 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 [157927], p. 4.88). The same values were adopted for the RESRAD model (Yu et al. 2001 [159465], p. L-20). It is recommended that the biosphere model also use these values.

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 [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 [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 [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 [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 [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/m³ for the biosphere model. This value is recommended as a default value for the RESRAD model (Yu et al. 2001 [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 [158519], p. 144), and it agrees well with the default value of 1.6×10^{-4} kg/m³ used in the GENII and GENII-S models (Napier et al. 1988 [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 [159465], p. L-17) as well as the GENII and GENII-S models (Napier et al. 1988 [157927], p. 4.88).

6.7.4 Carbon-14 in Animal Products

The transfer of ¹⁴C from the animal diet to the animal product follows the same route as that of stable carbon. The ¹⁴C activity concentration in an animal product is calculated in the biosphere model using the following formula (BSC 2003 [160699], Section 6.4.6.4):

$$Cd_{C-14,k} = \frac{(Cp_{C-14,j} \times Qf_k) + (Cw_{C-14} \times Qw_k) + (Cs_{C-14} \times Qs_k)}{(fc_{plant,j} \times Qf_k) + (fc_{water} \times Qw_k) + (fc_{soil} \times Qs_k)} \times fc_{anim,k} \quad (\text{Eq. 6-30})$$

where

- $Cd_{C-14,k}$ = activity concentration of ¹⁴C in animal product k (Bq/kg)
- Cw_{C-14} = activity concentration of ¹⁴C 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 carbon/kg animal product)

and the other parameters are defined in Equations 6.4.4-1 to 6.4.4-4, 6.4.6-1, and 6.4.6-6.

The other parameters were defined in Equations 6-9 to 6-11.

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 [157927], p. 4.88; Yu et al. 2001 [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 [103767], p. 262). Because this parameter appears in the denominator of Equation 6.32, the greater values are less conservative. Therefore, 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 [157927], p. 4.88). The RESRAD model uses the same values as the GENII model (Yu et al. 2001 [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 1.2×10^{-1} to 2.5×10^{-1} (Zach et al. 1996 [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 TSPA-LA.

6.8 CRITICAL THICKNESS

The critical thickness is the parameter that is used only for the volcanic ash exposure scenario for predictions of 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 non-cultivated land is calculated as (BSC 2003 [160699], Section 6.5.1.2)

$$Cs_{mc,i}(d_a) = \begin{cases} \frac{Cs_i}{\rho_a \times d_c} = Cs_{mc,i} & \text{when } d_a < d_c \\ \frac{Cs_i}{\rho_a \times d_a} = \frac{Cs_i}{\rho_a \times d_c} \frac{d_c}{d_a} = Cs_{mc,i} \frac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \quad (\text{Eq. 6-31})$$

where

- $Cs_{mc,i}(d_a)$ = activity concentration of radionuclide i in volcanic ash or in the mix of ash and dust of non-cultivated land (Bq/kg)
- Cs_i = activity concentration of radionuclide i in ash deposited on the ground surface (Bq/m²)
- ρ_a = bulk density of volcanic ash (kg/m³)
- d_c = critical thickness for resuspension on non-cultivated lands (m)
- d_a = thickness of ash deposited on the ground (m)
- $Cs_{mc,i}$ = 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 2003 [161239]).

Equation 6-31 was rewritten as

$$Cs_{mc,i}(d_a) = Cs_{mc,i} \times f(d_a) \quad (\text{Eq. 6-32})$$

where $f(d_a)$, a function of volcanic ash thickness (dimensionless), can be expressed as

$$f(d_a) = \begin{cases} 1 & \text{when } d_a < d_c \\ \frac{d_c}{d_a} & \text{when } d_a \geq d_c \end{cases} \quad (\text{Eq. 6-33})$$

where other parameters were defined in Equation 6-31.

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 ($f(d_a) = 1$) 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 ($f(d_a) = \frac{d_c}{d_a}$). 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 [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 [160672]). The value of the resuspendable layer thickness was 0.3 cm (3 mm) (McCartin and Lee 2001 [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. Under normal, variable wind conditions, the initial, predicted thickness of tephra deposit 20 km south of Yucca Mountain, calculated for the *Total System Performance Assessment for the Site Recommendation* (CRWMS M&O 2000 [153246], Section 3.10.5.1), ranged from less than 1×10^{-8} cm to about 10 cm. About 66 percent of predicted depths were less than 0.1 mm, about 80 percent were less than 1 mm, and about 95 percent were less than 1 cm. The location of the

receptor considered for the TSPA analysis in support of an LA may differ from that used for the site recommendation (based on requirements in 10 CFR 63.302). Thus, ash thickness at the receptor location may be slightly different than that reported in the *Total System Performance Assessment for the Site Recommendation* (CRMWS M&O 2000 [153246], Section 3.10.5.1). 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 [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 [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 depth of more than 1 cm within a few months (Anspaugh et al. 1975 [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. The recommendations are included in the data set titled *Environmental Transport Input Parameters for the Biosphere Model*, DTN: MO0306SPAETPBM.001.

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 RADIONUCLIDE TRANSPORT TO CROPS

7.1.1 Soil-to-plant Transfer Factors for Leafy Vegetables

The soil-to-plant TFs for leafy vegetables in the modern climate, groundwater exposure scenario are listed in Table 7-1.

Table 7-1. Soil-to-plant Transfer Factors for Leafy Vegetables, Modern 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	1.2E-01	2.5	1.2E-02	1.2E+00
Lead	1.5E-02	4.6	3.0E-04	7.7E-01
Radium	6.8E-02	2.7	5.1E-03	9.2E-01
Actinium	4.3E-03	2.0	7.2E-04	2.6E-02
Thorium	4.3E-03	2.8	3.2E-04	5.9E-02
Protactinium	4.6E-03	3.8	1.4E-04	1.4E-01
Uranium	1.1E-02	2.0	1.8E-03	6.6E-02
Neptunium	5.9E-02	4.4	1.3E-03	2.6E+00
Plutonium	2.9E-04	2.0	4.9E-05	1.7E-03
Americium	1.2E-03	2.5	1.2E-04	1.3E-02

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.

7.1.2 Soil-to-plant Transfer Factors for Other Vegetables

The soil-to-plant TFs for other vegetables in the modern climate, groundwater exposure scenario are listed in Table 7-2.

Table 7-2. Soil-to-plant Transfer Factors for Other Vegetables, Modern 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.

7.1.3 Soil-to-plant Transfer Factors for Fruit

The soil-to-plant TFs for fruit in the modern climate, groundwater exposure scenario are listed in Table 7-3.

Table 7-3. Soil-to-plant Transfer Factors for Fruit, Modern 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.

7.1.4 Soil-to-plant Transfer Factors for Grain (Chicken Feed)

The soil-to-plant TFs for grain in the modern climate, groundwater exposure scenario are listed in Table 7-4.

Table 7-4. Soil-to-plant Transfer Factors for Grain (Chicken Feed), Modern 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.

7.1.5 Soil-to-plant Transfer Factors for Forage Crops

The soil-to-plant TFs for forage crops in the modern climate, groundwater exposure scenario are listed in Table 7-5.

Table 7-5. Soil-to-plant Transfer Factors for Forage Crops, Modern 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.

7.1.6 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 modern climate and future climate under the groundwater exposure scenario, and for the volcanic ash exposure scenario.

7.1.7 Dry Deposition Velocity

Deposition velocity for the modern 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.

7.1.8 Translocation Factor

It is recommended that the translocation factor for the modern 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
Root 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 dairy cows	1.0

7.1.9 Weathering Half-Time

The weathering half-time (called the weathering half-life in the biosphere model) for modern 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%), (14 days; 50%), (30 days; 100%).

7.2 RADIONUCLIDE TRANSPORT TO ANIMAL PRODUCTS

7.2.1 Animal Consumption Rates of Water, Feed, and Soil

The animal consumption rates of water, feed, and soil for the modern climate, groundwater exposure scenario 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 dairy 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

7.2.2 Transfer Coefficients for Meat

The animal intake-to-animal product TCs for meat in the modern climate, groundwater exposure scenario are listed in Table 7-8.

Table 7-8. Transfer Coefficients for Meat, Modern 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.

7.2.3 Transfer Coefficients for Poultry

The animal intake-to-animal products TCs for poultry in the modern climate, groundwater exposure scenario are listed in Table 7-9.

Table 7-9. Transfer Coefficients for Poultry, Modern 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.

7.2.4 Transfer Coefficients for Milk

The animal intake-to-animal products TCs for milk in the modern climate, groundwater exposure scenario are listed in Table 7-10.

Table 7-10. Transfer Coefficients for Milk, Modern 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/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.

7.2.5 Transfer Coefficients for Eggs

The animal intake-to-animal product TCs for eggs in the modern climate, groundwater exposure scenario are listed in Table 7-11.

Table 7-11. Transfer Coefficients for Eggs, Modern 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	5.9E-01	2.3	7.2E-02	4.8E+00
Lead	5.6E-02	10.0	1.5E-04	2.1E+01
Radium	3.9E-04	10.0	1.0E-06	1.5E-01
Actinium	2.9E-03	2.3	3.4E-04	2.5E-02
Thorium	3.5E-03	7.3	2.0E-05	5.9E-01
Protactinium	2.0E-03	2.0	3.4E-04	1.2E-02
Uranium	6.3E-01	2.5	6.0E-02	6.7E+00
Neptunium	3.4E-03	2.4	3.4E-04	3.3E-02
Plutonium	1.7E-03	7.4	9.7E-06	2.9E-01
Americium	4.9E-03	2.0	8.2E-04	2.9E-02

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.

7.3 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 modern and future climates are summarized in Table 7-12. These 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. The Values of Bioaccumulation Factor and the 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	Modern 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	1.2E+03		
Strontium	4.6E+01	2.0	7.8E+00	2.8E+02		
Technetium	2.0E+01	2.0	3.3E+00	1.2E+02		
Tin	2.5E+03	2.0	4.2E+02	1.5E+04		
Iodine	4.5E+01	2.6	3.8E+00	5.3E+02		
Cesium	3.5E+03	2.2	4.7E+02	2.5E+04		
Lead	2.9E+02	2.5	2.7E+01	3.1E+03		
Radium	6.7E+01	2.2	9.2E+00	5.0E+02		
Actinium	2.9E+01	3.0	1.7E+00	5.0E+02		
Thorium	1.1E+02	2.5	1.0E+01	1.2E+03		
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		

7.4 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 modern 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.

7.4.1 Airflow Rate

Airflow rate for evaporative coolers is represented by a piece-wise linear cumulative distribution represented by the following points:

$$(1,700 \text{ m}^3/\text{h}; 0\%), (8,300 \text{ m}^3/\text{h}; 50\%), (10,200 \text{ m}^3/\text{h}; 100\%)$$

7.4.2 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.

Correlation coefficient between the water evaporation rate and airflow rate for evaporative coolers is equal to 0.8.

7.4.3 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.

7.5 EXHALATION OF RADON FROM SOIL

7.5.1 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 $0.25 \text{ (Bq/m}^3\text{)/(Bq/kg)} = 0.25 \text{ kg/m}^3$. This value is appropriate for the groundwater exposure scenario for the modern and future climates.

7.5.2 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 $300 \text{ (Bq/m}^3\text{)/(Bq/(m}^2 \text{ s))} = 300 \text{ s/m}$. This value is appropriate for the volcanic ash exposure scenario for the modern and future climates.

7.5.3 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 modern and future climates and for the groundwater and volcanic ash exposure scenarios.

7.5.4 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 log-normal 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 modern and future climates and for the groundwater and volcanic ash exposure scenarios.

7.5.5 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%), (2.3 m; 50%), (2.7 m; 100%).

This distribution is appropriate for the modern and future climates and for the groundwater and volcanic ash exposure scenarios.

7.5.6 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 modern and future climates and for the groundwater and volcanic ash exposure scenarios.

7.6 CARBON-14 TRANSPORT IN THE ENVIRONMENT

Parameter values for the ^{14}C submodel developed in this analysis apply to the groundwater exposure scenario.

7.6.1 Carbon Emission Rate from Soil

A fixed value of 22 y^{-1} is recommended for the emission rate of carbon from soil for the modern and future climates.

7.6.2 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 ($3,714,450 \text{ m}^3$) to the average annual irrigation rate for the modern and future climates.

7.6.3 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.

7.6.4 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 from 1.5 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.

7.6.5 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 modern and future climates.

7.7 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).

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 stable carbon in chicken feed	0.40
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

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8.2 DATA TRACKING NUMBERS CITED

- 160653 MO0211SPADIMEN.005. Dimensions of Catfish Ponds in Amargosa Valley. Submittal date: 11/05/2002.
- 162452 MO0303SEPFEPS2.000. LA FEP List. Submittal date: 03/26/2003.
- 148887 MO9811DEDCRMCR.000. Data Reported in the Engineering Design Climatology and Regional Meteorology Conditions Report. Submittal date: 11/12/98.
- 150856 SN0006T0502900.002. Updated Igneous Consequence Data for Total System Performance Assessment-Site Recommendation (TSPA-SR). Submittal date: 06/15/2000.

8.3 CODES, STANDARDS, AND REGULATIONS

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

160555 24 CFR 3280. Housing and Urban Development: Manufactured Home Construction and Safety Standards. Readily available.

8.4 CITED PROCEDURES

159604 AP-2.27Q, Rev. 0, ICN 0. *Planning for Science Activities*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020701.0184.

8.5 ANALYSIS OUTPUT

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

ATTACHMENT I
**CALCULATION OF SOIL-TO-PLANT TRANSFER FACTORS, ANIMAL INTAKE-TO-
ANIMAL PRODUCT TRANSFER COEFFICIENTS, AND BIOACCUMULATION
FACTORS FOR AQUATIC FOOD**

CALCULATION OF TRANSFER FACTORS, TRANSFER COEFFICIENTS AND BIOACCUMULATION FACTORS

**File name: *Calculation of TFs TCs and BF.s.xls*
and *Calculation of TFs TCs and BF.s Formulas.xls***

Hardware used to Conduct Calculations—Dell Precision Workstation 530, Microsoft Windows 2000, CPU# 151554.

Description of the File—The Microsoft Excel 97 SR-2 workbook *Calculation of TFs TCs and BF.s.xls* consists of 10 worksheets, containing information presented in Table I-1.

Table I-1. Description of the *Calculation of TFs TCs and BF.s.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 through 6-7
Other Vegetables	Ditto for other vegetables	6-8 through 6-13
Fruit	Ditto for fruit	6-14 through 6-19
Grain	Ditto for grain	6-20 through 6-25
Pasture	Ditto for forage plants	6-26 through 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 through 6-44
Poultry	Ditto for poultry	6-46 through 6-51
Milk	Ditto for milk	6-52 through 6-57
Eggs	Ditto for eggs	6-58 through 6-63
Fish	Calculation of GM and GSD for bioaccumulation factors for freshwater fish based on values from references.	6-64 and 6-65

The companion workbook *Calculation of TFs TCs and BF.s Formulas.xls* contains the formula view of the workbook *Calculation of TFs TCs and BF.s.xls*.

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 $x_1, x_2, \dots, x_n$ was calculated by using the built-in Excel function GEOMEAN for the specified range of values.

- GSD of a set of values $x_1, x_2, \dots, x_n$, GSD, was calculated in the Excel spreadsheet using the following formula:

$$GSD = e^{STDEV(LN(x_1), LN(x_2), \dots, LN(x_n))} \quad (\text{Eq. I-1})$$

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:

$$\begin{aligned} \text{lower truncation} &= \frac{GM}{GSD^{2.576}} \\ \text{upper truncation} &= GM \times GSD^{2.576} \end{aligned} \quad (\text{Eq. I-2})$$

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.

Figure I-1a contains the image of the Excel 97 SR-2 spreadsheet *Leafy Vegetables* showing the calculation of the TFs for leafy vegetables for the biosphere model.

Figures I-1b and I-1c contain the images of the Excel 97 SR-2 spreadsheet *Leafy Vegetables* showing the formulas used to calculate the TFs for leafy vegetables for the biosphere model.

Figure I-2a contains the image of the Excel 97 SR-2 spreadsheet *Other Vegetables* showing the calculation of the TFs for other vegetables for the biosphere model.

Figures I-2b and I-2c contain the images of the Excel 97 SR-2 spreadsheet *Other Vegetables* showing the formulas used to calculate the TFs for other vegetables for the biosphere model.

Figure I-3a contains the image of the Excel 97 SR-2 spreadsheet *Fruit* showing the calculation of the TFs for fruits from the BIOMASS data.

Figure I-3b contains the image of the Excel 97 SR-2 spreadsheet *Fruit* showing the formulas used to calculate of the TFs for fruits from the BIOMASS data.

Figure I-3c contains the image of the Excel 97 SR-2 spreadsheet *Fruit* showing the calculation of the TFs for fruit for the biosphere model.

Figures I-3d and I-3e contain the images of the Excel 97 SR-2 spreadsheet *Fruit* showing the formulas used to calculate the TFs for fruit for the biosphere model.

Figure I-4a contains the image of the Excel 97 SR-2 spreadsheet *Grain* showing the calculation of the TFs for grain for the biosphere model.

Figures I-4b and I-4c contain the images of the Excel 97 SR-2 spreadsheet *Grain* showing the formulas used to calculate the TFs for grain for the biosphere model.

Figure I-5a contains the image of the Excel 97 SR-2 spreadsheet *Forage* showing the calculation of the TFs for forage crops for the biosphere model.

Figures I-5b and I-5c contain the images of the Excel 97 SR-2 spreadsheet *Forage* showing the formulas used to calculate the TFs for forage crops for the biosphere model.

Figure I-6a contains the image of the Excel 97 SR-2 spreadsheet *Meat* showing the calculation of the TCs for meat for the biosphere model.

Figures I-6b and I-6c contain the images of the Excel 97 SR-2 spreadsheet *Meat* showing the formulas used to calculate the TCs for meat for the biosphere model.

Figure I-7a contains the image of the Excel 97 SR-2 spreadsheet *Poultry* showing the calculation of the TCs for poultry for the biosphere model.

Figures I-7b and I-7c contain the images of the Excel 97 SR-2 spreadsheet *Poultry* showing the formulas used to calculate the TCs for poultry for the biosphere model.

Figure I-8a contains the image of the Excel 97 SR-2 spreadsheet *Milk* showing the calculation of the TCs for milk for the biosphere model.

Figures I-8b and I-8c contain the images of the Excel 97 SR-2 spreadsheet *Milk* showing the formulas used to calculate the TCs for milk for the biosphere model.

Figure I-9a contains the image of the Excel 97 SR-2 spreadsheet *Eggs* showing the calculation of the TCs for eggs for the biosphere model.

Figures I-9b and I-9c contain the images of the Excel 97 SR-2 spreadsheet *Eggs* showing the formulas used to calculate the TCs for eggs for the biosphere model.

Figures I-10a and I-10b contain the images of the Excel 97 SR-2 spreadsheet *Fish* showing the calculation of the bioaccumulation factors for fish for the biosphere model.

Figures I-10c and I-10d contain the images of the Excel 97 SR-2 spreadsheet *Fish* showing the formulas used to calculate the bioaccumulation factors for fish for the biosphere model.

The calculations can be reproduced by a qualified individual without recourse to the originator.

Microsoft Excel - Calculation of TFs TCs and BFs

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Figure I-1a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Leafy Vegetables

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

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	B	C	D	E	F	G	H	I	J
1	Soil-to-Plant Transfer Fa								
2	Leafy Vegetables								
3									
4	Reference		Tc	I	Np	Pu	Am	Cl	Se
5		0							
6	Baes et al. 1984, p. 10	1	9.5	0.15	0.1	0.00045	0.0055	70	0.025
7	IAEA 1994, pp. 17-25	2	180		0.046	0.000124	0.00036		
8	Kennedy and Strenge 1992, pp. 6.25-6.27	3	44	0.0034	0.013	0.00039	0.00058	70	0.025
9	LaPlante and Poor 1997, p. 2-13	4	76	0.0034	0.069	0.00034	0.0012		0.025
10	Rittmann 1993, p. 35-36	5	40	0.4	1	0.0004	0.002	50	0.5
11	Sheppard 1995, pp. 55-57	6		0.0032	0.046	0.00026	0.00082		
12	Till and Meyer 1983, pp. 5-50 - 5-51	7				0.000175			
13	Wang et al. 1993, pp. 25-26	8	40	0.15	0.013	0.00039	0.002	70	0.025
14	This analysis	9	=D15	=E15	=F15	=G15	=H15	=I15	=J15
15	Geomean	10	=GEOMEAN(D6:D13)	=GEOMEAN(E6:E13)	=GEOMEAN(F6:F13)	=GEOMEAN(G6:G13)	=GEOMEAN(H6:H13)	=GEOMEAN(I6:I13)	=GEOMEAN(J6:J13)
16	GeoSTD		=EXP(D31)	=EXP(E31)	=EXP(F31)	=EXP(G31)	=EXP(H31)	=EXP(I31)	=EXP(J31)
17	GeoSTD used					2		2	
18	Low 99%		=D15/(D16^2.576)	=E15/(E16^2.576)	=F15/(F16^2.576)	=G15/(G16^2.576)	=H15/(H16^2.576)	=I15/(I16^2.576)	=J15/(J16^2.576)
19	High 99%		=D15*(D16^2.576)	=E15*(E16^2.576)	=F15*(F16^2.576)	=G15*(G16^2.576)	=H15*(H16^2.576)	=I15*(I16^2.576)	=J15*(J16^2.576)
20									
21									
22		ln(x)	=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)	=LN(I6)	=LN(J6)
23			=LN(D7)	=LN(E7)	=LN(F7)	=LN(G7)	=LN(H7)		
24			=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)	=LN(I8)	=LN(J8)
25			=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)		=LN(J9)
26			=LN(D10)	=LN(E10)	=LN(F10)	=LN(G10)	=LN(H10)	=LN(I10)	=LN(J10)
27				=LN(E11)	=LN(F11)	=LN(G11)	=LN(H11)		
28						=LN(G12)			
29			=LN(D13)	=LN(E13)	=LN(F13)	=LN(G13)	=LN(H13)	=LN(I13)	=LN(J13)
30									
31		std(ln(x))	=STDEV(D22:D29)	=STDEV(E22:E29)	=STDEV(F22:F29)	=STDEV(G22:G29)	=STDEV(H22:H29)	=STDEV(I22:I29)	=STDEV(J22:J29)

Figure I-1b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Leafy Vegetables (Part 1)

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

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	K	L	M	N	O	P	Q	R	S
1									
2	Leafy Vegetables								
3									
4	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
5									
6	2.5	0.03	0.08	0.045	0.015	0.0035	0.00085	0.0025	0.0085
7	1.3		0.28	0.01	0.07		0.0018		0.0083
8	1.6	0.03	0.13	0.0058	0.075	0.0035	0.0066	0.0025	0.017
9	1.1	0.03	0.11	0.0011	0.08	0.0035	0.011	0.0025	0.023
10	2	0.1	0.02	0.1	0.1	0.01	0.004	0.05	0.004
11	2.15		0.15	0.015	0.023		0.016		0.021
12	2.2		0.41		0.44				
13	1.6	0.03	0.13	0.045	0.075	0.0035	0.004	0.0025	0.0085
14	=K15	=L15	=M15	=N15	=O15	=P15	=Q15	=R15	=S15
15	=GEOMEAN(K6:K13)	=GEOMEAN(L6:L13)	=GEOMEAN(M6:M13)	=GEOMEAN(N6:N13)	=GEOMEAN(O6:O13)	=GEOMEAN(P6:P13)	=GEOMEAN(Q6:Q13)	=GEOMEAN(R6:R13)	=GEOMEAN(S6:S13)
16	=EXP(K31)	=EXP(L31)	=EXP(M31)	=EXP(N31)	=EXP(O31)	=EXP(P31)	=EXP(Q31)	=EXP(R31)	=EXP(S31)
17	2	2				2			2
18	=K15/(2^2.576)	=L15/(2^2.576)	=M15/(M16^2.576)	=N15/(N16^2.576)	=O15/(O16^2.576)	=P15/(2^2.576)	=Q15/(Q16^2.576)	=R15/(R16^2.576)	=S15/(2^2.576)
19	=K15*(2^2.576)	=L15*(2^2.576)	=M15*(M16^2.576)	=N15*(N16^2.576)	=O15*(O16^2.576)	=P15*(2^2.576)	=Q15*(Q16^2.576)	=R15*(R16^2.576)	=S15*(2^2.576)
20									
21									
22	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)
23	=LN(K7)		=LN(M7)	=LN(N7)	=LN(O7)		=LN(Q7)		=LN(S7)
24	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)
25	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)
26	=LN(K10)	=LN(L10)	=LN(M10)	=LN(N10)	=LN(O10)	=LN(P10)	=LN(Q10)	=LN(R10)	=LN(S10)
27	=LN(K11)		=LN(M11)	=LN(N11)	=LN(O11)		=LN(Q11)		=LN(S11)
28	=LN(K12)		=LN(M12)		=LN(O12)				
29	=LN(K13)	=LN(L13)	=LN(M13)	=LN(N13)	=LN(O13)	=LN(P13)	=LN(Q13)	=LN(R13)	=LN(S13)
30									
31	=STDEV(K22:K29)	=STDEV(L22:L29)	=STDEV(M22:M29)	=STDEV(N22:N29)	=STDEV(O22:O29)	=STDEV(P22:P29)	=STDEV(Q22:Q29)	=STDEV(R22:R29)	=STDEV(S22:S29)
32									

Figure I-1c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Leafy Vegetables (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

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	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Soil-to-Plant Transfer Factors for Other Vegetables																	
2																		
3																		
4	Reference		Tc	I	Np	Pu	Am	Cl	Se	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
5		0																
6	Baes et al. 1984, p. 11	1	1.5E+00	5.0E-02	1.0E-02	4.5E-05	2.5E-04	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
7	IAEA 1994, pp. 17-25	2	4.3E+00	2.0E-02	2.1E-02	3.7E-04	5.2E-04			7.5E-01		5.1E-02	5.1E-03	6.5E-03		2.3E-04		1.2E-02
8	Kennedy and Strenge 1992, pp. 6.25-6.27	3	1.1E+00	5.0E-02	9.4E-03	2.0E-04	4.1E-04	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
9	LaPlante and Poor 1997, p. 2-13	4	1.1E+01	2.0E-02	2.7E-02	2.3E-04	4.7E-04		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
10	Rittmann 1993, p. 35-36	5	4.0E+01	4.0E-01	1.0E+00	4.0E-04	2.0E-03	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
11	Sheppard 1995, pp. 55-57	6	6.6E+00	1.9E-03	2.8E-02	1.6E-04	5.0E-04			1.3E+00		9.1E-02	9.2E-03	1.4E-02		1.0E-02		1.3E-02
12	Till and Meyer 1983, pp. 5-50 - 5-51	7		3.0E-02	4.0E-05	1.6E-04	6.4E-05			1.2E+00		4.2E-02		1.7E-01		2.2E-04		6.5E-04
13	Wang et al. 1993, pp. 25-26	8	1.5E+00	5.0E-02	1.7E-02	1.9E-04	4.1E-04	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
14	This analysis	9	4.4E+00	3.2E-02	3.1E-02	1.9E-04	4.0E-04	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
15	Geomean	10	4.4E+00	3.2E-02	3.1E-02	1.9E-04	4.0E-04	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
16	GeoSTD		3.7	4.4	4.9	2.0	2.6	1.2	3.8	2.0	3.6	1.7	3.1	5.3	4.9	5.6	10.3	2.8
17	GeoSTD used							2.0				2.0					10.0	
18	Low 99%		1.5E-01	7.0E-04	5.0E-04	3.3E-05	3.5E-05	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
19	High 99%		1.2E+02	1.5E+00	1.9E+00	1.1E-03	4.6E-03	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
20																		
21																		
22		ln(x)	4.1E-01	-3.0E+00	-4.6E+00	-1.0E+01	-8.3E+00	4.2E+00	-3.7E+00	-1.4E+00	-5.1E+00	-3.5E+00	-4.7E+00	-6.5E+00	-8.0E+00	-9.4E+00	-8.3E+00	-5.5E+00
23			1.5E+00	-3.9E+00	-3.9E+00	-7.9E+00	-7.6E+00			-2.9E-01		-3.0E+00	-5.3E+00	-5.0E+00		-8.4E+00		-4.4E+00
24			9.5E-02	-3.0E+00	-4.7E+00	-8.5E+00	-7.8E+00	4.2E+00	-3.7E+00	-2.1E-01	-5.1E+00	-3.0E+00	-5.7E+00	-5.7E+00	-8.0E+00	-9.0E+00	-8.3E+00	-4.3E+00
25			2.4E+00	-3.9E+00	-3.6E+00	-8.4E+00	-7.7E+00		-3.7E+00	-1.5E-01	-3.5E+00	-2.6E+00	-5.1E+00	-4.3E+00	-5.7E+00	-8.1E+00	-6.0E+00	-4.5E+00
26			3.7E+00	-9.2E-01	0.0E+00	-7.8E+00	-6.2E+00	3.9E+00	-6.9E-01	6.9E-01	-2.3E+00	-3.9E+00	-2.3E+00	-2.3E+00	-4.6E+00	-5.5E+00	-3.0E+00	-5.5E+00
27			1.9E+00	-6.3E+00	-3.6E+00	-8.7E+00	-7.6E+00			2.6E-01		-2.4E+00	-4.7E+00	-4.3E+00		-4.6E+00		-4.3E+00
28				-3.5E+00		-8.7E+00	-9.7E+00			1.8E-01		-3.2E+00		-1.8E+00		-8.4E+00		-7.3E+00
29			4.1E-01	-3.0E+00	-4.1E+00	-8.6E+00	-7.8E+00	4.2E+00	-3.7E+00	-9.9E-01	-5.1E+00	-2.3E+00	-5.2E+00	-5.7E+00	-8.0E+00	-8.5E+00	-8.3E+00	-5.1E+00
30																		
31		std(ln(x))	1.3E+00	1.5E+00	1.6E+00	6.7E-01	9.5E-01	1.7E-01	1.3E+00	6.8E-01	1.3E+00	5.4E-01	1.1E+00	1.7E+00	1.6E+00	1.7E+00	2.3E+00	1.0E+00
32																		

Figure I-2a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Other Vegetables

Microsoft Excel - Calculation of TFs TCs and BF's Formulas									
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	B	C	D	E	F	G	H	I	J
1	Soil-to-Plant Transfer Fa								
2	Other vegetables								
3									
4	Reference		Tc	I	Np	Pu	Am	Cl	Se
5		0							
6	Baes et al. 1984, p. 11	1	1.5	0.05	0.01	0.000045	0.00025	70	0.025
7	IAEA 1994, pp. 17-25	2	4.3	0.02	0.021	0.00037	0.00052		
8	Kennedy and Strenge 1992, pp. 6.25-6.27	3	1.1	0.05	0.0094	0.0002	0.00041	70	0.025
9	LaPlante and Poor 1997, p. 2-13	4	11	0.02	0.027	0.00023	0.00047		0.025
10	Rittmann 1993, p. 35-36	5	40	0.4	1	0.0004	0.002	50	0.5
11	Sheppard 1995, pp. 55-57	6	6.56	0.0019	0.028	0.00016	0.0005		
12	Till and Meyer 1983, pp. 5-50 – 5-51	7		0.03	0.00004	0.00016	0.000064		
13	Wang et al. 1993, pp. 25-26	8	1.5	0.05	0.017	0.00019	0.00041	70	0.025
14	This analysis	9	=D15	=E15	=F15	=G15	=H15	=I15	=J15
15	Geomean	10	=GEOMEAN(D6:D13)	=GEOMEAN(E6:E13)	=GEOMEAN(F6:F11,F13)	=GEOMEAN(G6:G13)	=GEOMEAN(H6:H13)	=GEOMEAN(I6:I13)	=GEOMEAN(J6:J13)
16	GeoSTD		=EXP(D31)	=EXP(E31)	=EXP(F31)	=EXP(G31)	=EXP(H31)	=EXP(I31)	=EXP(J31)
17	GeoSTD used							2	
18	Low 99%		=D15/(D16^2.576)	=E15/(E16^2.576)	=F15/(F16^2.576)	=G15/(G16^2.576)	=H15/(H16^2.576)	=I15/(I16^2.576)	=J15/(J16^2.576)
19	High 99%		=D15*(D16^2.576)	=E15*(E16^2.576)	=F15*(F16^2.576)	=G15*(G16^2.576)	=H15*(H16^2.576)	=I15*(I16^2.576)	=J15*(J16^2.576)
20									
21									
22		ln(x)	=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)	=LN(I6)	=LN(J6)
23			=LN(D7)	=LN(E7)	=LN(F7)	=LN(G7)	=LN(H7)		
24			=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)	=LN(I8)	=LN(J8)
25			=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)	=LN(I9)	=LN(J9)
26			=LN(D10)	=LN(E10)	=LN(F10)	=LN(G10)	=LN(H10)	=LN(I10)	=LN(J10)
27			=LN(D11)	=LN(E11)	=LN(F11)	=LN(G11)	=LN(H11)		
28			=LN(E12)			=LN(G12)	=LN(H12)		
29			=LN(D13)	=LN(E13)	=LN(F13)	=LN(G13)	=LN(H13)	=LN(I13)	=LN(J13)
30									
31		std(ln(x))	=STDEV(D22:D29)	=STDEV(E22:E29)	=STDEV(F22:F27,F29)	=STDEV(G22:G29)	=STDEV(H22:H29)	=STDEV(I22:I29)	=STDEV(J22:J29)

Figure I-2b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Other Vegetables (Part 1)

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

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Arial Narrow 10 B I U

542

	K	L	M	N	O	P	Q	R	S
1									
2	Other vegetables								
3									
4	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
5									
6	0.25	0.006	0.03	0.009	0.0015	0.00035	0.000085	0.00025	0.004
7	0.75		0.051	0.0051	0.0065		0.00023		0.012
8	0.81	0.006	0.049	0.0032	0.0032	0.00035	0.00012	0.00025	0.014
9	0.86	0.03	0.072	0.0064	0.013	0.0035	0.00031	0.0025	0.011
10	2	0.1	0.02	0.1	0.1	0.01	0.004	0.05	0.004
11	1.3		0.091	0.0092	0.014		0.01		0.013
12	1.2		0.042		0.17		0.00022		0.00065
13	0.37	0.006	0.098	0.0056	0.0035	0.00035	0.00021	0.00025	0.0064
14	=K15	=L15	=M15	=N15	=O15	=P15	=Q15	=R15	=S15
15	=GEOMEAN(K6:K13)	=GEOMEAN(L6:L13)	=GEOMEAN(M6:M13)	=GEOMEAN(N6:N13)	=GEOMEAN(O6:O13)	=GEOMEAN(P6:P13)	=GEOMEAN(Q6:Q13)	=GEOMEAN(R6:R13)	=GEOMEAN(S6:S13)
16	=EXP(K31)	=EXP(L31)	=EXP(M31)	=EXP(N31)	=EXP(O31)	=EXP(P31)	=EXP(Q31)	=EXP(R31)	=EXP(S31)
17			2				10		
18	=K15/(K16^2.576)	=L15/(L16^2.576)	=M15/(M16^2.576)	=N15/(N16^2.576)	=O15/(O16^2.576)	=P15/(P16^2.576)	=Q15/(Q16^2.576)	=R15/(R16^2.576)	=S15/(S16^2.576)
19	=K15*(K16^2.576)	=L15*(L16^2.576)	=M15*(M16^2.576)	=N15*(N16^2.576)	=O15*(O16^2.576)	=P15*(P16^2.576)	=Q15*(Q16^2.576)	=R15*(R16^2.576)	=S15*(S16^2.576)
20									
21									
22	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)
23	=LN(K7)		=LN(M7)	=LN(N7)	=LN(O7)		=LN(Q7)		=LN(S7)
24	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)
25	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)
26	=LN(K10)	=LN(L10)	=LN(M10)	=LN(N10)	=LN(O10)	=LN(P10)	=LN(Q10)	=LN(R10)	=LN(S10)
27	=LN(K11)		=LN(M11)	=LN(N11)	=LN(O11)		=LN(Q11)		=LN(S11)
28	=LN(K12)		=LN(M12)		=LN(O12)		=LN(Q12)		=LN(S12)
29	=LN(K13)	=LN(L13)	=LN(M13)	=LN(N13)	=LN(O13)	=LN(P13)	=LN(Q13)	=LN(R13)	=LN(S13)
30									
31	=STDEV(K22:K29)	=STDEV(L22:L29)	=STDEV(M22:M29)	=STDEV(N22:N29)	=STDEV(O22:O29)	=STDEV(P22:P29)	=STDEV(Q22:Q29)	=STDEV(R22:R29)	=STDEV(S22:S29)

Figure I-2c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Other Vegetables (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

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Figure I-3a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Fruit for the BIOMASS Data

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2														
3		Calculation	IAEA/BIOMASS TFs											
4			Cs		Sr		Pu		Am		I		U	
5			TF	ln(TF)	TF	ln(TF)	TF	ln(TF)	TF	ln(TF)	TF	ln(TF)	TF	
6			0.016	=LN(C6)	0.089	=LN(E6)	0.0016	=LN(G6)	0.00023	=LN(I6)	0.064	=LN(K6)	0.05	
7			0.036	=LN(C7)	0.13	=LN(E7)	0.0015	=LN(G7)	0.004	=LN(I7)	0.1	=LN(K7)		
8			0.1	=LN(C8)	0.36	=LN(E8)	0.00032	=LN(G8)	0.00033	=LN(I8)	0.058	=LN(K8)		
9			0.35	=LN(C9)	0.15	=LN(E9)	0.0014	=LN(G9)	0.0012	=LN(I9)	0.2	=LN(K9)		
10			0.0035	=LN(C10)	0.21	=LN(E10)	0.0011	=LN(G10)	0.0007	=LN(I10)				
11			0.017	=LN(C11)	0.14	=LN(E11)	0.0042	=LN(G11)	0.0036	=LN(I11)				
12			0.0086	=LN(C12)	0.45	=LN(E12)	0.0015	=LN(G12)	0.004	=LN(I12)				
13			0.028	=LN(C13)	0.07	=LN(E13)	0.00018	=LN(G13)	0.00028	=LN(I13)				
14			0.017	=LN(C14)	0.42	=LN(E14)								
15			0.0021	=LN(C15)	0.65	=LN(E15)								
16			0.035	=LN(C16)	0.1	=LN(E16)								
17			0.0027	=LN(C17)	0.12	=LN(E17)								
18			0.0085	=LN(C18)	0.1	=LN(E18)								
19														
20		Geomean	=GEOMEAN(C6:C18)		=GEOMEAN(E6:E18)		=GEOMEAN(G6:G13)		=GEOMEAN(I6:I13)		=GEOMEAN(K6:K9)			
21		std(ln x)	=STDEV(D6:D18)		=STDEV(F6:F18)		=STDEV(H6:H13)		=STDEV(J6:J13)		=STDEV(L6:L9)			
22		Geostdev	=EXP(D21)		=EXP(F21)		=EXP(H21)		=EXP(J21)		=EXP(L21)			
23														

Figure I-3b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Fruit for the BIOMASS Data

Microsoft Excel - Calculation of TFs TCs and BFs

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Figure I-3c. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Fruit

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

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Arial Narrow 10 B I U

166 =

	B	C	D	E	F	G	H	I	J
23									
24	Soil-to-Plant Transfer Factor	Fruit							
25	Reference	Tc	I	Np	Pu	Am	Cl	Se	
26		0							
27	Baes et al. 1984, p. 11	1	1.5	0.05	0.01	0.000045	0.00025	70	0.025
28	IAEA 1994, pp. 17-25	2		0.02					
29	BIOMASS 2001, pp. 82-92	3		0.093		0.001	0.001		
30	Kennedy and Streng 1992, pp. 6.25-6.27	4	1.5	0.05	0.01	0.000045	0.00025	70	0.025
31	LaPlante and Poor 1997, p. 2-13	5	11	0.02	0.027	0.00023	0.00047		0.025
32	Rittmann 1993, pp. 35-36	6	40	0.4	1	0.0004	0.002	50	0.5
33	Till and Meyer 1983, pp. 5-50 - 5-51	7							
34	Wang et al. 1993, pp. 25-26	8	1.5	0.05	0.017	0.00019	0.00041	70	0.025
35	This analysis	9	=D36	=E36	=F36	=G36	=H36	=I36	=J36
36	Geomean	10	=GEOMEAN(D27:D34)	=GEOMEAN(E27:E34)	=GEOMEAN(F27:F34)	=GEOMEAN(G27:G34)	=GEOMEAN(H27:H34)	=GEOMEAN(I27:I34)	=GEOMEAN(J27:J34)
37	GeoSTD		=EXP(D52)	=EXP(E52)	=EXP(F52)	=EXP(G52)	=EXP(H52)	=EXP(I52)	=EXP(J52)
38	GeoSTD used							2	
39	Low 99%		=D36/(D37^2.576)	=E36/(E37^2.576)	=F36/(F37^2.576)	=G36/(G37^2.576)	=H36/(H37^2.576)	=I36/(I37^2.576)	=J36/(J37^2.576)
40	High 99%		=D36*(D37^2.576)	=E36*(E37^2.576)	=F36*(F37^2.576)	=G36*(G37^2.576)	=H36*(H37^2.576)	=I36*(I37^2.576)	=J36*(J37^2.576)
41									
42									
43		ln(x)	=LN(D27)	=LN(E27)	=LN(F27)	=LN(G27)	=LN(H27)	=LN(I27)	=LN(J27)
44				=LN(E28)					
45				=LN(E29)		=LN(G29)	=LN(H29)		
46			=LN(D30)	=LN(E30)	=LN(F30)	=LN(G30)	=LN(H30)	=LN(I30)	=LN(J30)
47			=LN(D31)	=LN(E31)	=LN(F31)	=LN(G31)	=LN(H31)	=LN(I31)	=LN(J31)
48			=LN(D32)	=LN(E32)	=LN(F32)	=LN(G32)	=LN(H32)	=LN(I32)	=LN(J32)
49									
50			=LN(D34)	=LN(E34)	=LN(F34)	=LN(G34)	=LN(H34)	=LN(I34)	=LN(J34)
51									
52		std(ln(x))	=STDEV(D43:D50)	=STDEV(E43:E50)	=STDEV(F43:F50)	=STDEV(G43:G50)	=STDEV(H43:H50)	=STDEV(I43:I50)	=STDEV(J43:J50)
53									

Figure I-3d. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Fruit (Part 1)

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

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Arial Narrow 10 B I U

564

	K	L	M	N	O	P	Q	R	S
23									
24	Fruit								
25	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
26									
27	0.25	0.006	0.03	0.009	0.0015	0.00035	0.000085	0.00025	0.004
28	0.2		0.22						
29	0.18		0.017						0.05
30	0.17	0.006	0.22	0.009	0.0061	0.00035	0.000085	0.00025	0.004
31	0.2	0.03	0.072	0.0064	0.013	0.0035	0.00031	0.0025	0.011
32	2	0.1	0.02	0.1	0.1	0.003	0.004	0.05	0.004
33	0.24		0.026		0.0035				0.0017
34	0.37	0.006	0.098	0.0056	0.0035	0.00035	0.00021	0.00025	0.0064
35	=K36	=L36	=M36	=N36	=O36	=P36	=Q36	=R36	=S36
36	=GEOMEAN(K27:K34)	=GEOMEAN(L27:L34)	=GEOMEAN(M27:M34)	=GEOMEAN(N27:N34)	=GEOMEAN(O27:O34)	=GEOMEAN(P27:P34)	=GEOMEAN(Q27:Q34)	=GEOMEAN(R27:R34)	=GEOMEAN(S27:S34)
37	=EXP(K52)	=EXP(L52)	=EXP(M52)	=EXP(N52)	=EXP(O52)	=EXP(P52)	=EXP(Q52)	=EXP(R52)	=EXP(S52)
38							10		
39	=K36/(K37^2.576)	=L36/(L37^2.576)	=M36/(M37^2.576)	=N36/(N37^2.576)	=O36/(O37^2.576)	=P36/(P37^2.576)	=Q36/(Q37^2.576)	=R36/(10^2.576)	=S36/(S37^2.576)
40	=K36*(K37^2.576)	=L36*(L37^2.576)	=M36*(M37^2.576)	=N36*(N37^2.576)	=O36*(O37^2.576)	=P36*(P37^2.576)	=Q36*(Q37^2.576)	=R36*(10^2.576)	=S36*(S37^2.576)
41									
42									
43	=LN(K27)	=LN(L27)	=LN(M27)	=LN(N27)	=LN(O27)	=LN(P27)	=LN(Q27)	=LN(R27)	=LN(S27)
44	=LN(K28)		=LN(M28)						
45	=LN(K29)		=LN(M29)						=LN(S29)
46	=LN(K30)	=LN(L30)	=LN(M30)	=LN(N30)	=LN(O30)	=LN(P30)	=LN(Q30)	=LN(R30)	=LN(S30)
47	=LN(K31)	=LN(L31)	=LN(M31)	=LN(N31)	=LN(O31)	=LN(P31)	=LN(Q31)	=LN(R31)	=LN(S31)
48	=LN(K32)	=LN(L32)	=LN(M32)	=LN(N32)	=LN(O32)	=LN(P32)	=LN(Q32)	=LN(R32)	=LN(S32)
49	=LN(K33)		=LN(M33)		=LN(O33)				=LN(S33)
50	=LN(K34)	=LN(L34)	=LN(M34)	=LN(N34)	=LN(O34)	=LN(P34)	=LN(Q34)	=LN(R34)	=LN(S34)
51									
52	=STDEV(K43:K50)	=STDEV(L43:L50)	=STDEV(M43:M50)	=STDEV(N43:N50)	=STDEV(O43:O50)	=STDEV(P43:P50)	=STDEV(Q43:Q50)	=STDEV(R43:R50)	=STDEV(S43:S50)
53									

Figure I-3e. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Fruit (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

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Figure I-4a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Grain

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

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Arial Narrow 10 B I U

141

	B	C	D	E	F	G	H	I	J
1	Soil-to-Plant Transfer Factors								
2	Grain								
3									
4	Reference		Tc	I	Np	Pu	Am	Cl	Se
5		0							
6	Baes et al. 1984, p. 11	1	1.5	0.05	0.01	0.000045	0.00025	70	0.025
7	IAEA 1994, pp. 17-25	2	0.73		0.0027	0.0000086	0.000022		
8	Kennedy and Strenge 1992, pp. 6.25-6.27	3	0.73	0.05	0.0027	0.000026	0.000059	70	0.025
9	LaPlante and Poor 1997, p. 2-13	4	0.73	0.02	0.0027	0.0000086	0.000022		0.025
10	Rittmann 1993, pp. 35-36	5	40	0.4	0.1	0.00004	0.0002	1	0.05
11	Sheppard 1995, pp. 55-57	6	0.83	0.00024	0.0035	0.00002	0.00006		
12	Till and Meyer 1983, pp. 5-50 - 5-51	7			0.00012	0.0000015	0.000028		
13	Wang et al. 1993, pp. 25-26	8	1.5	0.05	0.017	0.00019	0.00041	70	0.025
14	This analysis	9	=D15	=E15	=F15	=G15	=H15	=I15	=J15
15	Geomean	10	=GEOMEAN(D6:D13)	=GEOMEAN(E6:E13)	=GEOMEAN(F6:F13)	=GEOMEAN(G6:G13)	=GEOMEAN(H6:H13)	=GEOMEAN(I6:I13)	=GEOMEAN(J6:J13)
16	GeoSTD		=EXP(D31)	=EXP(E31)	=EXP(F31)	=EXP(G31)	=EXP(H31)	=EXP(I31)	=EXP(J31)
17	GeoSTD used			10					2
18	Low 99%		=D15/(D16^2.576)	=E15/(10^2.576)	=F15/(F16^2.576)	=G15/(G16^2.576)	=H15/(H16^2.576)	=I15/(I16^2.576)	=J15/(J16^2.576)
19	High 99%		=D15*(D16^2.576)	=E15*(10^2.576)	=F15*(F16^2.576)	=G15*(G16^2.576)	=H15*(H16^2.576)	=I15*(I16^2.576)	=J15*(J16^2.576)
20									
21									
22		ln(x)	=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)	=LN(I6)	=LN(J6)
23			=LN(D7)		=LN(F7)	=LN(G7)	=LN(H7)		
24			=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)	=LN(I8)	=LN(J8)
25			=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)		=LN(J9)
26			=LN(D10)	=LN(E10)	=LN(F10)	=LN(G10)	=LN(H10)	=LN(I10)	=LN(J10)
27			=LN(D11)	=LN(E11)	=LN(F11)	=LN(G11)	=LN(H11)		
28					=LN(F12)	=LN(G12)	=LN(H12)		
29			=LN(D13)	=LN(E13)	=LN(F13)	=LN(G13)	=LN(H13)	=LN(I13)	=LN(J13)
30									
31		std(ln(x))	=STDEV(D22:D29)	=STDEV(E22:E29)	=STDEV(F22:F29)	=STDEV(G22:G29)	=STDEV(H22:H29)	=STDEV(I22:I29)	=STDEV(J22:J29)

Figure I-4b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Grain (Part 1)

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

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Arial Narrow 10 B I U

544

	K	L	M	N	O	P	Q	R	S
1									
2	Grain								
3									
4	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
5									
6	0.25	0.006	0.03	0.009	0.0015	0.00035	0.000085	0.00025	0.004
7	0.17		0.028	0.0047	0.0012		0.000034		0.0013
8	0.13	0.006	0.026	0.0047	0.0012	0.00035	0.000034	0.00025	0.0013
9	0.12	0.03	0.01	0.0047	0.0012	0.0035	0.000034	0.0025	0.0013
10	0.2	0.01	0.01	0.01	0.01	0.0003	0.0004	0.02	0.0002
11	0.17		0.012	0.0012	0.0018		0.0013		0.0016
12	0.077		0.012	0.014	0.058		0.002		0.00016
13	0.37	0.006	0.098	0.0056	0.0035	0.00035	0.00021	0.00025	0.0064
14	=K15	=L15	=M15	=N15	=O15	=P15	=Q15	=R15	=S15
15	=GEOMEAN(K6:K13)	=GEOMEAN(L6:L13)	=GEOMEAN(M6:M13)	=GEOMEAN(N6:N13)	=GEOMEAN(O6:O13)	=GEOMEAN(P6:P13)	=GEOMEAN(Q6:Q13)	=GEOMEAN(R6:R13)	=GEOMEAN(S6:S13)
16	=EXP(K31)	=EXP(L31)	=EXP(M31)	=EXP(N31)	=EXP(O31)	=EXP(P31)	=EXP(Q31)	=EXP(R31)	=EXP(S31)
17	2								
18	=K15/(2^2.576)	=L15/(L16^2.576)	=M15/(M16^2.576)	=N15/(N16^2.576)	=O15/(O16^2.576)	=P15/(P16^2.576)	=Q15/(Q16^2.576)	=R15/(R16^2.576)	=S15/(S16^2.576)
19	=K15*(2^2.576)	=L15*(L16^2.576)	=M15*(M16^2.576)	=N15*(N16^2.576)	=O15*(O16^2.576)	=P15*(P16^2.576)	=Q15*(Q16^2.576)	=R15*(R16^2.576)	=S15*(S16^2.576)
20									
21									
22	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)
23	=LN(K7)		=LN(M7)	=LN(N7)	=LN(O7)		=LN(Q7)		=LN(S7)
24	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)
25	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)
26	=LN(K10)	=LN(L10)	=LN(M10)	=LN(N10)	=LN(O10)	=LN(P10)	=LN(Q10)	=LN(R10)	=LN(S10)
27	=LN(K11)		=LN(M11)	=LN(N11)	=LN(O11)		=LN(Q11)		=LN(S11)
28	=LN(K12)		=LN(M12)	=LN(N12)	=LN(O12)		=LN(Q12)		=LN(S12)
29	=LN(K13)	=LN(L13)	=LN(M13)	=LN(N13)	=LN(O13)	=LN(P13)	=LN(Q13)	=LN(R13)	=LN(S13)
30									
31	=STDEV(K22:K29)	=STDEV(L22:L29)	=STDEV(M22:M29)	=STDEV(N22:N29)	=STDEV(O22:O29)	=STDEV(P22:P29)	=STDEV(Q22:Q29)	=STDEV(R22:R29)	=STDEV(S22:S29)

Figure I-4c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Grain (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

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Figure I-5a. Image of the Excel Spreadsheet Showing Calculation of Transfer Factors for Forage Crops

Microsoft Excel - Calculation of TFs TCs and BFs Formulas									
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Arial Narrow 10 B I U \$ % , .00 +.00 102%									
I44									
	B	C	D	E	F	G	H	I	J
1	Soil-to-Plant Transfer Factors								
2	Forage								
3									
4	Reference		Tc	I	Np	Pu	Am	Cl	Se
5		0							
6	Baes et al. 1984, p. 10	1	9.5	0.15	0.1	0.00045	0.000055	70	0.025
7	IAEA 1994, pp. 17-25	2	8.1	0.0034	0.0081	0.0008	0.00071		
8	IAEA 2001, pp. 67-68	3	80	0.1	0.5	0.1	0.1		1
9	Kennedy and Streng 1992, pp. 6.25-6.27	4	44	0.0034	0.013	0.00039	0.00058	70	0.025
10	LaPlante and Poor 1997, p. 2-13	5	76	0.0034	0.069	0.00034	0.0012		0.025
11	NCRP 1984, p. 75	6				0.00085			
12	NCRP 1996, pp. 52-54	7	40	0.1	0.1	0.1	0.1	100	0.5
13	Rittmann 1993, p. 35-36	8	40	0.4	1	0.0004	0.002	50	0.5
14	Sheppard 1995, pp. 55-57	9	5.6	0.0016	0.024	0.00013	0.00042		
15	Till and Meyer 1983, pp. 5-50 - 5-51	10		1.84	0.0048	0.00023	0.0017		
16	Wang et al. 1993, pp. 25-26	11	40	0.17	0.1	0.00027	0.004	100	0.5
17	This analysis	12	=D18	=E18	=F18	=G18	=H18	=I18	=J18
18	Geomean	13	=GEOMEAN(D6:D16)	=GEOMEAN(E6:E16)	=GEOMEAN(F6:F16)	=GEOMEAN(G6:G16)	=GEOMEAN(H6:H16)	=GEOMEAN(I6:I16)	=GEOMEAN(J6:J16)
19	GeoSTD		=EXP(D37)	=EXP(E37)	=EXP(F37)	=EXP(G37)	=EXP(H37)	=EXP(I37)	=EXP(J37)
20	GeoSTD used			10		10	10	2	
21	Low 99%		=D18/(D19^2.576)	=E18/(10^2.576)	=F18/(F19^2.576)	=G18/(10^2.576)	=H18/(10^2.576)	=I18/(2^2.576)	=J18/(J19^2.576)
22	High 99%		=D18*(D19^2.576)	=E18*(10^2.576)	=F18*(F19^2.576)	=G18*(10^2.576)	=H18*(10^2.576)	=I18*(2^2.576)	=J18*(J19^2.576)
23									
24									
25	ln(x)	=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)	=LN(I6)	=LN(J6)	
26		=LN(D7)	=LN(E7)	=LN(F7)	=LN(G7)	=LN(H7)			
27		=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)		=LN(J8)	
28		=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)	=LN(I9)	=LN(J9)	
29		=LN(D10)	=LN(E10)	=LN(F10)	=LN(G10)	=LN(H10)		=LN(J10)	
30					=LN(G11)				
31		=LN(D12)	=LN(E12)	=LN(F12)	=LN(G12)	=LN(H12)	=LN(I12)	=LN(J12)	
32		=LN(D13)	=LN(E13)	=LN(F13)	=LN(G13)	=LN(H13)	=LN(I13)	=LN(J13)	
33		=LN(D14)	=LN(E14)	=LN(F14)	=LN(G14)	=LN(H14)			
34			=LN(E15)	=LN(F15)	=LN(G15)	=LN(H15)			
35		=LN(D16)	=LN(E16)	=LN(F16)	=LN(G16)	=LN(H16)	=LN(I16)	=LN(J16)	
36									
37	std(ln(x))	=STDEV(D25:D35)	=STDEV(E25:E35)	=STDEV(F25:F35)	=STDEV(G25:G35)	=STDEV(H25:H35)	=STDEV(I25:I35)	=STDEV(J25:J35)	
38									

Figure I-5b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Forage Crops (Part 1)

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

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Arial Narrow 10 B I U

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	K	L	M	N	O	P	Q	R	S
1									
2	Forage								
3									
4	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
5									
6	2.5	0.03	0.08	0.045	0.015	0.0035	0.00085	0.0025	0.0085
7	0.66		0.17	0.0011	0.08		0.011		0.023
8	10	1	1	0.1	0.4	0.1	0.1	0.1	0.2
9	1.6	0.03	0.13	0.0058	0.075	0.0035	0.0066	0.0025	0.017
10	1.1	0.03	0.11	0.0011	0.08	0.0035	0.011	0.0025	0.023
11	1.8		0.041						
12	4	1	1	0.1	0.2	0.1	0.1	0.1	0.1
13	2	0.1	0.02	0.1	0.1	0.01	0.004	0.05	0.004
14	1.1		0.077	0.0078	0.012		0.0085		0.011
15	3.1		0.093		0.1		0.0046		0.00039
16	2	1	0.2	0.1	0.2	0.1	0.009	0.1	0.1
17	=K18	=L18	=M18	=N18	=O18	=P18	=Q18	=R18	=S18
18	=GEOMEAN(K6:K16)	=GEOMEAN(L6:L16)	=GEOMEAN(M6:M16)	=GEOMEAN(N6:N16)	=GEOMEAN(O6:O16)	=GEOMEAN(P6:P16)	=GEOMEAN(Q6:Q16)	=GEOMEAN(R6:R16)	=GEOMEAN(S6:S16)
19	=EXP(K37)	=EXP(L37)	=EXP(M37)	=EXP(N37)	=EXP(O37)	=EXP(P37)	=EXP(Q37)	=EXP(R37)	=EXP(S37)
20									
21	=K18/(K19^2.576)	=L18/(L19^2.576)	=M18/(M19^2.576)	=N18/(N19^2.576)	=O18/(O19^2.576)	=P18/(P19^2.576)	=Q18/(Q19^2.576)	=R18/(R19^2.576)	=S18/(S19^2.576)
22	=K18*(K19^2.576)	=L18*(L19^2.576)	=M18*(M19^2.576)	=N18*(N19^2.576)	=O18*(O19^2.576)	=P18*(P19^2.576)	=Q18*(Q19^2.576)	=R18*(R19^2.576)	=S18*(S19^2.576)
23									
24									
25	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)
26	=LN(K7)		=LN(M7)	=LN(N7)	=LN(O7)		=LN(Q7)		=LN(S7)
27	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)
28	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)
29	=LN(K10)	=LN(L10)	=LN(M10)	=LN(N10)	=LN(O10)	=LN(P10)	=LN(Q10)	=LN(R10)	=LN(S10)
30	=LN(K11)		=LN(M11)						
31	=LN(K12)	=LN(L12)	=LN(M12)	=LN(N12)	=LN(O12)	=LN(P12)	=LN(Q12)	=LN(R12)	=LN(S12)
32	=LN(K13)	=LN(L13)	=LN(M13)	=LN(N13)	=LN(O13)	=LN(P13)	=LN(Q13)	=LN(R13)	=LN(S13)
33	=LN(K14)		=LN(M14)	=LN(N14)	=LN(O14)		=LN(Q14)		=LN(S14)
34	=LN(K15)		=LN(M15)		=LN(O15)		=LN(Q15)		=LN(S15)
35	=LN(K16)	=LN(L16)	=LN(M16)	=LN(N16)	=LN(O16)	=LN(P16)	=LN(Q16)	=LN(R16)	=LN(S16)
36									
37	=STDEV(K25:K35)	=STDEV(L25:L35)	=STDEV(M25:M35)	=STDEV(N25:N35)	=STDEV(O25:O35)	=STDEV(P25:P35)	=STDEV(Q25:Q35)	=STDEV(R25:R35)	=STDEV(S25:S35)
38									

Figure I-5c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Factors for Forage Crops (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

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Figure I-6a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Meat

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

File Edit View Insert Format Tools Data Window Help

Arial Narrow 10 B I U

	B	C	D	E	F	G	H	I	J
1	Animal Feed-to-Animal Produ								
2	Meat								
3	Reference	Tc	I	Np	Pu	Am	Cl	Se	
4		0							
5	Baes et al. 1984, p. 51	1	0.0085	0.007	0.000055	0.0000005	0.0000035	0.08	0.015
6	Davis et al. 1993, pp. 233-234	2	0.0085	0.007	0.000055	0.000002	0.0000035		0.015
7	IAEA 1994, p. 37	3	0.0001	0.04	0.001	0.00001	0.00004	0.02	
8	IAEA 2001, pp. 67-68	4	0.001	0.05	0.01	0.0002	0.0001		0.1
9	Kennedy and Strenge 1992, pp. 6.29-6.30	5	0.0085	0.007	0.000055	0.0000005	0.0000035	0.08	0.015
10	LaPlante and Poor 1997, p. 2-13	6	0.0001	0.04	0.001	0.00001	0.00004		0.015
11	Mills et al. 1983, pp. 145-146	7	0.00099	0.02	0.005	0.005	0.005		1
12	NCRP 1984, pp. 85	8		0.007					
13	NCRP 1996, pp. 52-54	9	0.0001	0.04	0.001	0.0001	0.00005	0.04	0.1
14	Ng 1982, p. 63	10		0.0072		0.000001			
15	Reg. Guide 1.109, p. 37	11	0.4	0.0029	0.0002				
16	Rittmann 1993, p. 35-36	12	0.00099	0.002	0.001	0.000002	0.00002	0.03	1
17	Smith et al. 1996, p. 5-27	13	0.006	0.003	0.00012	0.0002	0.0004		0.54
18	Till and Meyer 1983, p. 5-87	14	0.0087	0.0072	0.0000036	0.000001	0.0000036		
19	Wang et al. 1993, pp. 27-29; Yu et al. 2001, p. D-16	15	0.0001	0.007	0.001	0.0001	0.00005	0.06	0.1
20	This analysis	16	=GEOMEAN(D5:D11,D13,D15:D19)	=E21	=F21	=G21	=H21	=I21	=J21
21	Geomean	17	=GEOMEAN(D5:D11,D13,D15:D19)	=GEOMEAN(E5:E19)	=GEOMEAN(F5:F19)	=GEOMEAN(G5:G19)	=GEOMEAN(H5:H19)	=GEOMEAN(I5:I19)	=GEOMEAN(J5:J19)
22	GeoSTD		=EXP(D44)	=EXP(E44)	=EXP(F44)	=EXP(G44)	=EXP(H44)	=EXP(I44)	=EXP(J44)
23	GeoSTD used					10		2	
24	Low 99%		=D20/(D22^2.576)	=E21/(E22^2.576)	=F21/(F22^2.576)	=G21/(G22^2.576)	=H21/(H22^2.576)	=I21/(I22^2.576)	=J21/(J22^2.576)
25	High 99%		=D20*(D22^2.576)	=E21*(E22^2.576)	=F21*(F22^2.576)	=G21*(G22^2.576)	=H21*(H22^2.576)	=I21*(I22^2.576)	=J21*(J22^2.576)
26									
27									
28		ln(x)	=LN(D5)	=LN(E5)	=LN(F5)	=LN(G5)	=LN(H5)	=LN(I5)	=LN(J5)
29			=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)		=LN(J6)
30			=LN(D7)	=LN(E7)	=LN(F7)	=LN(G7)	=LN(H7)	=LN(I7)	
31			=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)		=LN(J8)
32			=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)	=LN(I9)	=LN(J9)
33			=LN(D10)	=LN(E10)	=LN(F10)	=LN(G10)	=LN(H10)		=LN(J10)
34			=LN(D11)	=LN(E11)	=LN(F11)	=LN(G11)	=LN(H11)		=LN(J11)
35				=LN(E12)					
36			=LN(D13)	=LN(E13)	=LN(F13)	=LN(G13)	=LN(H13)	=LN(I13)	=LN(J13)
37				=LN(E14)		=LN(G14)			
38			=LN(D15)	=LN(E15)	=LN(F15)				
39			=LN(D16)	=LN(E16)	=LN(F16)	=LN(G16)	=LN(H16)	=LN(I16)	=LN(J16)
40			=LN(D17)	=LN(E17)	=LN(F17)	=LN(G17)	=LN(H17)		=LN(J17)
41			=LN(D18)	=LN(E18)	=LN(F18)	=LN(G18)	=LN(H18)		
42			=LN(D19)	=LN(E19)	=LN(F19)	=LN(G19)	=LN(H19)	=LN(I19)	=LN(J19)
43									
44		std(ln(x))	=STDEV(D28:D34,D36,D39:D42)	=STDEV(E28:E42)	=STDEV(F28:F42)	=STDEV(G28:G42)	=STDEV(H28:H42)	=STDEV(I28:I42)	=STDEV(J28:J42)

Figure I-6b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Meat (Part 1)

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

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Arial Narrow 10 B I U

	K	L	M	N	O	P	Q	R	S	T
1										
2	Meat									
3	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U	
4										
5	0.0003	0.08	0.02	0.0003	0.00025	0.000025	0.000006	0.00001	0.0002	
6	0.00081	0.08	0.026	0.0004	0.0009	0.000025	0.000006	0.00001	0.0002	
7	0.003		0.05	0.0004	0.0009				0.0003	
8	0.01	0.01	0.05	0.0007	0.005	0.00002	0.0001	0.000005	0.003	
9	0.0003	0.08	0.02	0.0003	0.00025	0.000025	0.000006	0.00001	0.0002	
10	0.003	0.08	0.05	0.0004	0.0009	0.000025	0.000006	0.00001	0.0003	
11	0.0003	0.00099	0.03	0.00099	0.00099	0.005	0.005	0.005	0.005	
12	0.0008		0.03		0.0005					
13	0.01	0.01	0.05	0.0008	0.001	0.00002	0.0001	0.000005	0.0008	
14	0.0003		0.02							
15	0.0006		0.004							
16	0.0008	0.01	0.03	0.0004	0.0009	0.0004	0.005	0.005	0.0002	
17			0.05	0.01	0.0013	0.0016	0.0027	0.00005	0.00069	
18	0.00081		0.002	0.0004	0.00051		0.0002		0.00034	
19	0.003	0.01	0.03	0.0008	0.001	0.00002	0.0001	0.005	0.00034	
20	=K21	=L21	=M21	=N21	=O21	=P21	=Q21	=R21	=S21	
21	=GEOMEAN(K5:K19)	=GEOMEAN(L5:L19)	=GEOMEAN(M5:M19)	=GEOMEAN(N5:N19)	=GEOMEAN(O5:O19)	=GEOMEAN(P5:P19)	=GEOMEAN(Q5:Q19)	=GEOMEAN(R5:R19)	=GEOMEAN(S5:S19)	
22	=EXP(K44)	=EXP(L44)	=EXP(M44)	=EXP(N44)	=EXP(O44)	=EXP(P44)	=EXP(Q44)	=EXP(R44)	=EXP(S44)	
23							10	10		
24	=K21/(K22^2.576)	=L21/(L22^2.576)	=M21/(M22^2.576)	=N21/(N22^2.576)	=O21/(O22^2.576)	=P21/(P22^2.576)	=Q21/(Q22^2.576)	=R21/(R22^2.576)	=S21/(S22^2.576)	
25	=K21*(K22^2.576)	=L21*(L22^2.576)	=M21*(M22^2.576)	=N21*(N22^2.576)	=O21*(O22^2.576)	=P21*(P22^2.576)	=Q21*(Q22^2.576)	=R21*(R22^2.576)	=S21*(S22^2.576)	
26										
27										
28	=LN(K5)	=LN(L5)	=LN(M5)	=LN(N5)	=LN(O5)	=LN(P5)	=LN(Q5)	=LN(R5)	=LN(S5)	
29	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)	
30	=LN(K7)	=LN(L7)	=LN(M7)	=LN(N7)	=LN(O7)	=LN(P7)	=LN(Q7)	=LN(R7)	=LN(S7)	
31	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)	
32	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)	
33	=LN(K10)	=LN(L10)	=LN(M10)	=LN(N10)	=LN(O10)	=LN(P10)	=LN(Q10)	=LN(R10)	=LN(S10)	
34	=LN(K11)	=LN(L11)	=LN(M11)	=LN(N11)	=LN(O11)	=LN(P11)	=LN(Q11)	=LN(R11)	=LN(S11)	
35	=LN(K12)		=LN(M12)		=LN(O12)					
36	=LN(K13)	=LN(L13)	=LN(M13)	=LN(N13)	=LN(O13)	=LN(P13)	=LN(Q13)	=LN(R13)	=LN(S13)	
37	=LN(K14)		=LN(M14)							
38	=LN(K15)		=LN(M15)							
39	=LN(K16)	=LN(L16)	=LN(M16)	=LN(N16)	=LN(O16)	=LN(P16)	=LN(Q16)	=LN(R16)	=LN(S16)	
40			=LN(M17)	=LN(N17)	=LN(O17)	=LN(P17)	=LN(Q17)	=LN(R17)	=LN(S17)	
41	=LN(K18)		=LN(M18)	=LN(N18)	=LN(O18)	=LN(P18)	=LN(Q18)	=LN(R18)	=LN(S18)	
42	=LN(K19)	=LN(L19)	=LN(M19)	=LN(N19)	=LN(O19)	=LN(P19)	=LN(Q19)	=LN(R19)	=LN(S19)	
43										
44	=STDEV(K28:K42)	=STDEV(L28:L42)	=STDEV(M28:M42)	=STDEV(N28:N42)	=STDEV(O28:O42)	=STDEV(P28:P42)	=STDEV(Q28:Q42)	=STDEV(R28:R42)	=STDEV(S28:S42)	

Figure I-6c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Meat (Part 2)

Microsoft Excel - Calculation of TFs TCs and BF_s

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Figure I-7a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Poultry

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

File Edit View Insert Format Tools Data Window Help

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Arial Narrow 10 B I U

145

	B	C	D	E	F	G	H	I	J	
1	Animal Feed-to-Animal F									
2	Poultry									
3										
4	Reference		Tc	I	Np	Pu	Am	Cl	Se	Sr
5		0								
6	Davis et al. 1993, pp. 233-234	1	1.9	2.8	0.0055	0.0076	0.0085		9.3	0.3
7	IAEA 1994, p. 40	2	0.03	0.01		0.003	0.006		9	0.08
8	Kennedy and Streng 1992, pp. 6.29-6.30	3	0.03	0.018	0.004	0.00015	0.0002	0.03	8.5	0.035
9	Mills et al. 1983, pp. 145-146	4	0.00099	0.004	0.004	0.004	0.004		0.37	0.0009
10	Ng 1982, p. 63	5		0.2		0.00002	0.000072			0.032
11	Rittmann 1993, p. 35-36	6	0.03	0.018	0.004	0.00015	0.0002	0.03	8.5	0.035
12	Smith et al. 1996, p. 5-29	7	1.2	0.2	0.0017	0.1	0.1		8.3	
13	Till and Meyer 1983, p. 5-87	8								0.035
14	This analysis	9	=D15	=E15	=F15	=G15	=H15	=I15	=J15	=K15
15	Geomean	10	=GEOMEAN(D6:D13)	=GEOMEAN(E6:E13)	=GEOMEAN(F6:F13)	=GEOMEAN(G6:G13)	=GEOMEAN(H6:H13)	=GEOMEAN(I6:I13)	=GEOMEAN(J6:J13)	=GEOMEAN(K6:K13)
16	GeoSTD		=EXP(D31)	=EXP(E31)	=EXP(F31)	=EXP(G31)	=EXP(H31)	=EXP(I31)	=EXP(J31)	=EXP(K31)
17			10		2	10	10	2		
18	Low 99%		=D15/(10^2.576)	=E15/(E16^2.576)	=F15/(2^2.576)	=G15/(10^2.576)	=H15/(10^2.576)	=I15/(2^2.576)	=J15/(J16^2.576)	=K15/(K16^2.576)
19	High 99%		=D15*(10^2.576)	=E15*(E16^2.576)	=F15*(2^2.576)	=G15*(10^2.576)	=H15*(10^2.576)	=I15*(2^2.576)	=J15*(J16^2.576)	=K15*(K16^2.576)
20										
21										
22		ln(x)	=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)		=LN(J6)	=LN(K6)
23			=LN(D7)	=LN(E7)		=LN(G7)	=LN(H7)		=LN(J7)	=LN(K7)
24			=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)	=LN(I8)	=LN(J8)	=LN(K8)
25			=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)		=LN(J9)	=LN(K9)
26				=LN(E10)		=LN(G10)	=LN(H10)			=LN(K10)
27			=LN(D11)	=LN(E11)	=LN(F11)	=LN(G11)	=LN(H11)	=LN(I11)	=LN(J11)	=LN(K11)
28			=LN(D12)	=LN(E12)	=LN(F12)	=LN(G12)	=LN(H12)		=LN(J12)	
29										=LN(K12)
30										
31		std(ln(x))	=STDEV(D22:D29)	=STDEV(E22:E29)	=STDEV(F22:F29)	=STDEV(G22:G29)	=STDEV(H22:H29)	=STDEV(I22:I29)	=STDEV(J22:J29)	=STDEV(K22:K29)

Figure I-7b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Poultry (Part 1)

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

File Edit View Insert Format Tools Data Window Help

Arial Narrow 10 B I U

R44 =

	K	L	M	N	O	P	Q	R	S
1									
2	Poultry								
3									
4	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
5									
6	0.3	8	4.4	0.04	0.09	0.0025	0.0006	0.001	1.2
7	0.08		10						1
8	0.035	0.2	4.4	0.2	0.03	0.004	0.004	0.004	1.2
9	0.0009	0.00099	4.5	0.00099	0.00099	0.004	0.004	0.004	0.0012
10	0.032		4.4						
11	0.035	0.00099	4.4	0.00099	0.00099	0.004	0.004	0.004	1.2
12			12	1.2	0.48	0.0066	0.18	0.0041	0.1
13	0.035		0.01						
14	=K15	=L15	=M15	=N15	=O15	=P15	=Q15	=R15	=S15
15	=GEOMEAN(K6:K13)	=GEOMEAN(L6:L13)	=GEOMEAN(M6:M13)	=GEOMEAN(N6:N13)	=GEOMEAN(O6:O13)	=GEOMEAN(P6:P13)	=GEOMEAN(Q6:Q13)	=GEOMEAN(R6:R13)	=GEOMEAN(S6:S13)
16	=EXP(K31)	=EXP(L31)	=EXP(M31)	=EXP(N31)	=EXP(O31)	=EXP(P31)	=EXP(Q31)	=EXP(R31)	=EXP(S31)
17	10	10	10	10	10	2	2	10	10
18	=K15/(K16^2.576)	=L15/(L16^2.576)	=M15/(M16^2.576)	=N15/(N16^2.576)	=O15/(O16^2.576)	=P15/(P16^2.576)	=Q15/(Q16^2.576)	=R15/(R16^2.576)	=S15/(S16^2.576)
19	=K15*(K16^2.576)	=L15*(L16^2.576)	=M15*(M16^2.576)	=N15*(N16^2.576)	=O15*(O16^2.576)	=P15*(P16^2.576)	=Q15*(Q16^2.576)	=R15*(R16^2.576)	=S15*(S16^2.576)
20									
21									
22	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)
23	=LN(K7)		=LN(M7)						=LN(S7)
24	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)
25	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)
26	=LN(K10)		=LN(M10)						
27	=LN(K11)	=LN(L11)	=LN(M11)	=LN(N11)	=LN(O11)	=LN(P11)	=LN(Q11)	=LN(R11)	=LN(S11)
28			=LN(M12)	=LN(N12)	=LN(O12)	=LN(P12)	=LN(Q12)	=LN(R12)	=LN(S12)
29	=LN(K13)		=LN(M13)						
30									
31	=STDEV(K22:K29)	=STDEV(L22:L29)	=STDEV(M22:M29)	=STDEV(N22:N29)	=STDEV(O22:O29)	=STDEV(P22:P29)	=STDEV(Q22:Q29)	=STDEV(R22:R29)	=STDEV(S22:S29)

Figure I-7c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Poultry (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

File Edit View Insert Format Tools Data Window Help

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Figure I-8a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Milk

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

File Edit View Insert Format Tools Data Window Help

Arial Narrow 10 B I U

	B	C	D	E	F	G	H	I	J
1	Animal Feed-to-Animal Produ								
2	Milk								
3	Reference	Tc	I	Np	Pu	Am	Cl	Se	
4		0							
5	Baes et al. 1984, p. 50	1	0.01	0.01	0.000005	0.0000001	0.0000004	0.015	0.004
6	Davis et al. 1993, pp. 233-234	2	0.00099	0.0099	0.000005	0.0000001	0.00000041		0.004
7	IAEA 1994, pp. 35	3	0.00014	0.01	0.000005	0.0000011	0.0000015	0.017	
8	IAEA 2001, pp. 67-68	4	0.001	0.01	0.00005	0.000003	0.00002		0.001
9	Kennedy and Strenge 1992, pp. 6.29-6.30	5	0.01	0.01	0.000005	0.0000001	0.0000004	0.015	0.004
10	LaPlante and Poor 1997, p. 2-13	6	0.00014	0.01	0.000005	0.0000011	0.0000015		0.004
11	Mills et al. 1983, pp. 145-146	7	0.012	0.01	0.0000025	0.00000025	0.0000025		0.023
12	NCRP 1984, pp. 82-83	8		0.012		0.0000001			
13	NCRP 1996, pp. 52-64	9	0.001	0.01	0.00001	0.000001	0.000002	0.02	0.01
14	Ng 1982, p. 62	10		0.0099		0.0000001	0.00000041	0.017	0.004
15	Reg. Guide 1.109, p. 37	11	0.025	0.006	0.000005				
16	Rittmann 1993, p. 35-36	12	0.0003	0.012	0.00001	0.0000001	0.0000003	0.02	0.023
17	Smith et al. 1996, p. 5-27	13	0.0075	0.003	0.000005	0.000005	0.000005		0.004
18	Till and Meyer 1983, p. 5-86	14	0.0099	0.0099	0.000005	0.0000000027	0.00002		
19	Wang et al. 1993, pp. 30-32; Yu et al. 2001, p. D-16	15	0.001	0.01	0.000005	0.000001	0.000002	0.02	0.01
20	This analysis	16	=D21	=E21	=F21	=G21	=H21	=I21	=J21
21	Geomean	17	=GEOMEAN(D5:D19)	=GEOMEAN(E5:E19)	=GEOMEAN(F5:F19)	=GEOMEAN(G5:G19)	=GEOMEAN(H5:H19)	=GEOMEAN(I5:I19)	=GEOMEAN(J5:J19)
22	GeoSTD		=EXP(D44)	=EXP(E44)	=EXP(F44)	=EXP(G44)	=EXP(H44)	=EXP(I44)	=EXP(J44)
23	Geo STD used		2				2		
24	Low 99%		=D21/(D22^2.576)	=E21/(E22^2.576)	=F21/(F22^2.576)	=G21/(G22^2.576)	=H21/(H22^2.576)	=I21/(I22^2.576)	=J21/(J22^2.576)
25	High 99%		=D21*(D22^2.576)	=E21*(E22^2.576)	=F21*(F22^2.576)	=G21*(G22^2.576)	=H21*(H22^2.576)	=I21*(I22^2.576)	=J21*(J22^2.576)
26									
27									
28	ln(x)	=LN(D5)	=LN(E5)	=LN(F5)	=LN(G5)	=LN(H5)	=LN(I5)	=LN(J5)	
29		=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)		=LN(J6)	
30		=LN(D7)	=LN(E7)	=LN(F7)	=LN(G7)	=LN(H7)	=LN(I7)		
31		=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)		=LN(J8)	
32		=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)	=LN(I9)	=LN(J9)	
33		=LN(D10)	=LN(E10)	=LN(F10)	=LN(G10)	=LN(H10)		=LN(J10)	
34		=LN(D11)	=LN(E11)	=LN(F11)	=LN(G11)	=LN(H11)		=LN(J11)	
35		=LN(E12)		=LN(G12)					
36		=LN(D13)	=LN(E13)	=LN(F13)	=LN(G13)	=LN(H13)	=LN(I13)	=LN(J13)	
37		=LN(E14)		=LN(G14)	=LN(H14)	=LN(I14)		=LN(J14)	
38		=LN(D15)	=LN(E15)	=LN(F15)					
39		=LN(D16)	=LN(E16)	=LN(F16)	=LN(G16)	=LN(H16)	=LN(I16)	=LN(J16)	
40		=LN(D17)	=LN(E17)	=LN(F17)	=LN(G17)	=LN(H17)		=LN(J17)	
41		=LN(D18)	=LN(E18)	=LN(F18)	=LN(G18)	=LN(H18)			
42		=LN(D19)	=LN(E19)	=LN(F19)	=LN(G19)	=LN(H19)	=LN(I19)	=LN(J19)	
43									
44	std(ln(x))	=STDEV(D28:D42)	=STDEV(E28:E42)	=STDEV(F28:F42)	=STDEV(G28:G42)	=STDEV(H28:H42)	=STDEV(I28:I42)	=STDEV(J28:J42)	

Figure I-8b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Milk (Part 1)

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

File Edit View Insert Format Tools Data Window Help

Arial Narrow 10 B I U

	K	L	M	N	O	P	Q	R	S	T
1										
2	Milk									
3	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U	
4										
5	0.0015	0.001	0.007	0.00025	0.00045	0.00002	0.000005	0.000005	0.0006	
6	0.0014	0.0012	0.0071	0.00026	0.0004	0.00002	0.000005	0.000005	0.00037	
7	0.0028		0.0079		0.0013				0.0004	
8	0.003	0.001	0.01	0.0003	0.001	0.000002	0.000005	0.000005	0.0006	
9	0.0015	0.001	0.007	0.00025	0.00045	0.00002	0.000005	0.000005	0.0006	
10	0.003	0.001	0.0079	0.00025	0.0013	0.00002	0.000005	0.000005	0.0004	
11	0.0015	0.0013	0.005	0.00001	0.0002	0.0000025	0.0000025	0.0000025	0.0006	
12	0.0014		0.0071		0.0004				0.0004	
13	0.002	0.001	0.01	0.0003	0.001	0.000002	0.000005	0.000005	0.0004	
14	0.0014	0.0012	0.0071	0.00026	0.0004				0.00037	
15	0.0008		0.012							
16	0.0013	0.001	0.007	0.00003	0.0002	0.00002	0.0000025	0.0000025	0.0006	
17			0.008	0.0003	0.0013	0.000004	0.000005	0.000005	0.0004	
18	0.0014		0.0071	0.00026	0.00045	0.00002	0.000005	0.000005	0.00061	
19	0.002	0.001	0.008	0.0003	0.001	0.00002	0.000005	0.000005	0.0006	
20	=K21	=L21	=M21	=N21	=O21	=P21	=Q21	=R21	=S21	
21	=GEOMEAN(K5:K19)	=GEOMEAN(L5:L19)	=GEOMEAN(M5:M19)	=GEOMEAN(N5:N19)	=GEOMEAN(O5:O19)	=GEOMEAN(P5:P19)	=GEOMEAN(Q5:Q19)	=GEOMEAN(R5:R19)	=GEOMEAN(S5:S19)	
22	=EXP(K44)	=EXP(L44)	=EXP(M44)	=EXP(N44)	=EXP(O44)	=EXP(P44)	=EXP(Q44)	=EXP(R44)	=EXP(S44)	
23	2	2	2				2	2	2	
24	=K21/(2^2.576)	=L21/(2^2.576)	=M21/(2^2.576)	=N21/(2^2.576)	=O21/(2^2.576)	=P21/(2^2.576)	=Q21/(2^2.576)	=R21/(2^2.576)	=S21/(2^2.576)	
25	=K21*(2^2.576)	=L21*(2^2.576)	=M21*(2^2.576)	=N21*(2^2.576)	=O21*(2^2.576)	=P21*(2^2.576)	=Q21*(2^2.576)	=R21*(2^2.576)	=S21*(2^2.576)	
26										
27										
28	=LN(K5)	=LN(L5)	=LN(M5)	=LN(N5)	=LN(O5)	=LN(P5)	=LN(Q5)	=LN(R5)	=LN(S5)	
29	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)	
30	=LN(K7)		=LN(M7)		=LN(O7)				=LN(S7)	
31	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)	
32	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)	
33	=LN(K10)	=LN(L10)	=LN(M10)	=LN(N10)	=LN(O10)	=LN(P10)	=LN(Q10)	=LN(R10)	=LN(S10)	
34	=LN(K11)	=LN(L11)	=LN(M11)	=LN(N11)	=LN(O11)	=LN(P11)	=LN(Q11)	=LN(R11)	=LN(S11)	
35	=LN(K12)		=LN(M12)		=LN(O12)				=LN(S12)	
36	=LN(K13)	=LN(L13)	=LN(M13)	=LN(N13)	=LN(O13)	=LN(P13)	=LN(Q13)	=LN(R13)	=LN(S13)	
37	=LN(K14)	=LN(L14)	=LN(M14)	=LN(N14)					=LN(S14)	
38	=LN(K15)		=LN(M15)							
39	=LN(K16)	=LN(L16)	=LN(M16)	=LN(N16)	=LN(O16)	=LN(P16)	=LN(Q16)	=LN(R16)	=LN(S16)	
40			=LN(M17)	=LN(N17)	=LN(O17)	=LN(P17)	=LN(Q17)	=LN(R17)	=LN(S17)	
41	=LN(K18)		=LN(M18)	=LN(N18)	=LN(O18)	=LN(P18)	=LN(Q18)	=LN(R18)	=LN(S18)	
42	=LN(K19)	=LN(L19)	=LN(M19)	=LN(N19)	=LN(O19)	=LN(P19)	=LN(Q19)	=LN(R19)	=LN(S19)	
43										
44	=STDEV(K28:K42)	=STDEV(L28:L42)	=STDEV(M28:M42)	=STDEV(N28:N42)	=STDEV(O28:O42)	=STDEV(P28:P42)	=STDEV(Q28:Q42)	=STDEV(R28:R42)	=STDEV(S28:S42)	
45										

Figure I-8c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Milk (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

FileEditViewInsertFormatToolsDataWindowHelp

Figure I-9a. Image of the Excel Spreadsheet Showing Calculation of Transfer Coefficients for Eggs

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

File Edit View Insert Format Tools Data Window Help

102%

Arial Narrow 10 B I U

142

	B	C	D	E	F	G	H	I	J
1	Animal Feed-to-Animal P								
2	Eggs								
3									
4	Reference	Ref. No.	Tc	I	Np	Pu	Am	Cl	Se
5		0							
6	Davis et al. 1993, p. 233-234	1	1.9	2.8	0.0055	0.0076	0.0085		9.3
7	IAEA 1994, p. 41	2	3	3		0.0005	0.004		9
8	Kennedy and Strenge 1992, pp. 6.29-6.30	3	3	2.8	0.002	0.008	0.009	2	9.3
9	LaPlante and Poor 1997, p. 2-13	4	3	3	0.002	0.0005	0.004		9
10	Mills et al. 1983, pp. 145-146	5	0.00099	1.6	0.002	0.002	0.002		2.1
11	Ng 1982, p. 63	6		4.4		0.000033	0.0039		
12	Rittmann 1993, p. 35-36	7	3	2.8	0.002	0.008	0.009	0.00099	9.3
13	Smith et al. 1996, p. 5-27	8	1.2	1.6	0.017	0.008	0.0039		8.3
14	This analysis	9	=D15	=E15	=F15	=G15	=H15	=I15	=J15
15	Geomean	10	=GEOMEAN(D6:D9,D12:D13)	=GEOMEAN(E6:E13)	=GEOMEAN(F6:F13)	=GEOMEAN(G6:G13)	=GEOMEAN(H6:H13)	=GEOMEAN(I6:I13)	=GEOMEAN(J6:J13)
16	GeoSTD		=EXP(D32)	=EXP(E32)	=EXP(F32)	=EXP(G32)	=EXP(H32)	=EXP(I32)	=EXP(J32)
17	GeoSTD used		2	2			2	10	2
18	Low 99%		=D15/(2^2.576)	=E15/(2^2.576)	=F15/(F16^2.576)	=G15/(G16^2.576)	=H15/(2^2.576)	=I15/(10^2.576)	=J15/(2^2.576)
19	High 99%		=D15*(2^2.576)	=E15*(2^2.576)	=F15*(F16^2.576)	=G15*(G16^2.576)	=H15*(2^2.576)	=I15*(10^2.576)	=J15*(2^2.576)
20									
21									
22		ln(x)	=LN(D6)	=LN(E6)	=LN(F6)	=LN(G6)	=LN(H6)		=LN(J6)
23			=LN(D7)	=LN(E7)		=LN(G7)	=LN(H7)		=LN(J7)
24			=LN(D8)	=LN(E8)	=LN(F8)	=LN(G8)	=LN(H8)	=LN(I8)	=LN(J8)
25			=LN(D9)	=LN(E9)	=LN(F9)	=LN(G9)	=LN(H9)		=LN(J9)
26			=LN(D10)	=LN(E10)	=LN(F10)	=LN(G10)	=LN(H10)		=LN(J10)
27				=LN(E11)		=LN(G11)	=LN(H11)		
28			=LN(D12)	=LN(E12)	=LN(F12)	=LN(G12)	=LN(H12)	=LN(I12)	=LN(J12)
29			=LN(D13)	=LN(E13)	=LN(F13)	=LN(G13)	=LN(H13)		=LN(J13)
30									
31									
32		std(ln(x))	=STDEV(D22:D25,D28:D29)	=STDEV(E22:E29)	=STDEV(F22:F29)	=STDEV(G22:G29)	=STDEV(H22:H29)	=STDEV(I22:I29)	=STDEV(J22:J29)

Figure I-9b. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Eggs (Part 1)

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

File Edit View Insert Format Tools Data Window Help

Arial Narrow 10 B I U

R44

	K	L	M	N	O	P	Q	R	S
1									
2	Eggs								
3									
4	Sr	Sn	Cs	Pb	Ra	Ac	Th	Pa	U
5									
6	0.3	8	4.4	0.04	0.09	0.0025	0.0006	0.001	1.2
7	0.2		0.4						1
8	0.3	0.8	0.49	0.8	0.00002	0.002	0.002	0.002	0.99
9	0.2	0.8	0.4	0.8	0.00002	0.002	0.002	0.002	1
10	0.4	0.00099	0.5	0.00099	0.00002	0.002	0.002	0.002	0.34
11	0.22		0.43						
12	0.3	0.00099	0.49	0.00099	0.00002	0.002	0.002	0.002	0.99
13			0.4	1.2	0.25	0.016	0.18	0.0041	0.1
14	=K15	=L15	=M15	=N15	=O15	=P15	=Q15	=R15	=S15
15	=GEOMEAN(K6:K13)	=GEOMEAN(L6:L13)	=GEOMEAN(M6:M13)	=GEOMEAN(N6:N13)	=GEOMEAN(O6:O13)	=GEOMEAN(P6:P13)	=GEOMEAN(Q6:Q13)	=GEOMEAN(R6:R13)	=GEOMEAN(S6:S13)
16	=EXP(K32)	=EXP(L32)	=EXP(M32)	=EXP(N32)	=EXP(O32)	=EXP(P32)	=EXP(Q32)	=EXP(R32)	=EXP(S32)
17	2	10	10	10	10			2	
18	=K15/(2^2.576)	=L15/(10^2.576)	=M15/(M16^2.576)	=N15/(10^2.576)	=O15/(10^2.576)	=P15/(P16^2.576)	=Q15/(Q16^2.576)	=R15/(2^2.576)	=S15/(S16^2.576)
19	=K15*(2^2.576)	=L15*(10^2.576)	=M15*(M16^2.576)	=N15*(10^2.576)	=O15*(10^2.576)	=P15*(P16^2.576)	=Q15*(Q16^2.576)	=R15*(2^2.576)	=S15*(S16^2.576)
20									
21									
22	=LN(K6)	=LN(L6)	=LN(M6)	=LN(N6)	=LN(O6)	=LN(P6)	=LN(Q6)	=LN(R6)	=LN(S6)
23	=LN(K7)		=LN(M7)						=LN(S7)
24	=LN(K8)	=LN(L8)	=LN(M8)	=LN(N8)	=LN(O8)	=LN(P8)	=LN(Q8)	=LN(R8)	=LN(S8)
25	=LN(K9)	=LN(L9)	=LN(M9)	=LN(N9)	=LN(O9)	=LN(P9)	=LN(Q9)	=LN(R9)	=LN(S9)
26	=LN(K10)	=LN(L10)	=LN(M10)	=LN(N10)	=LN(O10)	=LN(P10)	=LN(Q10)	=LN(R10)	=LN(S10)
27	=LN(K11)		=LN(M11)						
28	=LN(K12)	=LN(L12)	=LN(M12)	=LN(N12)	=LN(O12)	=LN(P12)	=LN(Q12)	=LN(R12)	=LN(S12)
29			=LN(M13)	=LN(N13)	=LN(O13)	=LN(P13)	=LN(Q13)	=LN(R13)	=LN(S13)
30									
31									
32	=STDEV(K22:K28)	=STDEV(L22:L29)	=STDEV(M22:M30)	=STDEV(N22:N29)	=STDEV(O22:O29)	=STDEV(P22:P29)	=STDEV(Q22:Q29)	=STDEV(R22:R29)	=STDEV(S22:S29)

Figure I-9c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Transfer Coefficients for Eggs (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs

File Edit View Insert Format Tools Data Window Help

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Arial Narrow 10 B I U

D5 = Davis et al. 1993, p. 233-234

Bioaccumulation in Freshwater Fish

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2																	
3																	
4																	
5				Davis et al. 1993, p. 233-234	IAEA 1994, p. 45	IAEA 2001, p. 73	Kennedy and Streng 1992, p. 6.32	Mills et al. 1983, p. 148-149	Napier et al. 1988b, p. 5.769-5.770	Regulatory Guide 1.109, p. 1.109-13	Till and Meyer 1983, p. 5- 98-5.103	Wang et al. 1993, p.33- 35; Yu et al. 2001, p. D-19	NCRP 1996, pp. 58-60				
6			1	2	3	4	5	6	7	8	9	10	Geomean	GeoSTD	Lo 99%	Hi 99%	
7		Element															
8		C	5.00E+04	5.00E+04		4.60E+03	4.60E+03	9.00E+03	4.60E+03		5.00E+04	5.0E+04	1.6E+04	3.3	2.3E+02	9.2E+04	
9		Cl				5.00E+01		5.00E+01			1.00E+03	1.0E+03	2.2E+02	5.6	2.6E+00	1.9E+04	
10		Se	1.70E+02		2.00E+02	1.70E+02	1.70E+02	1.00E+03			2.00E+02	2.0E+02	2.3E+02	1.9	3.9E+01	1.2E+03	
11		Sr	1.00E+02	6.00E+01	34	5.00E+01	3.00E+01	5.00E+01	3.00E+01	2.80E+01	6.00E+01	6.0E+01	4.6E+01	1.5	7.8E+00	2.8E+02	
12		Tc	1.50E+01	2.00E+01	2.00E+01	1.50E+01	1.50E+01	1.50E+01	1.50E+01	7.80E+01	2.00E+01	2.0E+01	2.0E+01	1.7	3.3E+00	1.2E+02	
13		Sn	3.00E+03	3.00E+03		3.00E+03		1.00E+03			3.00E+03	3.0E+03	2.5E+03	1.6	4.2E+02	1.5E+04	
14		I	5.00E+01	4.00E+01	4.00E+01	5.00E+02	1.50E+01	5.00E+01	1.50E+01	4.40E+01	4.00E+01	4.0E+01	4.5E+01	2.6	3.8E+00	5.3E+02	
15		Cs	1.00E+04	2.00E+03	4500	2.00E+03	2.00E+03	1.50E+04	2.00E+03	5.60E+03	2.00E+03	2.0E+03	3.5E+03	2.2	4.7E+02	2.5E+04	
16		Pb	3.00E+02	3.00E+02	3.00E+02	1.00E+02	1.00E+02	2.00E+03			3.00E+02	3.0E+02	2.9E+02	2.5	2.7E+01	3.1E+03	
17		Ra	5.00E+01	5.00E+01	5.00E+01	7.00E+01	5.00E+01	5.00E+01		5.20E+02	5.00E+01	5.0E+01	6.7E+01	2.2	9.2E+00	5.0E+02	
18		Ac	2.50E+01		1.50E+01	2.50E+01	2.50E+01	3.30E+02			1.50E+01	1.5E+01	2.9E+01	3.0	1.7E+00	5.0E+02	
19		Th	1.00E+03	1.00E+02	1.00E+02	1.00E+02	3.00E+01	1.00E+02		8.00E+01	1.00E+02	1.0E+02	1.1E+02	2.5	1.0E+01	1.2E+03	
20		Pa	1.10E+01	1.00E+01	1.00E+01	1.10E+01	1.10E+01	3.00E+01			1.00E+01	1.0E+01	1.2E+01	1.5	2.0E+00	7.1E+01	
21		U	5.00E+01	1.00E+01	1.00E+01	5.00E+01	2.00E+00	5.00E+01		7.50E+00	1.00E+01	1.0E+01	1.4E+01	3.0	8.4E+01	2.3E+02	
22		Np	2.50E+03	3.00E+01	3.00E+01	2.50E+02	1.00E+01	2.50E+03	1.00E+01		3.00E+01	3.0E+01	3.0E+01	2.9	1.9E+00	4.7E+02	
23		Pu	2.50E+02	3.00E+01	3.00E+01	2.50E+02	3.50E+00	2.50E+02		8.00E+00	3.00E+01	3.0E+01	4.1E+01	4.7	7.9E+01	2.2E+03	
24		Am	1.00E+02	3.00E+01	3.00E+01	2.50E+02	2.50E+01	1.00E+02			3.00E+01	3.0E+01	5.2E+01	2.3	5.8E+00	4.6E+02	
25																	
26																	

Figure I-10a. Image of the Excel Spreadsheet Showing Calculation of Bioaccumulation Factor for Fish (Part 1)

Microsoft Excel - Calculation of TFs TCs and BFs

File Edit View Insert Format Tools Data Window Help

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Arial Narrow 10 B I U

D5 = Davis et al. 1993, p. 233-234

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1																
2																
3																
4																
5				ln (x)										std (ln x)		
6	Lo 99%	Hi 99%		1	2	3	4	5	6	7	8	9	10			
7																
8	2.3E+02	9.2E+04		10.8197783	10.8197783		8.43381158	8.43381158	9.10497986	8.43381158		10.8197783	10.8197783	1.20584573		
9	2.6E+00	1.9E+04					3.91202301	3.91202301	3.91202301			6.90775528	6.90775528	1.72958683		
10	3.9E+01	1.2E+03		5.13579844		5.29831737	5.13579844	5.13579844	6.90775528			5.29831737	5.29831737	0.64416938		
11	7.8E+00	2.8E+02		4.60517019	4.09434456	3.52636052	3.91202301	3.40119738	3.91202301	3.40119738	3.33220451	4.09434456	4.09434456	0.41246996		
12	3.3E+00	1.2E+02		2.7080502	2.99573227	2.99573227	2.7080502	2.7080502	2.7080502	2.7080502	4.35670883	2.99573227	2.99573227	0.50171511		
13	4.2E+02	1.5E+04		8.00636757	8.00636757		8.00636757		6.90775528			8.00636757	8.00636757	0.44850659		
14	3.8E+00	5.3E+02		3.91202301	3.68887945	3.68887945	6.2146081	2.7080502	3.91202301	2.7080502	3.78418963	3.68887945	3.68887945	0.95973245		
15	4.7E+02	2.5E+04		9.21034037	7.60090246	8.41183268	7.60090246	7.60090246	9.61580548	7.60090246	8.63052188	7.60090246	7.60090246	0.77325759		
16	2.7E+01	3.1E+03		5.70378247	5.70378247	5.70378247	4.60517019	4.60517019	7.60090246			5.70378247	5.70378247	0.92595158		
17	9.2E+00	5.0E+02		3.91202301	3.91202301	3.91202301	4.24849524	3.91202301	3.91202301		6.25382881	3.91202301	3.91202301	0.77461674		
18	1.7E+00	5.0E+02		3.21887582		2.7080502	3.21887582	3.21887582	5.79909265			2.7080502	2.7080502	1.10178073		
19	1.0E+01	1.2E+03		6.90775528	4.60517019	4.60517019	4.60517019	3.40119738	4.60517019		4.38202663	4.60517019	4.60517019	0.91624786		
20	2.0E+00	7.1E+01		2.39789527	2.30258509	2.30258509	2.39789527	2.39789527	3.40119738			2.30258509	2.30258509	0.37693902		
21	8.4E-01	2.3E+02		3.91202301	2.30258509	2.30258509	3.91202301	0.69314718	3.91202301		2.01490302	2.30258509	2.30258509	1.089109		
22	1.9E+00	4.7E+02		7.82404601	3.40119738	3.40119738	5.52146092	2.30258509	7.82404601	2.30258509		3.40119738	3.40119738	1.07304623		
23	7.9E-01	2.2E+03		5.52146092	3.40119738	3.40119738	5.52146092	1.25276297	5.52146092		2.07944154	3.40119738	3.40119738	1.53789485		
24	5.8E+00	4.6E+02		4.60517019	3.40119738	3.40119738	5.52146092	3.21887582	4.60517019			3.40119738	3.40119738	0.8507994		
25																
26																
27																

Figure I-10b. Image of the Excel Spreadsheet Showing Calculation of Bioaccumulation Factor for Fish (Part 2)

Microsoft Excel - Calculation of TFs TCs and BFs Formulas

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M32

	B	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	E														
2	Fish														
3															
4															
5		Davis et al. 1993, p. 233-234	IAEA 1994, p. 45	IAEA 2001, p. 73	Kennedy and Streng 1992, p. 6.32	Mills et al. 1983, p. 148-149	Napier et al. 1988b, p. 5.769- 5.770	Regulatory Guide 1.109, p. 1.109-13	Till and Meyer 1983, p. 5- 98-5.103	Wang et al. 1993, p.33- 35; Yu et al. 2001, p. D-19	NCRP 1996, pp. 58-60				
6		1	2	3	4	5	6	7	8	9	10	Geomean	GeoSTD	Lo 99%	Hi 99%
7	Element														
8	C	50000	50000		4600	4600	9000	4600		50000	50000	=GEOMEAN(D8:M8)	=EXP(AC8)	=4600/(3.2^2.576)	=4600*(3.2^2.576)
9	Cl				50		50			1000	1000	=GEOMEAN(D9:M9)	=EXP(AC9)	=N9/(O9^2.576)	=N9*(O9^2.576)
10	Se	170		200	170	170	1000			200	200	=GEOMEAN(D10:M10)	=EXP(AC10)	=N10/(O10^2.576)	=N10*(O10^2.576)
11	Sr	100	60	34	50	30	50	30	28	60	60	=GEOMEAN(D11:M11)	=EXP(AC11)	=N11/(O11^2.576)	=N11*(O11^2.576)
12	Tc	15	20	20	15	15	15	15	78	20	20	=GEOMEAN(D12:M12)	=EXP(AC12)	=N12/(O12^2.576)	=N12*(O12^2.576)
13	Sn	3000	3000		3000		1000			3000	3000	=GEOMEAN(D13:M13)	=EXP(AC13)	=N13/(O13^2.576)	=N13*(O13^2.576)
14	I	50	40	40	500	15	50	15	44	40	40	=GEOMEAN(D14:M14)	=EXP(AC14)	=N14/(O14^2.576)	=N14*(O14^2.576)
15	Cs	10000	2000	4500	2000	2000	15000	2000	5600	2000	2000	=GEOMEAN(D15:M15)	=EXP(AC15)	=N15/(O15^2.576)	=N15*(O15^2.576)
16	Pb	300	300	300	100	100	2000			300	300	=GEOMEAN(D16:M16)	=EXP(AC16)	=N16/(O16^2.576)	=N16*(O16^2.576)
17	Ra	50	50	50	70	50	50		520	50	50	=GEOMEAN(D17:M17)	=EXP(AC17)	=N17/(O17^2.576)	=N17*(O17^2.576)
18	Ac	25		15	25	25	330			15	15	=GEOMEAN(D18:M18)	=EXP(AC18)	=N18/(O18^2.576)	=N18*(O18^2.576)
19	Th	1000	100	100	100	30	100		80	100	100	=GEOMEAN(D19:M19)	=EXP(AC19)	=N19/(O19^2.576)	=N19*(O19^2.576)
20	Pa	11	10	10	11	11	30			10	10	=GEOMEAN(D20:M20)	=EXP(AC20)	=N20/(O20^2.576)	=N20*(O20^2.576)
21	U	50	10	10	50	2	50		7.5	10	10	=GEOMEAN(D21:M21)	=EXP(AC21)	=N21/(O21^2.576)	=N21*(O21^2.576)
22	Np	2500	30	30	250	10	2500	10		30	30	=GEOMEAN(E22:H22,J22,L22,M22)	=EXP(AC22)	=N22/(O22^2.576)	=N22*(O22^2.576)
23	Pu	250	30	30	250	3.5	250		8	30	30	=GEOMEAN(D23:M23)	=EXP(AC23)	=N23/(O23^2.576)	=N23*(O23^2.576)
24	Am	100	30	30	250	25	100			30	30	=GEOMEAN(D24:M24)	=EXP(AC24)	=N24/(O24^2.576)	=N24*(O24^2.576)
25															
26															

Figure I-10c. Image of the Excel Spreadsheet Showing Formulas for Calculation of Bioaccumulation Factor for Fish (Part 1)

Microsoft Excel - Calculation of TFs TCs and BF's Formulas

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P37

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1																
2	Fish															
3																
4																
5				ln (x)										std (ln x)		
6	Lo 99%	Hi 99%	1	2	3	4	5	6	7	8	9	10				
7																
8	=4600/(3.2^2.576)	=4600*(3.2^2.576)	=LN(D8)	=LN(E8)		=LN(G8)	=LN(H8)	=LN(I8)	=LN(J8)		=LN(L8)	=LN(M8)	=STDEV(S8:AB8)			
9	=N9/(O9^2.576)	=N9*(O9^2.576)				=LN(G9)		=LN(I9)			=LN(L9)	=LN(M9)	=STDEV(S9:AB9)			
10	=N10/(O10^2.576)	=N10*(O10^2.576)	=LN(D10)		=LN(F10)	=LN(G10)	=LN(H10)	=LN(I10)			=LN(L10)	=LN(M10)	=STDEV(S10:AB10)			
11	=N11/(O11^2.576)	=N11*(O11^2.576)	=LN(D11)	=LN(E11)	=LN(F11)	=LN(G11)	=LN(H11)	=LN(I11)	=LN(J11)	=LN(K11)	=LN(L11)	=LN(M11)	=STDEV(S11:AB11)			
12	=N12/(O12^2.576)	=N12*(O12^2.576)	=LN(D12)	=LN(E12)	=LN(F12)	=LN(G12)	=LN(H12)	=LN(I12)	=LN(J12)	=LN(K12)	=LN(L12)	=LN(M12)	=STDEV(S12:AB12)			
13	=N13/(O13^2.576)	=N13*(O13^2.576)	=LN(D13)	=LN(E13)		=LN(G13)		=LN(I13)			=LN(L13)	=LN(M13)	=STDEV(S13:AB13)			
14	=N14/(O14^2.576)	=N14*(O14^2.576)	=LN(D14)	=LN(E14)	=LN(F14)	=LN(G14)	=LN(H14)	=LN(I14)	=LN(J14)	=LN(K14)	=LN(L14)	=LN(M14)	=STDEV(S14:AB14)			
15	=N15/(O15^2.576)	=N15*(O15^2.576)	=LN(D15)	=LN(E15)	=LN(F15)	=LN(G15)	=LN(H15)	=LN(I15)	=LN(J15)	=LN(K15)	=LN(L15)	=LN(M15)	=STDEV(S15:AB15)			
16	=N16/(O16^2.576)	=N16*(O16^2.576)	=LN(D16)	=LN(E16)	=LN(F16)	=LN(G16)	=LN(H16)	=LN(I16)			=LN(L16)	=LN(M16)	=STDEV(S16:AB16)			
17	=N17/(O17^2.576)	=N17*(O17^2.576)	=LN(D17)	=LN(E17)	=LN(F17)	=LN(G17)	=LN(H17)	=LN(I17)		=LN(K17)	=LN(L17)	=LN(M17)	=STDEV(S17:AB17)			
18	=N18/(O18^2.576)	=N18*(O18^2.576)	=LN(D18)		=LN(F18)	=LN(G18)	=LN(H18)	=LN(I18)			=LN(L18)	=LN(M18)	=STDEV(S18:AB18)			
19	=N19/(O19^2.576)	=N19*(O19^2.576)	=LN(D19)	=LN(E19)	=LN(F19)	=LN(G19)	=LN(H19)	=LN(I19)		=LN(K19)	=LN(L19)	=LN(M19)	=STDEV(S19:AB19)			
20	=N20/(O20^2.576)	=N20*(O20^2.576)	=LN(D20)	=LN(E20)	=LN(F20)	=LN(G20)	=LN(H20)	=LN(I20)			=LN(L20)	=LN(M20)	=STDEV(S20:AB20)			
21	=N21/(O21^2.576)	=N21*(O21^2.576)	=LN(D21)	=LN(E21)	=LN(F21)	=LN(G21)	=LN(H21)	=LN(I21)		=LN(K21)	=LN(L21)	=LN(M21)	=STDEV(S21:AB21)			
22	=N22/(O22^2.576)	=N22*(O22^2.576)	=LN(D22)	=LN(E22)	=LN(F22)	=LN(G22)	=LN(H22)	=LN(I22)	=LN(J22)		=LN(L22)	=LN(M22)	=STDEV(T22:W22,Y22,AA22:AB22)			
23	=N23/(O23^2.576)	=N23*(O23^2.576)	=LN(D23)	=LN(E23)	=LN(F23)	=LN(G23)	=LN(H23)	=LN(I23)		=LN(K23)	=LN(L23)	=LN(M23)	=STDEV(S23:AB23)			
24	=N24/(O24^2.576)	=N24*(O24^2.576)	=LN(D24)	=LN(E24)	=LN(F24)	=LN(G24)	=LN(H24)	=LN(I24)			=LN(L24)	=LN(M24)	=STDEV(S24:AB24)			
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Figure I-10d. Image of the Excel Spreadsheet Showing Formulas for Calculation of Bioaccumulation Factor for Fish (Part 2)

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ATTACHMENT II
CALCULATION OF THE VERTICAL WIND PROFILE

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 97 SR-2 workbook *Vertical wind profile.xls* consists of 2 worksheets, 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 6-70.

Figure III-1a contains the image of the Excel 97 SR-2 spreadsheet showing the calculation of the vertical wind profile.

Figures II-1b and II-1b contain the image of the Excel 97 SR-2 spreadsheet showing the formulas used in calculation of the vertical wind profile.

The calculations were based on Equation 6-28 described in Section 6.7.2.

Microsoft Excel - Vertical wind profile

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Figure II-1a. Image of the Excel Spreadsheet Showing Calculation of the Vertical Wind Profile

Microsoft Excel - Vertical wind profile

File Edit View Insert Format Tools Data Window Help

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D44

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1		Calculate												
2														
3		$u = (u^*k) \ln(z/z_0)$				$u = (u^*k) \ln(z/z_0)$			$u = (u^*k) \ln(z/z_0)$			$(u^*k) \ln(z/z_0)$		
4		k =	0.35	0.4		k =	0.35		k =	0.35		k =	0.35	
5		u(10) =	4.4	4.4		u* =	=C\$8		u* =	=C\$12		u* =	=C\$15	
6						z0 =	=C\$7		z0 =	=C\$11		z0 =	=C\$14	
7		z0 =	0.01	0.01										
8		u* =	=C\$5*C\$4/LN(10/C\$7)	=D\$5*D\$4/LN(10/D\$7)		z(m)		u(m/s)	z(m)		u(m/s)	z(m)		u(m/s)
9						0.02	=(G\$5/G\$4)*LN(F9/G\$6)							
10						0.05	=(G\$5/G\$4)*LN(F10/G\$6)		=F10	=(J\$5/J\$4)*LN(I10/J\$6)				
11		z0 =	0.02	0.02		0.2	=(G\$5/G\$4)*LN(F11/G\$6)		=F11	=(J\$5/J\$4)*LN(I11/J\$6)		=F11	=(M\$5/M\$4)*LN(L11/M\$6)	
12		u* =	=C\$5*C\$4/LN(10/C\$11)	=D\$5*D\$4/LN(10/D\$11)		0.5	=(G\$5/G\$4)*LN(F12/G\$6)		=F12	=(J\$5/J\$4)*LN(I12/J\$6)		=F12	=(M\$5/M\$4)*LN(L12/M\$6)	
13						1	=(G\$5/G\$4)*LN(F13/G\$6)		=F13	=(J\$5/J\$4)*LN(I13/J\$6)		=F13	=(M\$5/M\$4)*LN(L13/M\$6)	
14		z0 =	0.1	0.1		1.5	=(G\$5/G\$4)*LN(F14/G\$6)		=F14	=(J\$5/J\$4)*LN(I14/J\$6)		=F14	=(M\$5/M\$4)*LN(L14/M\$6)	
15		u* =	=C\$5*C\$4/LN(10/C\$14)	=D\$5*D\$4/LN(10/D\$14)		2	=(G\$5/G\$4)*LN(F15/G\$6)		=F15	=(J\$5/J\$4)*LN(I15/J\$6)		=F15	=(M\$5/M\$4)*LN(L15/M\$6)	
16						3	=(G\$5/G\$4)*LN(F16/G\$6)		=F16	=(J\$5/J\$4)*LN(I16/J\$6)		=F16	=(M\$5/M\$4)*LN(L16/M\$6)	
17						5	=(G\$5/G\$4)*LN(F17/G\$6)		=F17	=(J\$5/J\$4)*LN(I17/J\$6)		=F17	=(M\$5/M\$4)*LN(L17/M\$6)	
18		Input blocks				9	=(G\$5/G\$4)*LN(F18/G\$6)		=F18	=(J\$5/J\$4)*LN(I18/J\$6)		=F18	=(M\$5/M\$4)*LN(L18/M\$6)	
19						10	=(G\$5/G\$4)*LN(F19/G\$6)		=F19	=(J\$5/J\$4)*LN(I19/J\$6)		=F19	=(M\$5/M\$4)*LN(L19/M\$6)	
20														
21		Average wzo to 1 m				1	=1/(F21-G\$6)*G\$5/G\$4*(F21*(LN(F21/G\$6)-1)+G\$6)		1	=1/(I21-J\$6)*J\$5/J\$4*(I21*(LN(I21/J\$6)-1)+J\$6)		1	=1/(L21-M\$6)*M\$5/M\$4*(L21*(LN(L21/M\$6)-1)+M\$6)	
22		z0 to 2 m				2	=1/(F22-G\$6)*G\$5/G\$4*(F22*(LN(F22/G\$6)-1)+G\$6)		2	=1/(I22-J\$6)*J\$5/J\$4*(I22*(LN(I22/J\$6)-1)+J\$6)		2	=1/(L22-M\$6)*M\$5/M\$4*(L22*(LN(L22/M\$6)-1)+M\$6)	
23														
24		Varying "k"												
25		u* also changes												
26														
27		z0 from Fig												
28		the calculator												
29														
30		the wind speed												
31		the wind speed												
32														
33														

Figure II-1b. Image of the Excel Spreadsheet Showing the Formulas Used to Calculate of the Vertical Wind Profile (Part 1)

Microsoft Excel - Vertical wind profile

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D44 =

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1													
2													
3			$u = (u^*/k) \cdot \ln(z/z_0)$		$u = (u^*/k) \cdot \ln(z/z_0)$			$u = (u^*/k) \cdot \ln(z/z_0)$					
4			$k = 0.4$		$k = 0.4$			$k = 4$					
5			$u^* = D8$		$u^* = D12$			$u^* = D15$					
6			$z_0 = C7$		$z_0 = C11$			$z_0 = C14$					
7													
8			$z(m)$		$z(m)$			$z(m)$					
9													
10		0.05	$= (P5/P4) \cdot \ln(O10/P6)$		$= F10$	$= (S5/S4) \cdot \ln(R10/S6)$							
11		0.2	$= (P5/P4) \cdot \ln(O11/P6)$		$= F11$	$= (S5/S4) \cdot \ln(R11/S6)$		$= F11$	$= (V5/V4) \cdot \ln(U11/V6)$				
12		0.5	$= (P5/P4) \cdot \ln(O12/P6)$		$= F12$	$= (S5/S4) \cdot \ln(R12/S6)$		$= F12$	$= (V5/V4) \cdot \ln(U12/V6)$				
13		1	$= (P5/P4) \cdot \ln(O13/P6)$		$= F13$	$= (S5/S4) \cdot \ln(R13/S6)$		$= F13$	$= (V5/V4) \cdot \ln(U13/V6)$				
14		1.5	$= (P5/P4) \cdot \ln(O14/P6)$		$= F14$	$= (S5/S4) \cdot \ln(R14/S6)$		$= F14$	$= (V5/V4) \cdot \ln(U14/V6)$				
15		2	$= (P5/P4) \cdot \ln(O15/P6)$		$= F15$	$= (S5/S4) \cdot \ln(R15/S6)$		$= F15$	$= (V5/V4) \cdot \ln(U15/V6)$				
16		3	$= (P5/P4) \cdot \ln(O16/P6)$		$= F16$	$= (S5/S4) \cdot \ln(R16/S6)$		$= F16$	$= (V5/V4) \cdot \ln(U16/V6)$				
17		5	$= (P5/P4) \cdot \ln(O17/P6)$		$= F17$	$= (S5/S4) \cdot \ln(R17/S6)$		$= F17$	$= (V5/V4) \cdot \ln(U17/V6)$				
18		9	$= (P5/P4) \cdot \ln(O18/P6)$		$= F18$	$= (S5/S4) \cdot \ln(R18/S6)$		$= F18$	$= (V5/V4) \cdot \ln(U18/V6)$				
19		10	$= (P5/P4) \cdot \ln(O19/P6)$		$= F19$	$= (S5/S4) \cdot \ln(R19/S6)$		$= F19$	$= (V5/V4) \cdot \ln(U19/V6)$				
20													
21													
22													
23													
24													
25													
26													

Figure II-1c. Image of the Excel Spreadsheet Showing the Formulas Used to Calculate of the Vertical Wind Profile (Part 2)

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ATTACHMENT III
LIST OF FILES AND CD-ROM

Figure III-1. List of Files Included on the CD-ROM Accompanying Attachment III.