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Overview of Biosphere Modeling and the AMBER Code

Sandia National Laboratories

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INER

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Biosphere Model – What/Why?

Objective: To evaluate long-term human health impacts from dose caused by radionuclide release from a radioactive waste disposal system.

Approach: Define the biosphere and its boundary, identify important environmental exposure pathways and radionuclides, establish a conceptual biosphere model, implement the model and use it to analyze system response.

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Presentation Topics

- BIOMASS Methodology
- BIOMASS Example Reference Biospheres
- Comparison to Yucca Mountain Biosphere
- Sample Yucca Mountain Results
- Sensitivity and Uncertainty with AMBER

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BIOMASS

- BIOMASS – BIOsphere Modeling and ASSessment, an IAEA Coordinated Research Project on Biosphere Modeling and Assessment
- Initiated in October, 1996 with 3 themes:
  - Radioactive Waste Disposal – development of standard or reference biospheres for assessing long-term radioactive waste repository safety
  - Environmental Releases – development of increased confidence for assessing radiation exposure to environmental releases
  - Biosphere Processes – improved modeling of radionuclide transfer in the biosphere
- Theme 1 Working Group developed the key document *"Reference Biospheres" for solid radioactive waste disposal*, IAEA-BIOMASS-6, July 2003

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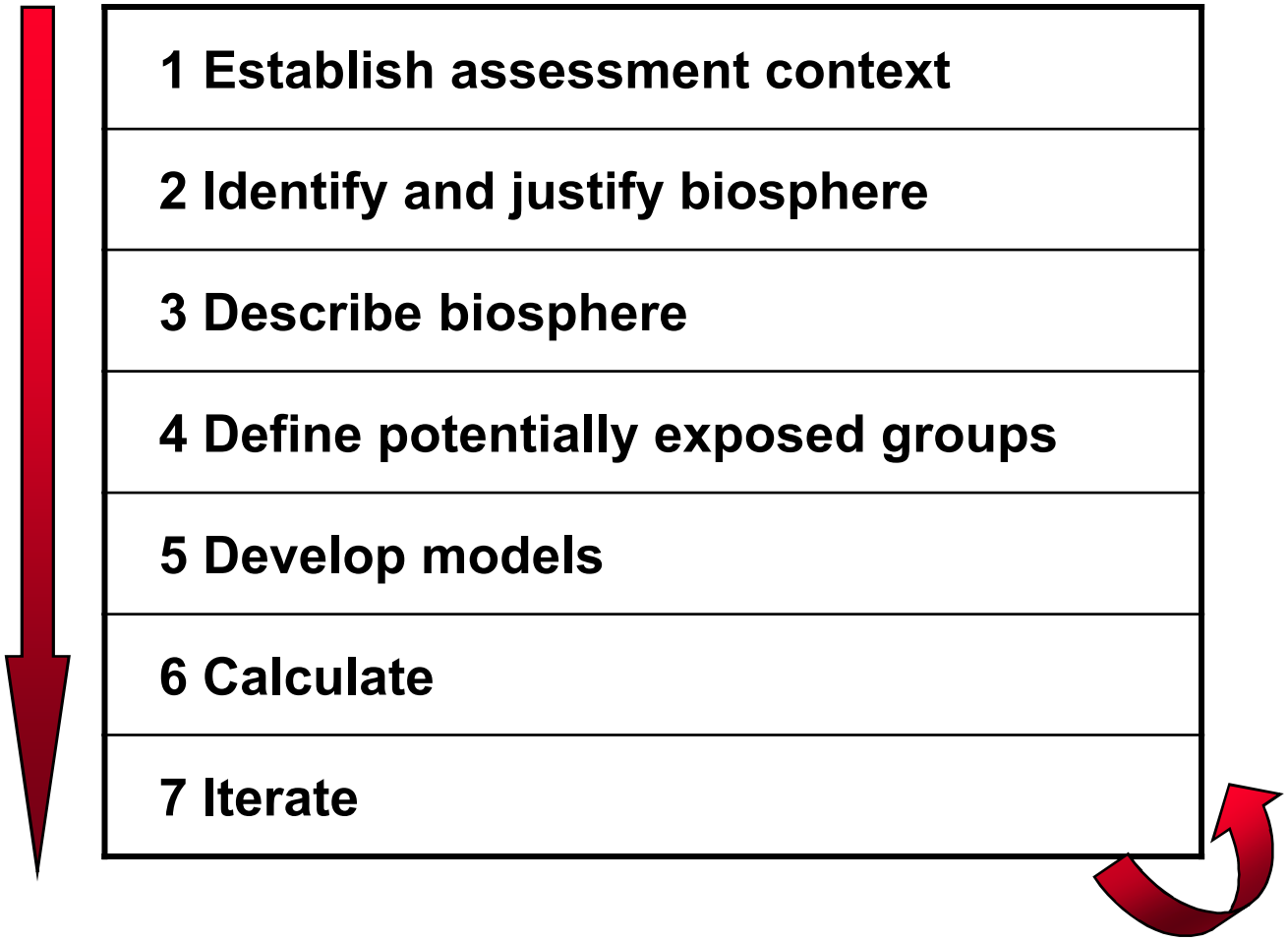
IAEA BIOMASS Methodology



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Example Reference Biospheres

Pathways	Source Term	
	Water Well	Aquifer
Drinking Water Pathway	ERB1A	ERB1B
Multiple Pathways	ERB2A	ERB2B

Changing Biosphere ERB3

Aquifer source term examples highlight importance of geosphere/biosphere interface assumptions, i.e., used when geosphere model only gives release rate from a discharge point into an aquifer, rather than concentration at point of distribution.

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IAEA Reference Biospheres

- **ERB1 Drinking Water Well (single transfer and exposure pathway; difference in subcases is whether or not to include aquifer dilution in biosphere domain)**
  - **ERB1A: Constant contaminant *concentration* in well (based on geosphere modeling results)**
  - **ERB1B: Constant contaminant *release rate* (includes aquifer in biosphere domain)**
- **ERB2 Agricultural Exposure w/Multiple Pathways**
  - **ERB2A Agricultural Well: Constant contaminant *concentration*, multiple exposure pathways**
  - **ERB2B Natural Discharge: Constant contaminant *release rate*, includes aquifer in biosphere domain, multiple pathways**
- **ERB3 Changing Biosphere**

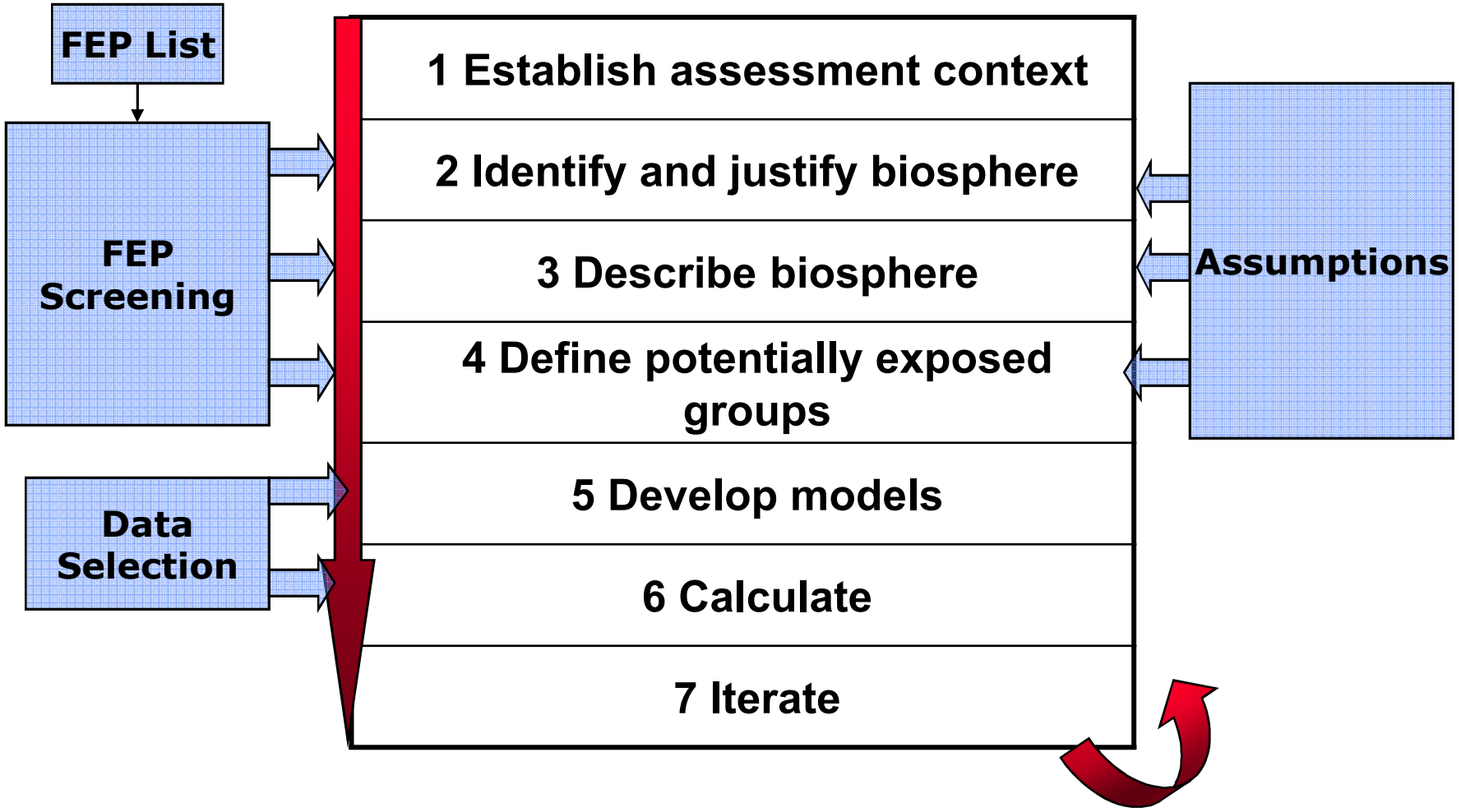
1. Assessment Context

- Purpose
- Endpoint
- Philosophy
- Repository system
- Site context
- Source terms
- Geosphere/biosphere interface
- Timeframes
- Societal assumptions

Context: BIOMASS vs. YMP

Element	ERB2A	YMP ERMYN
Purpose	Reference agricultural well scenario	TSPA dose assessment
Endpoint	Annual individual effective dose for critical groups	BDCF based on TEDE for RMEI
Philosophy	"Equitable"; "caution" in defining critical group	Reasonable but conservative
Repository	Deep repository for long-lived waste	Deep repository for long-lived waste
Site Context	Generic inland repository; accessible aquifer, no biosphere change	Amargosa Valley; groundwater use; limited biosphere change
Source Terms	Constant unit concentration (Bq/m3) for each radionuclide	Constant unit concentration (Bq/m3 or pCi/L) for each nuclide
Geo/Bio Interface	Well intruding into aquifer plume pumping consistent w/agricultural and domestic use	Well pumps contaminated groundwater for drinking, agricultural, and domestic use
Timeframe	Up to 1 million years	Up to 10,000 years, up to 1 million years
Societal Assumptions	Agricultural community using modern practices producing most of their dietary needs	Current Amargosa lifestyle; rural, vegetable garden, farm animals, fishpond; small fraction of local food production

IAEA BIOMASS Methodology



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Steps 2-5

- **Step 2 – Identify and justify biosphere**
  - **Select relevant model components and component types consistent with assessment context, regulatory criteria**
- **Step 3 - Describe biosphere**
  - **Develop more detailed site- and assessment-specific description of the model components**
- **Step 4 – Define potentially exposed groups**
  - **Identify exposure modes, routes, human activities**
- **Step 5 – Develop models**

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Pathways and Exposure Scenarios

Exposure Pathway	Environmental Pathway	YMP	ERB2A
External Exposure	Contaminated Soil	√	√
	Water Immersion		√
Inhalation	Soil Resuspension	√	√
	Radioactive Gas	√	
	Water Evaporation	√	√

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Pathways and Exposure Scenarios
(continued)

Exposure Pathway	Environmental Pathway	YMP	ERB2A
Ingestion	Soil	√	√
	Drinking Water	√	√
	Leafy Vegetables	√	√
	Root Vegetables	√	√
	Fruit	√	
	Grain	√	√
	Fresh feed for cows	√	√
	Stored feed for poultry	√	
	Meat	√	√
	Milk	√	√
	Offal		√
	Poultry	√	
	Eggs	√	
	Fish	√	√

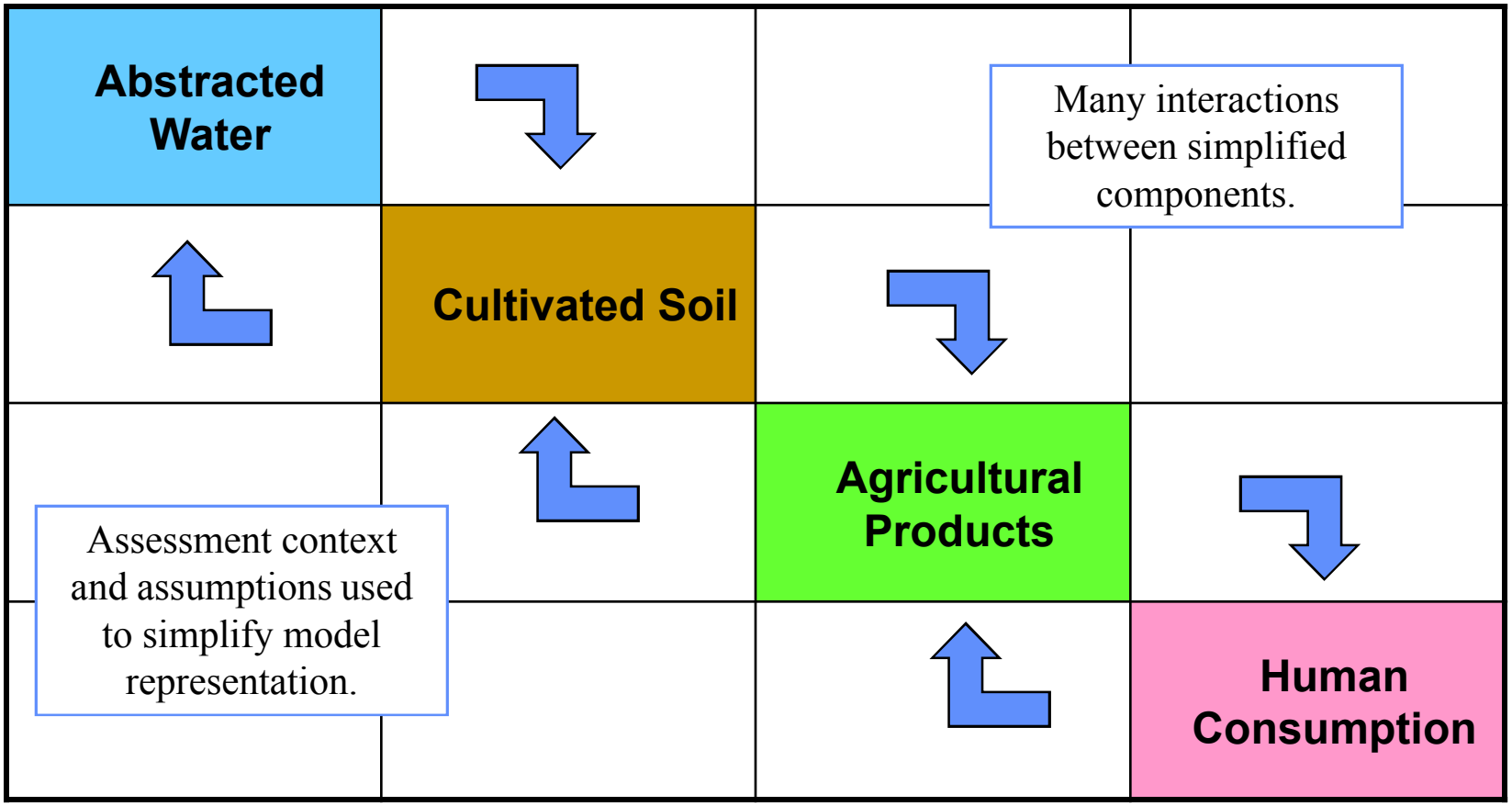
YMP Biosphere FEPS

1. Ashfall
2. Climate change
3. Water table rise affects SZ
4. Water management activities
5. Wells
6. Chemical characteristics of groundwater in SZ
7. Soil type
8. Radionuclide accumulation in soils
9. Soil and sediment transport in the biosphere
10. Surface water transport and mixing
11. Precipitation
12. Biosphere characteristics
13. Radionuclide alteration during biosphere transport
14. Human characteristics (physiology, metabolism)
15. Human lifestyle
16. Dwellings

YMP Biosphere FEPS
(continued)

17. Wild and natural land and water use
18. Agricultural land use and irrigation
19. Animal farms and fisheries
20. Urban and industrial land and water use
21. Radioactive decay and ingrowth
22. Atmospheric transport of contaminants
23. Contaminated drinking water, foodstuffs and drugs
24. Plant uptake
25. Animal uptake
26. Fish uptake
27. Contaminated non-food products and exposure
28. Ingestion
29. Inhalation
30. External exposure
31. Radiation doses
32. Radon and radon daughter exposure

Interaction Matrixes



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ERB2A Interaction Matrix

	1	2	3	4	5	6	7	8	9
1	Aquifer	Water abstraction	x	x	x	x	x	Ingestion	x
2	x	Water Storage and Distribution System	Volatilisation (I, C, Cl) Degassing (Rn)	IrrigationSediment transfer	Irrigation and interception	Drinking waterSediment consumption	x	x	DecayHuman consumption
3	x	x	Annosphere (external & internal)	Vapour / aerosol deposition	Vapour / aerosol deposition	Vapour / aerosol inhalation	x	Vapour / aerosol inhalation	DecayAdvection
4	x	x	SuspensionVolatilisation (I, C, Cl) Gas (Rn)	Cultivated Soil	Root uptakeSoil splash	Consumption of soil on fodder crops	Transfer of soil on crops	Ingestion	DecayLeaching / percolationErosion
5	x	x	Transpiration (3H)Respiration (14C)	WeatheringLeaf litterPloughed in detritus	Food and Fodder Crops	Ingestion of fodder	Harvesting	Ingestion	Decay
6	x	x	Eructation (14C)	Manuring	x	Farm Animals	SlaughteringMilkingEgg collect	Ingestion	Decay
7	x	x	Volatilisation (I, C, Cl)	Green manuring / composting	x	Consumption of stored fodder	Farm product storage distribution & processing	x	ConsumptionDecaySilage leachate
8	x	x	Respiration	Excretion	x	x	x	Human Community	x
9	x (Recharge)	x	x	x	x	x	x	x	Sinks

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Radionuclide Transfer Interaction Matrix (YMP Groundwater Scenario)

i,j	1	2	3	4	5	6	7
1	**SOURCE** (groundwater)	irrigation	evaporation	irrigation interception	ingestion of water	bio-accumulation (water use in fisheries)	drinking water ingestion
2	leaching [a]	**SURFACE SOIL**	particle resuspension, gas release, soil erosion [a]	root uptake	soil ingestion	—	soil ingestion, external exposure
3	—	dust deposit	**AIR**	dust deposition, photosynthesis	—	—	inhalation of particulates, gases, and aerosols
4	—	weathering, harvest removal	—	**PLANTS** (crops)	ingestion of feed	—	crop ingestion
5	—	fertilization	—	—	**ANIMALS** (animal products)	—	animal product ingestion
6	—	—	—	—	—	**FISH**	fish ingestion
7	—	—	—	—	—	—	**HUMAN** (receptor)

Ref: Biosphere Model Report, Table 6.3-2, p.6-22, MDL-MGR-MD-000001, Rev.01, YMP 11/04

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Radionuclide Transfer Interaction Matrix (YMP Volcanic Ash Scenario)

(i, j)	1	2	3	4	5	6	7
1	**SOURCE** (volcanic ash)	ashfall	—	—	—	—	—
2	—	**SURFACE SOIL** (ash or ash-soil mixture)	particle resuspension, gas release	root uptake	soil ingestion	—	soil ingestion, ground exposure
3	—	particle deposition	**AIR**	particle deposition	—	—	inhalation of particulates and gas
4	—	weathering, harvest removal	—	**PLANTS** (crops)	feed ingestion	—	crop ingestion
5	—	fertilization	—	—	**ANIMALS** (animal products)	—	animal product ingestion
6	—	—	—	—	—	**FISH**	—
7	—	—	—	—	—	—	**HUMAN** (receptor)

Ref: Biosphere Model Report, Table 6.3-4, p.6-42, MDL-MGR-MD-000001, Rev.01, YMP 11/04

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YMP Biosphere Submodels

- **Soil – based on ERB2A**
- **Air – particulate resuspension, gaseous diffusion, evaporative cooler aerosol generation**
- **Plant – root uptake, direct deposition of irrigation water, $^{14}CO_2$ photosynthesis, deposition of resuspended particles**
- **Animal - (exclude animal inhalation); fresh forage ingestion (alfalfa, grain)**
- **Fish - (local fish farm)**
- **Ingestion - (meat, poultry, milk, eggs; leafy vegetables, other vegetables, fruit, grain); much less local food consumption than ERB2A**
- **Inhalation – duration of exposure, breathing rates**
- **External Exposure –exposure due to contaminated soil; includes building shielding factors**
- **^{14}C – gas transport and plant uptake model**

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Yucca Mountain

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YMP Regional Characteristics

- **Desert environment – low precipitation, low relative humidity, hot summer, cool winter, no natural surface water**
- **In 2000, 1176 people in 422 homes within 1300 km^2 area; 40% unemployed, 15% mining, 5% agriculture**
- **90% live in mobile homes; 75% use evaporative coolers 5 months/year; 50% have gardens**
- **Limited agricultural activity, e.g., animal feed, small commercial farms, 1 dairy, 1 fish farm**

1988 Double-wide on 5 acres with mountain view. ($150,000) DeLee & Associates, www.amargosarealty.com

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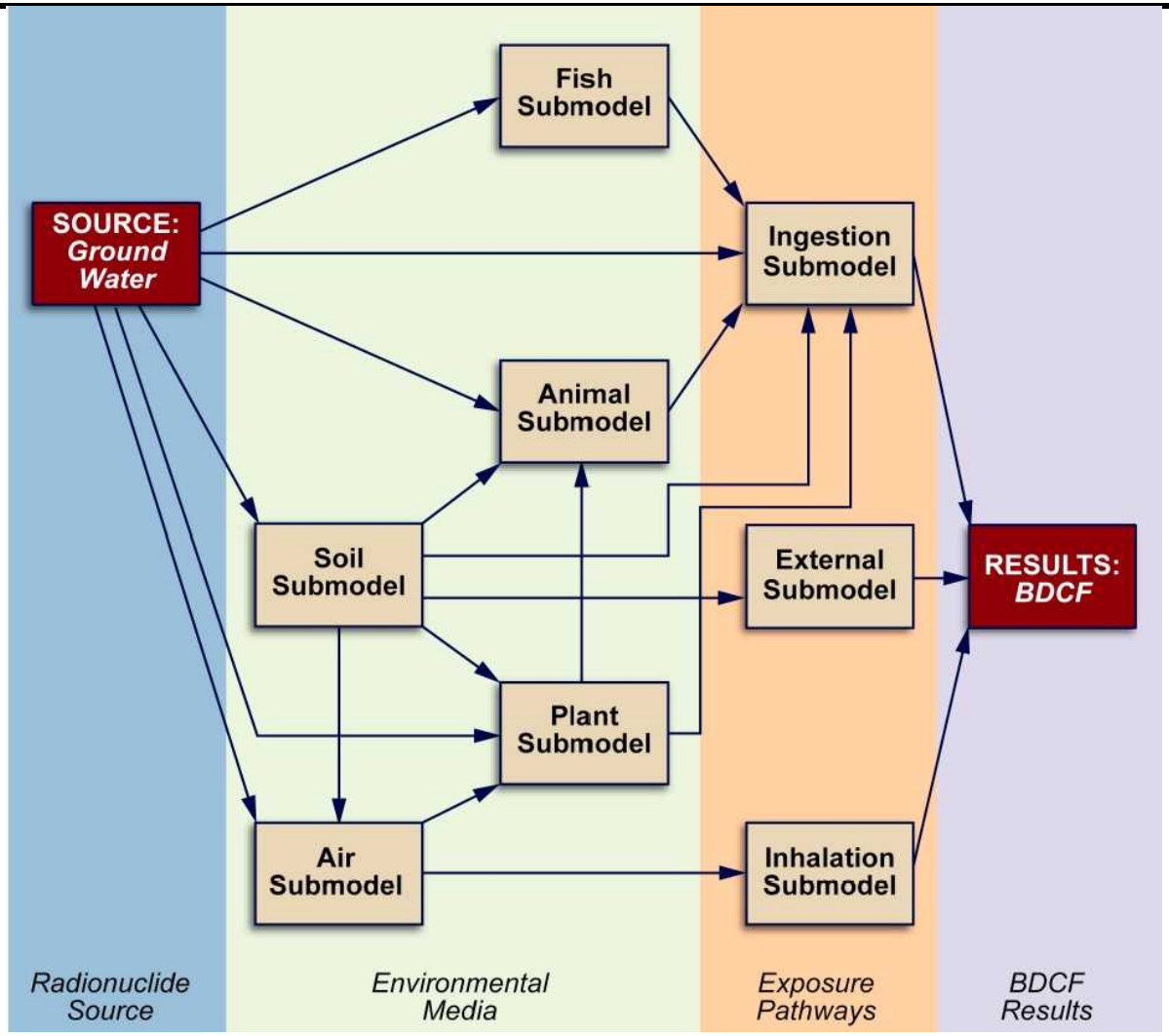
Biosphere Submodel Relationships (Groundwater Scenario)



Ref: Biosphere Model Report, Figure 6.3-2, p.6-30, MDL-MGR-MD-000001, Rev.01, YMP 11/04

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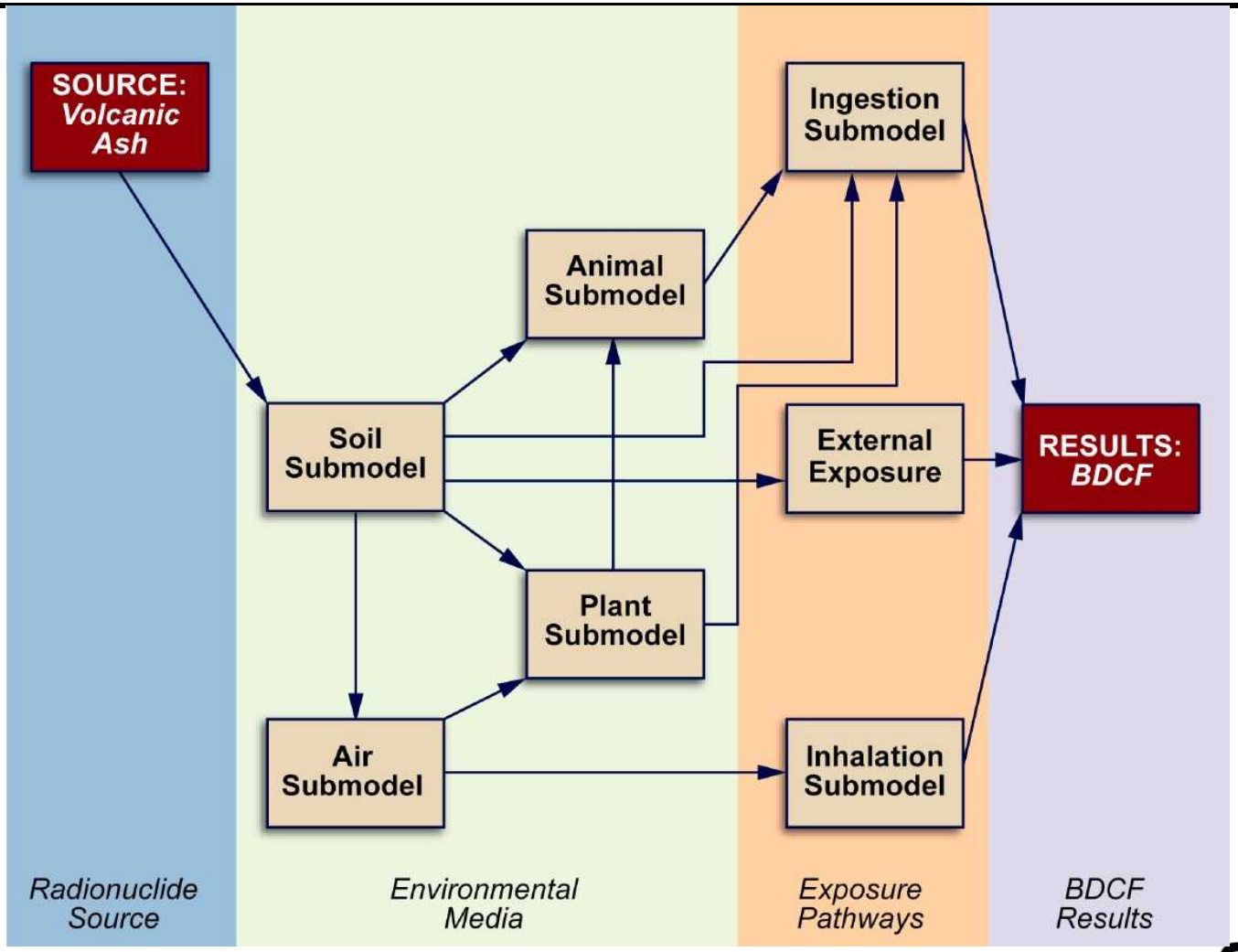
Biosphere Submodel Relationships (Volcanic Ash Scenario)



Ref: Biosphere Model Report, Figure 6.3-4, p.6-47, MDL-MGR-MD-000001, Rev.01, YMP 11/04

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Steps 6-7. Calculate & Iterate

- Develop mathematical representation of conceptual model
- Implement calculation
- Perform analysis

Importance, Sensitivity and Uncertainty

- **Importance – Identify radionuclides, pathways, and processes having greatest impact on dose values and distributions**
- **Sensitivity – Magnitude of change in dose due to parameter variations and along different pathways**
- **Uncertainty – Measure of the variability in results due to range of parameter values.**

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YMP Pathway Dose Contributions (Present Climate)

RN	External exposure	Inhalation			Ingestion										
		Particul. Matter	Evap. Cooler	Radon	Water	Leafy Veget.	Other Veget.	Fruit	Grain	Meat	Milk	Poultry	Eggs	Fish	Soil
C-14	0.0	0.0	0.0	0.0	18.0	2.9	3.7	10.1	0.7	6.4	3.1	0.7	6.2	48.6	0.0
Cl-36	0.1	0.0	0.1	0.0	15.2	3.4	5.1	17.3	2.7	23.5	19.0	0.0	10.6	9.4	0.0
Se-79	0.0	0.1	0.0	0.0	15.0	0.7	0.4	1.4	0.1	48.6	2.9	1.7	19.1	3.2	0.5
Sr-90	0.3	0.1	0.1	0.0	78.4	4.8	2.4	3.9	0.4	2.1	2.6	0.0	1.2	3.4	0.2
Tc-99	0.0	0.0	0.2	0.0	56.4	10.7	1.8	6.3	0.5	3.8	11.8	0.2	9.2	1.1	0.0
Sn-126	97.7	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	1.0	0.0
I-129	0.1	0.1	0.0	0.0	69.0	2.1	0.5	1.9	0.3	3.9	5.8	0.2	11.6	3.6	0.6
Cs-135	0.0	0.1	0.0	0.0	15.1	1.3	0.8	3.7	0.2	9.4	5.2	6.6	5.0	51.1	1.0
Cs-137	37.9	0.0	0.0	0.0	12.6	0.4	0.1	0.5	0.0	1.7	1.0	0.9	0.7	42.7	0.1
Pb-210	0.0	0.1	0.1	0.0	71.1	2.2	0.4	1.4	0.2	0.2	0.1	0.0	1.2	22.6	0.3
Ra-226	6.1	0.3	0.0	89.4	1.7	0.3	0.1	0.5	0.0	0.1	0.1	0.0	0.6	0.1	0.5
Ac-227	0.3	15.8	16.4	0.0	61.6	1.8	0.3	1.0	0.2	0.1	0.0	0.0	0.0	2.3	0.2
Th-229	3.0	72.2	5.1	0.0	16.1	0.6	0.1	0.4	0.1	0.1	0.0	0.0	0.1	2.0	0.9
Th-230	5.3	12.6	0.8	77.6	2.4	0.3	0.1	0.5	0.0	0.1	0.1	0.0	0.5	0.3	0.6
Th-232	24.5	52.9	3.5	0.0	14.9	0.8	0.2	0.5	0.1	0.1	0.1	0.0	0.0	1.6	0.9
Pa-231	1.3	81.4	1.0	0.0	13.5	0.7	0.2	0.7	0.1	0.1	0.0	0.0	0.0	0.2	1.8
U-232	12.1	20.3	13.2	0.0	47.5	1.4	0.2	0.9	0.2	0.1	0.1	0.2	1.0	2.8	0.3
U-233	1.4	72.3	5.8	0.0	21.1	0.8	0.2	0.6	0.1	0.1	0.1	0.3	1.8	0.4	0.9
U-234	0.4	54.0	8.1	5.8	29.7	1.0	0.2	0.7	0.1	0.1	0.2	0.4	2.4	0.5	0.8
U-236	0.0	57.0	8.7	0.0	31.8	1.1	0.2	0.8	0.1	0.1	0.2	0.4	2.6	0.6	0.8
U-238	3.8	53.6	8.2	0.0	31.7	1.0	0.2	0.8	0.1	0.1	0.2	0.4	2.6	0.6	0.8
Np-237	2.2	18.9	4.5	0.0	63.7	2.4	0.8	3.6	0.2	0.8	0.0	0.0	0.0	2.4	1.0
Pu-238	0.0	15.2	5.0	0.0	69.2	2.1	0.3	1.2	0.2	0.0	0.0	0.0	0.0	5.9	0.8
Pu-239	0.0	44.4	3.1	0.0	43.5	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.7	2.5
Pu-240	0.0	43.3	3.2	0.0	44.4	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.8	2.4
Pu-242	0.0	45.0	3.1	0.0	43.0	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.1	3.7	2.5
Am-241	0.1	30.3	4.1	0.0	57.4	1.9	0.3	1.2	0.2	0.1	0.0	0.0	0.0	3.1	1.7
Am-243	4.8	41.6	3.1	0.0	43.5	1.5	0.3	1.0	0.2	0.1	0.0	0.0	0.0	2.4	2.3

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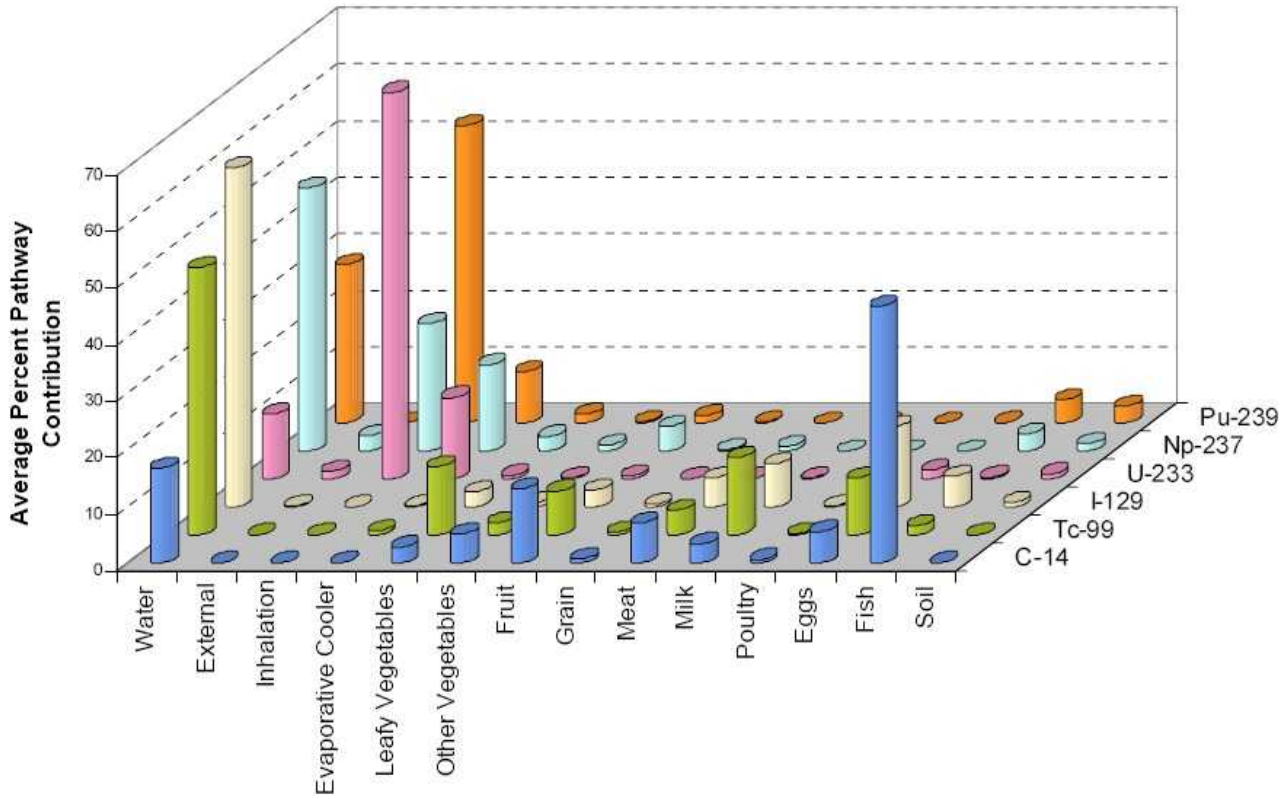
YMP Pathway Dose Contributions (Present Climate)



Source: Excel file *Detailed Pathway Analysis GW_MC.xls* (Appendix A).

Figure 6.2-5. Pathway Contributions for the Groundwater Exposure Scenario and Present-Day Climate

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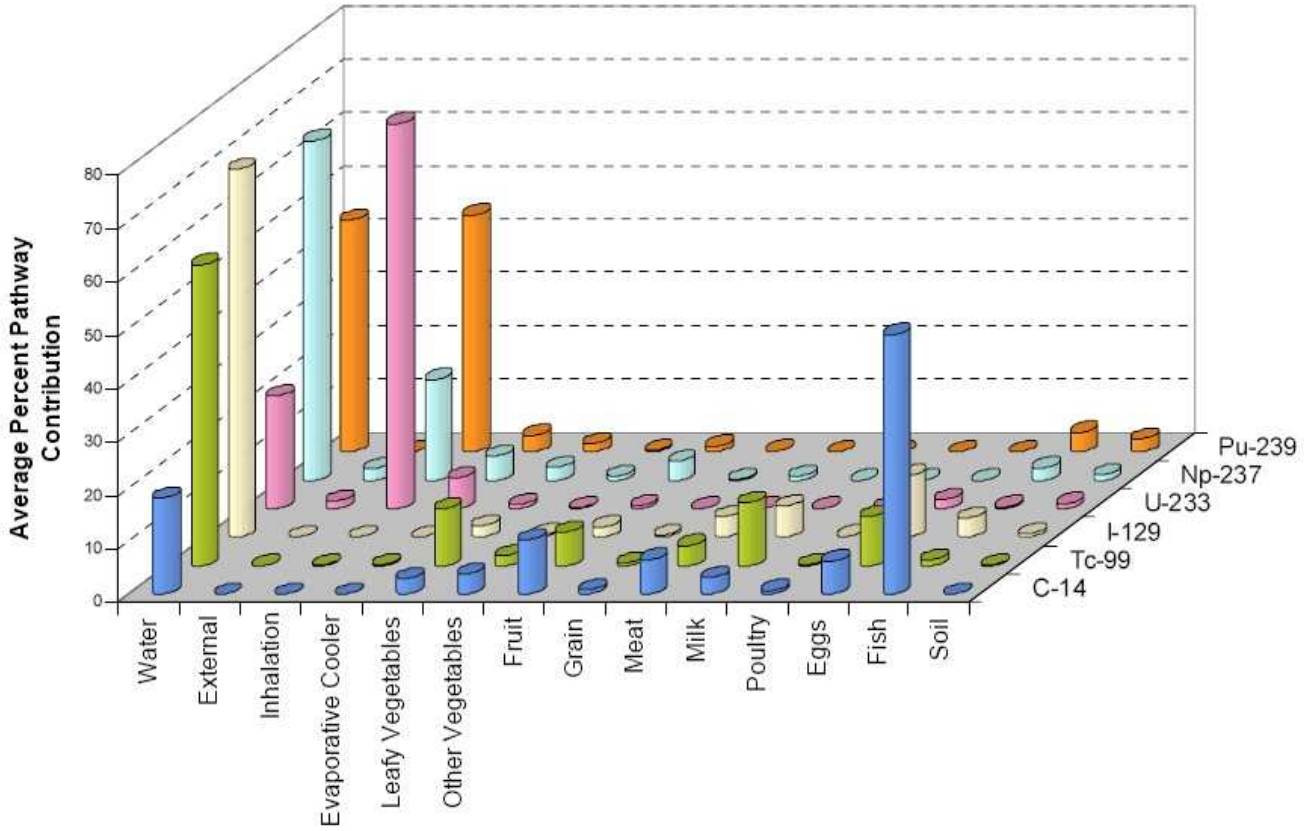
YMP Pathway Dose Contributions (Future Climate)



Source: Excel file *Detailed Pathway Analysis GW_MC.xls* (Appendix A).

Figure 6.2-6. Pathway Contributions for the Groundwater Exposure Scenario and Future Climate

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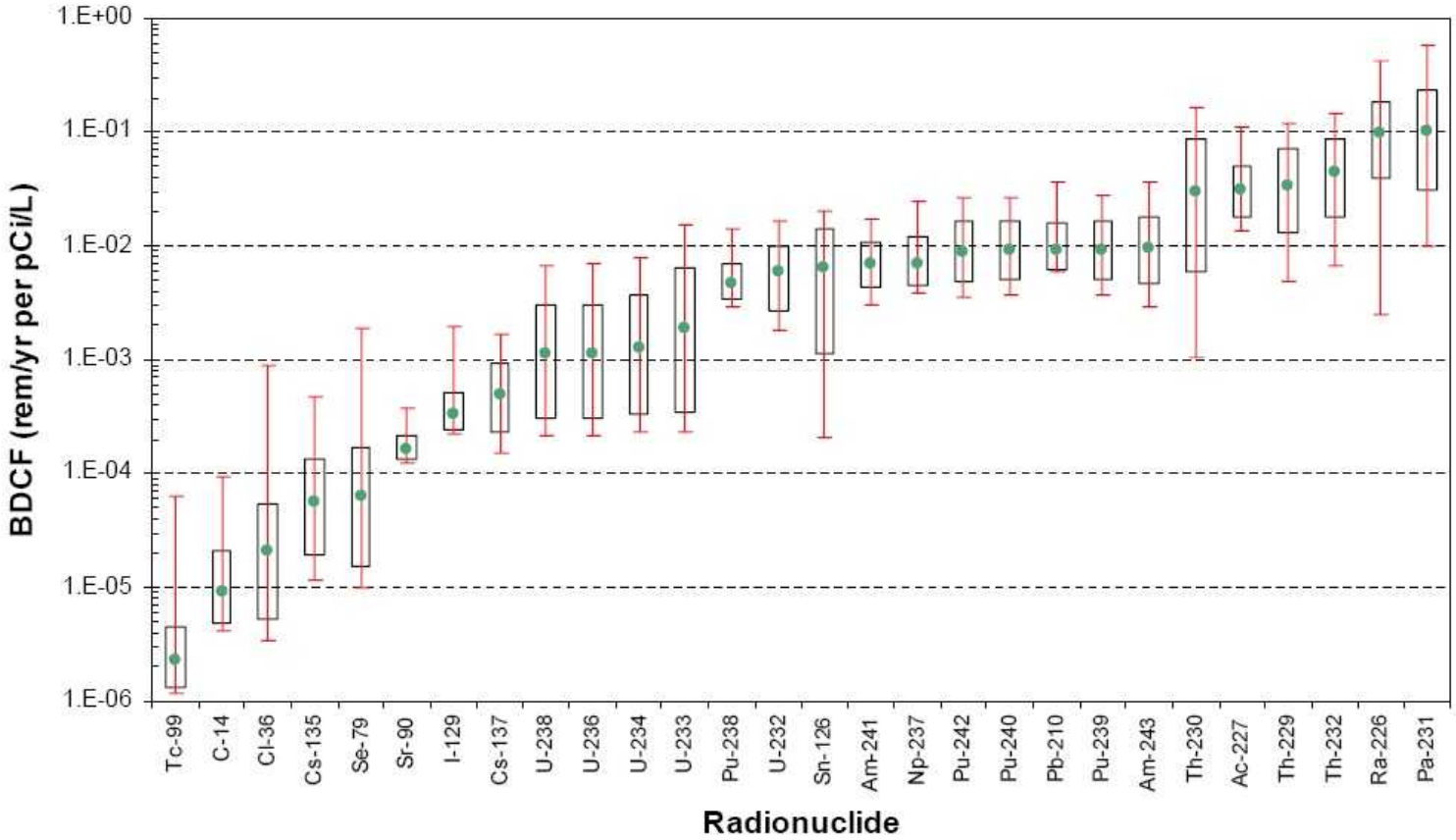
Uncertainty

- Conceptual Model Uncertainty - inclusion/exclusion of pathways
- Mathematical Model Uncertainty – simplified analytical methods
- Input Parameter Uncertainty – e.g., parameter distributions
- Conceptual and Mathematical Model Uncertainty are fixed during model execution; multiple realizations over parameter distributions can be used to characterize output variable uncertainty.

YMP BCDF Distribution (Present Climate)



Source: Excel file *GW BDCF Variability Plots.xls* (Appendix A).

NOTE: Boxes represent 5th to 95th percentile range. The vertical solid line represents the range. Circle represents the mean BDCF.

Figure 6.2-2. BDCF Distributions for the Groundwater Exposure Scenario and the Present-Day Climate Sorted by the Mean BDCF Value

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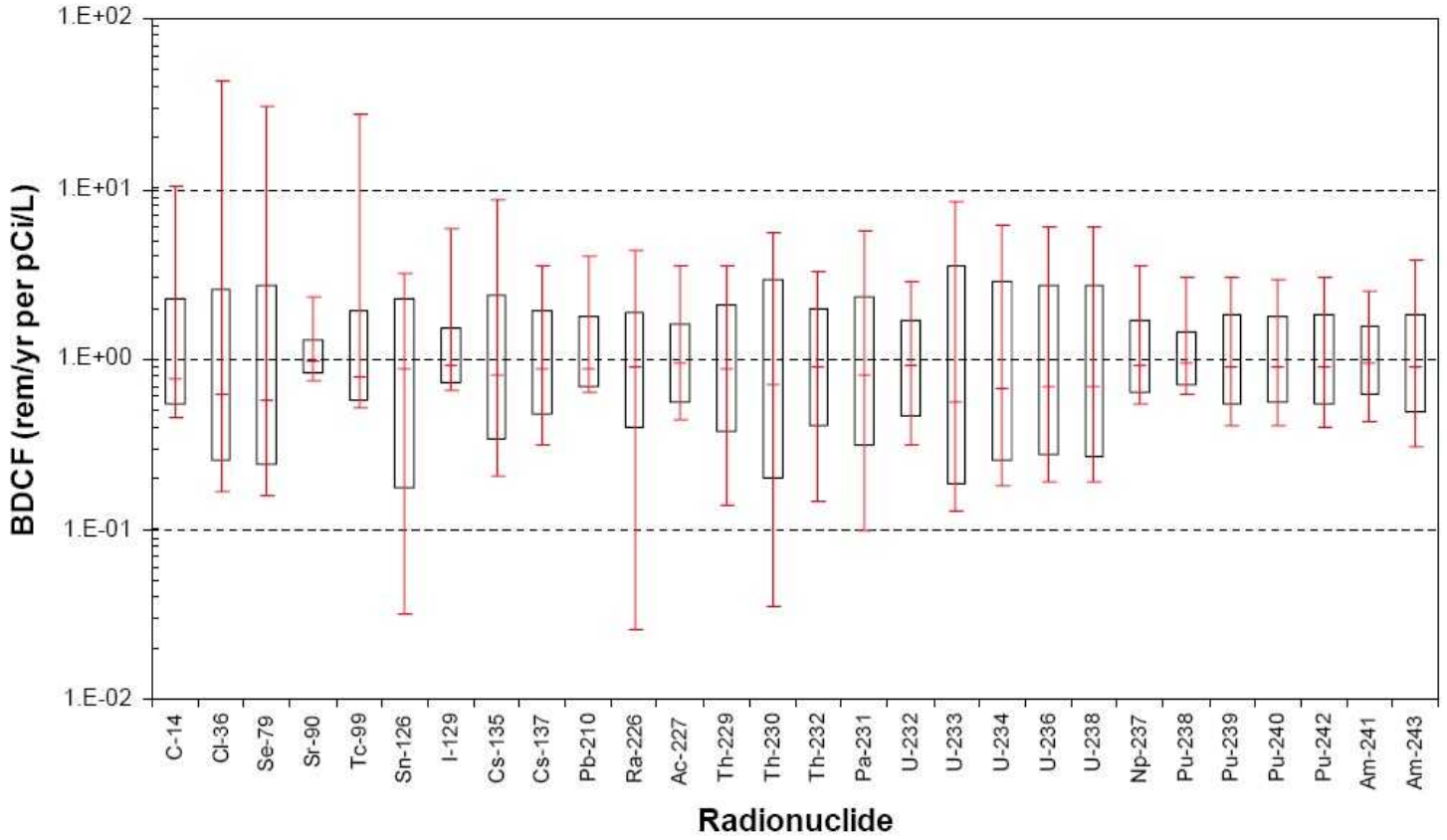
YMP BCDF Distribution (Present Climate)



Source: Excel file *GW BDCF Variability Plots.xls* (Appendix A).

NOTE: Boxes represent 5th to 95th percentile range. The vertical solid line represents the range and the tick mark on the line is the median.

Figure 6.2-3. BDCF Distributions for Groundwater Exposure Scenario, Present-Day Climate, Normalized to the Mean Value

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Correlation Between BDCF and Selected Parameters (Tc-99)

GoldSim Input Parameter	Correlation Coefficient
Overwatering rate	-0.637
Technetium transfer coefficient for milk	0.265
Technetium transfer factor for leafy vegetables	0.201
Technetium transfer coefficient for meat	0.179
Technetium transfer factor for fruit	0.174
Technetium transfer coefficient for eggs	0.159
Technetium transfer factor for grain	0.141
Dry-to-wet weight ratio for fruit	0.141
Technetium transfer factor for cattle forage	0.137
Technetium transfer factor for other vegetables	0.131
Weathering half-life	0.129
Technetium partition coefficient (K_d)	-0.125

Source: Excel file *GW MC Correlations.xls* (Appendix A).

Sensitivity of BDCF to Irrigation Rate

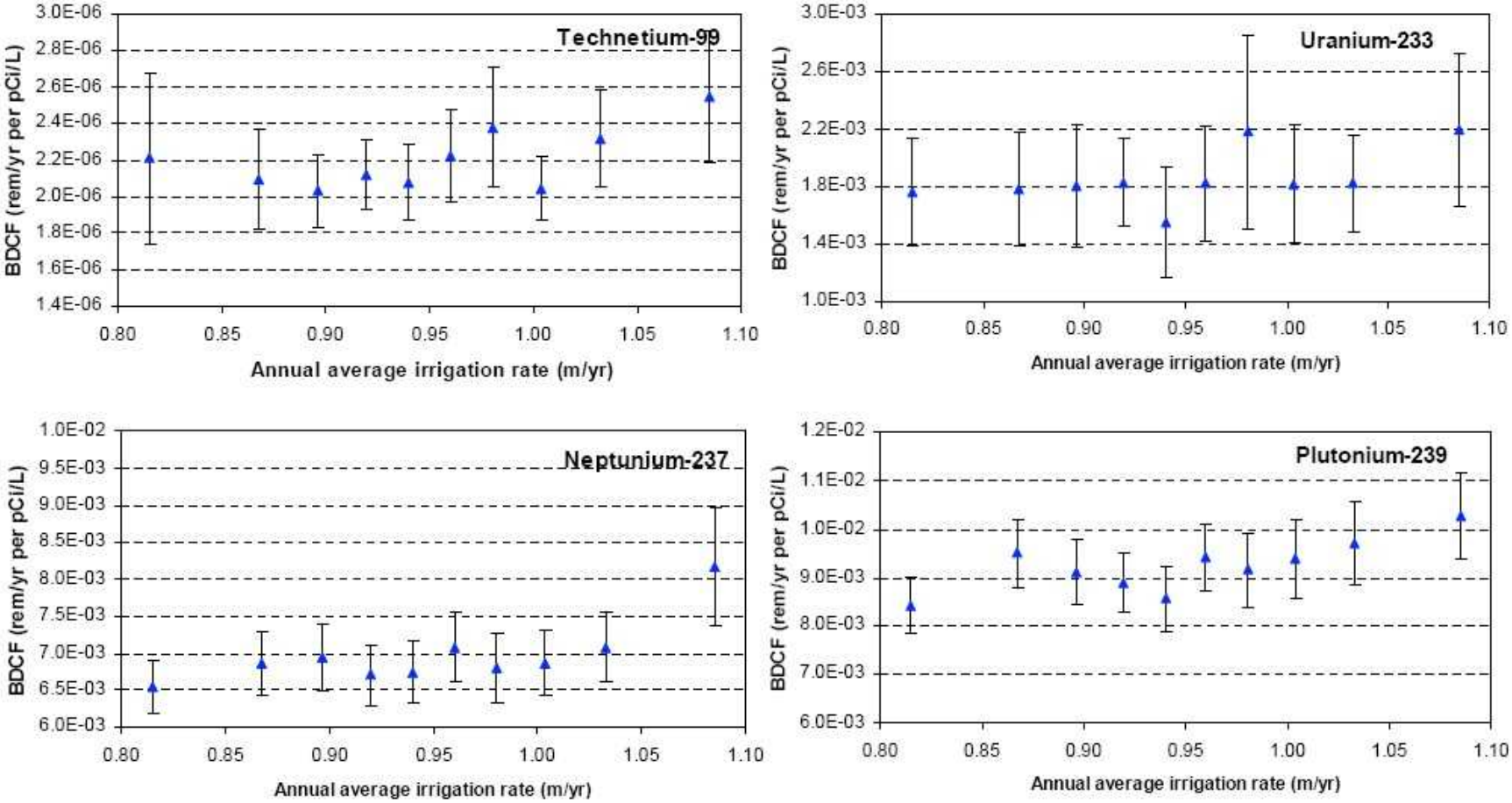

Figure 6.2-8. Dependence of BDCF for the Groundwater Exposure Scenario and Present-Day Climate on Annual Average Irrigation Rate

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AMBER Sample Problem ERB2A

- Constant contaminant concentration in agricultural well
- Four nuclides modeled: Nb-94 (external irradiation), Tc-99 (foodchain, highly mobile), I-129 (foodchain), Np-237 (dust inhalation)
- Timeframe – 1 million years
- Agricultural community producing a high proportion of total diet

AMBER Sample Problem ERB2A (modified)

- Eleven parameters were modifed with YMP distributions: Kd (I-129, Np-237, Tc-99), Consumption rates (meat, milk, leafy vegetables, root vegetables, grain), human inadvertent soil ingestion, irrigation rate, infiltration rate

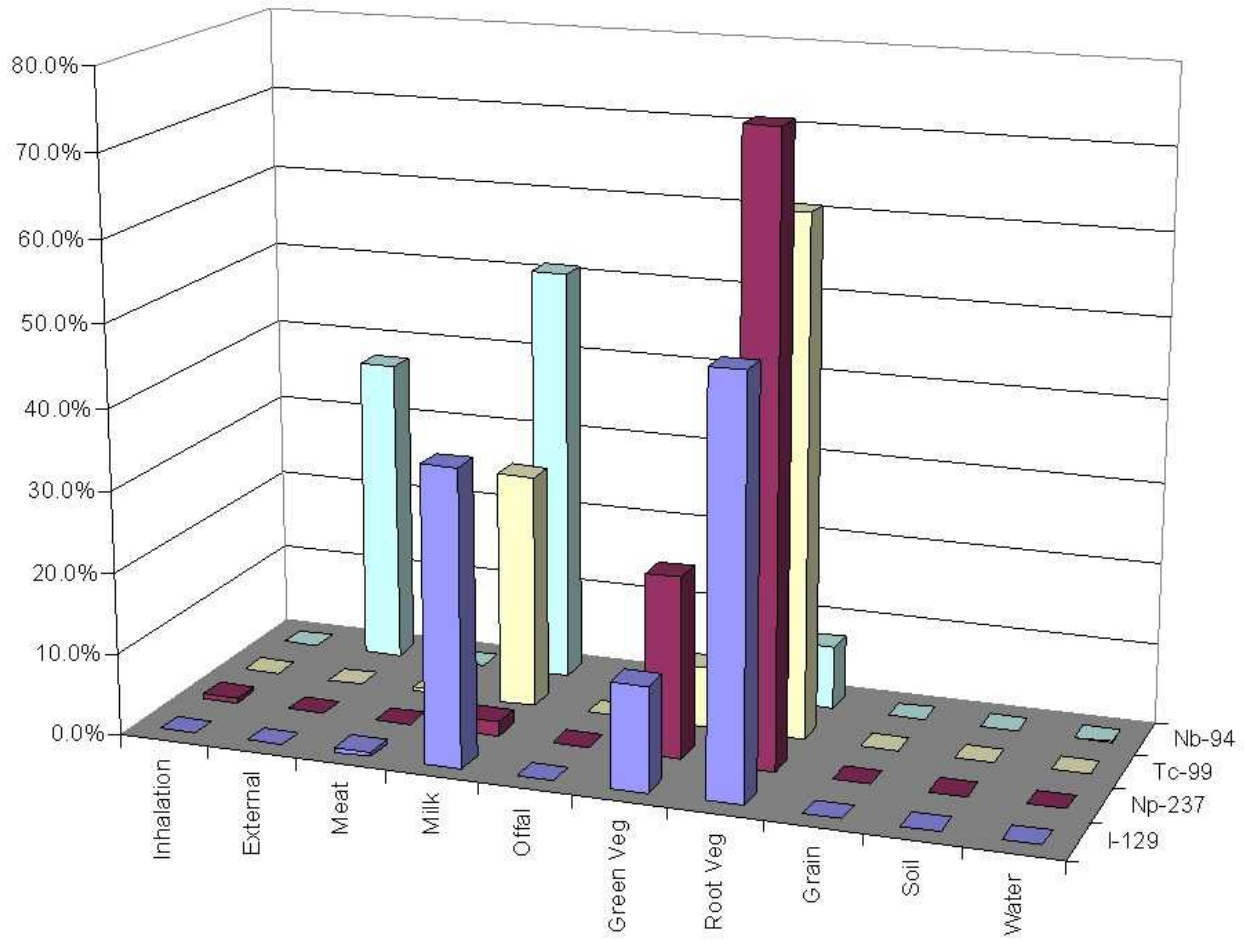
- Added pathway dose parameters (D_extall, D_ext, D_ingestall, D_ingest, D_inhaltot, D_inhal)

- Best estimate values used for deterministic runs, followed by sensitivity and uncertainty calculations using parameter distributions

Parameter Distributions - Modified ERB2A

Definition	Distribution	AMBER
Irrigation rate (m3/y)	0.94 ± 0.08 Min. 0.73, Max 1.15 Gaussian	0.2
Soil ingestion rate (kg/y)	Cumulative: 1.825E-2, 0%; 3.65E-2, 50%; 7.30e-2, 100% - 0.0365 mean	8.3E-3
Consumption rate, leafy vegetable (kg/y)	3.78 ± 0.88 lognormal	290
Consumption rate, other vegetable (kg/y)	4.73 ± 0.67 lognormal	320
Consumption rate, grain (kg/y)	0.23 ± 0.10 lognormal	470
Consumption rate, meat (kg/yr)	2.85 ± 0.65 lognormal	210
Consumption rate, milk (kg/y)	4.66 ± 1.68 lognormal	740
Partition coefficient, Tc-99 (m3/kg)	1.E-3 ± 1.4E-4 lognormal	1.7E-5
Partition coefficient, I-129 (m3/kg)	4.5E-3 ± 7.4E-3 lognormal	1.0E-2
Partition coefficient, Np-237 (m3/kg)	2.5E-2 ± 3.3E-3 lognormal	3.0e-2
Infiltration Rate (m/y)	Cumulative: .09, 0%; .030, 19%; .045, 38%; .076, 57%; .128, 76%; .233, 95%; .275, 100% - 0.079 mean	0.1

Pathway Analysis - Modified ERB2A



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Pathway Analysis - Modified ERB2A

PATHWAY	I-129	Np-237	Tc-99	Nb-94	Sum
Dust	1.63E-09	2.21E-06	1.84E-12	3.69E-09	2.22E-06
Aerosol-water	1.58E-17	2.19E-14	5.69E-18	4.34E-17	2.20E-14
Inhalation	**1.63E-09**	**2.21E-06**	**1.84E-12**	**3.69E-09**	**2.22E-06**
External-water	1.17E-12	3.07E-12	4.02E-15	2.19E-10	2.23E-10
External-soil	1.55E-08	9.09E-08	4.65E-13	9.71E-06	9.81E-06
External	**1.55E-08**	**9.09E-08**	**4.69E-13**	**9.71E-06**	**9.81E-06**
Meat	2.38E-06	1.10E-07	6.37E-08	1.74E-09	2.56E-06
Milk	1.54E-04	7.09E-06	5.14E-06	1.32E-05	1.79E-04
Offal	4.71E-08	2.17E-09	4.41E-10	4.25E-10	5.02E-08
Animal products	1.56E-04	7.20E-06	5.21E-06	1.32E-05	1.82E-04
Green Veg	5.43E-05	8.97E-05	1.33E-06	8.96E-07	1.46E-04
Root Veg	2.15E-04	3.05E-04	1.14E-05	1.99E-06	5.33E-04
Grain	1.27E-08	5.26E-09	3.71E-10	6.19E-11	1.84E-08
Crops	2.69E-04	3.95E-04	1.27E-05	2.89E-06	6.79E-04
Soil (consumption)	3.66E-08	3.59E-08	6.67E-13	4.67E-10	7.29E-08
Water	1.32E-07	1.32E-07	7.68E-10	2.04E-09	2.67E-07
Ingestion	4.26E-04	4.02E-04	1.79E-05	1.61E-05	8.62E-04
Total	4.26E-04	4.04E-04	1.79E-05	2.58E-05	8.74E-04

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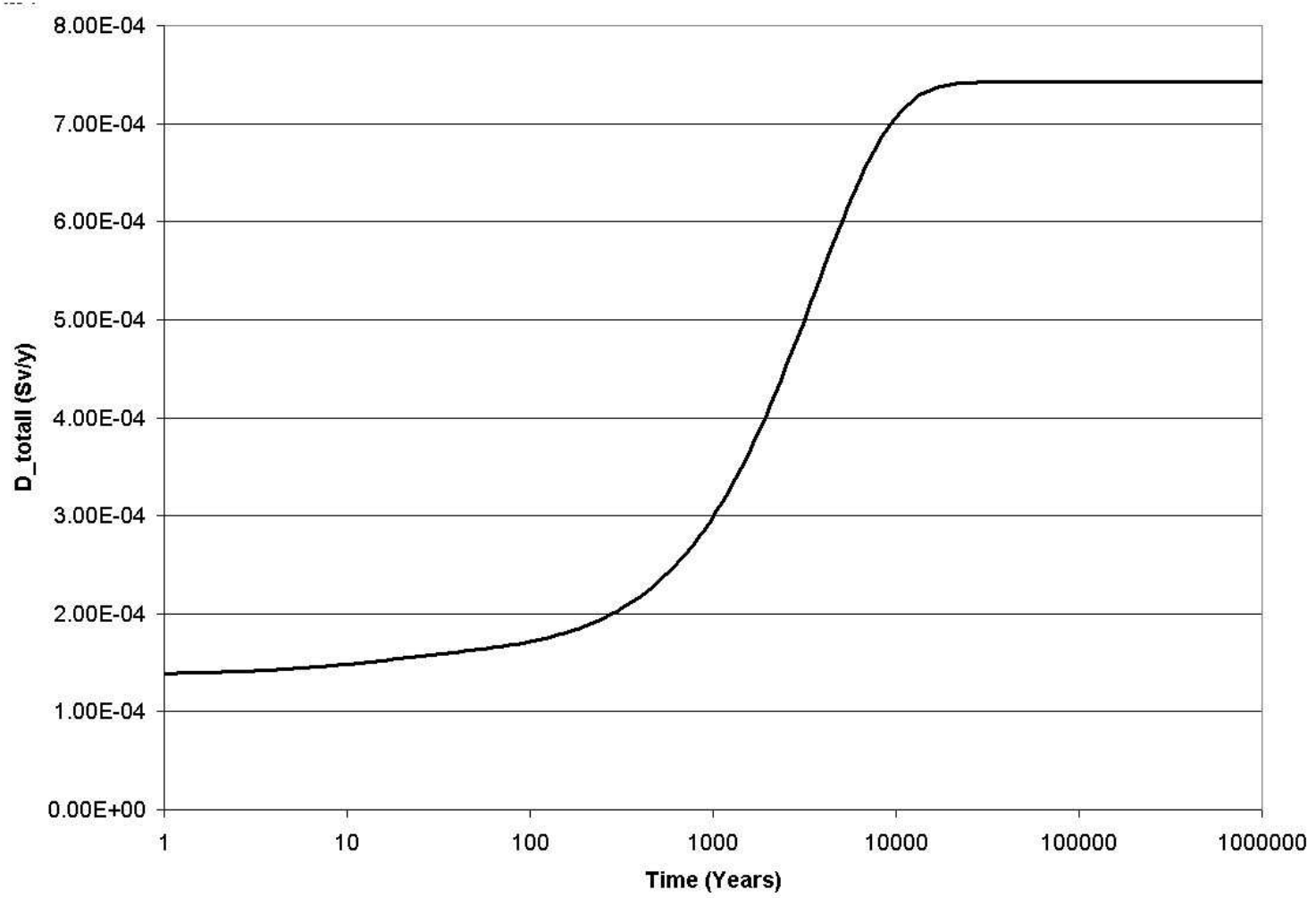
ERB2A Total Annual Dose

(Deterministic)



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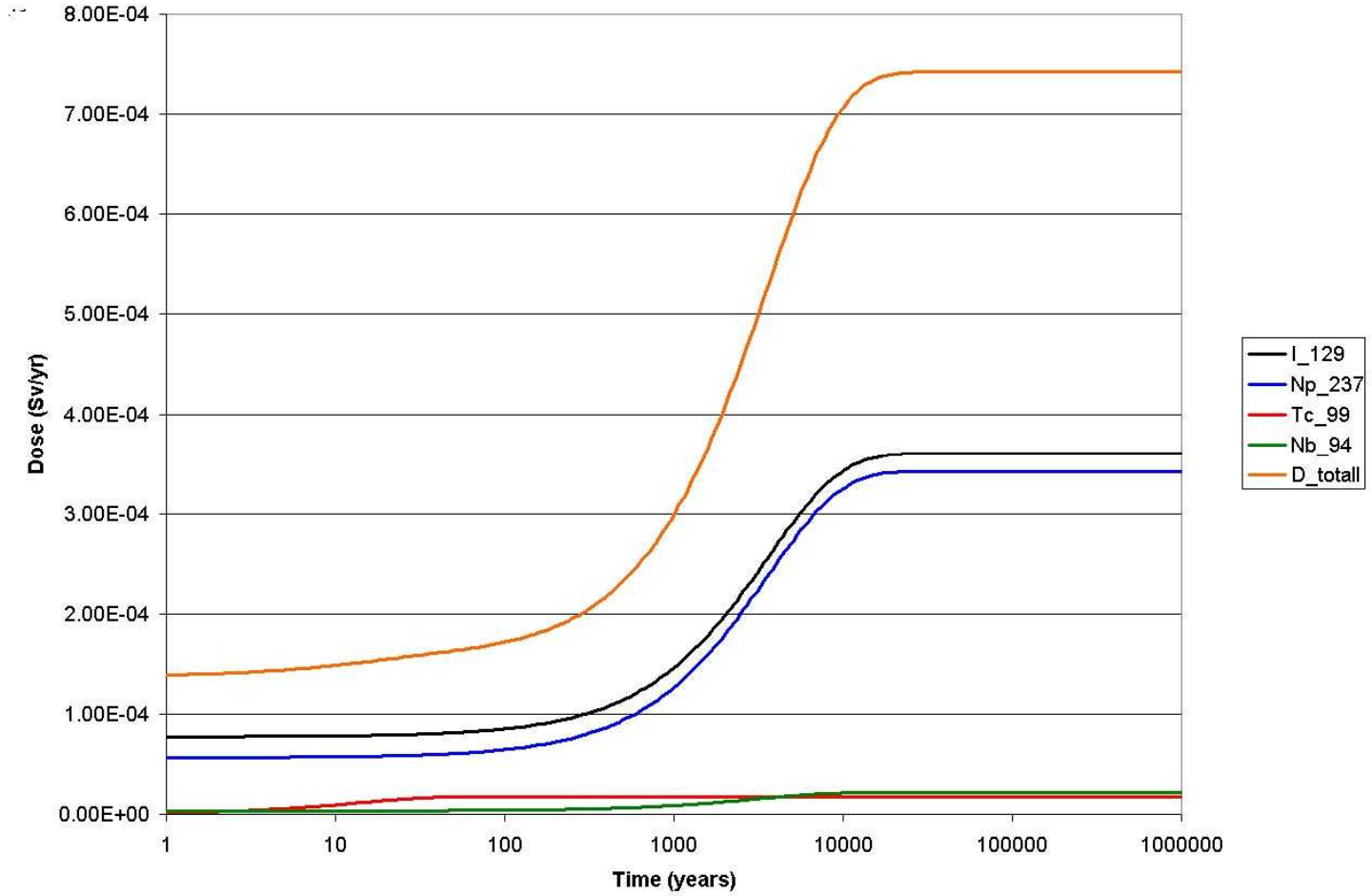
ERB2A - Nuclide Contributions to Dose



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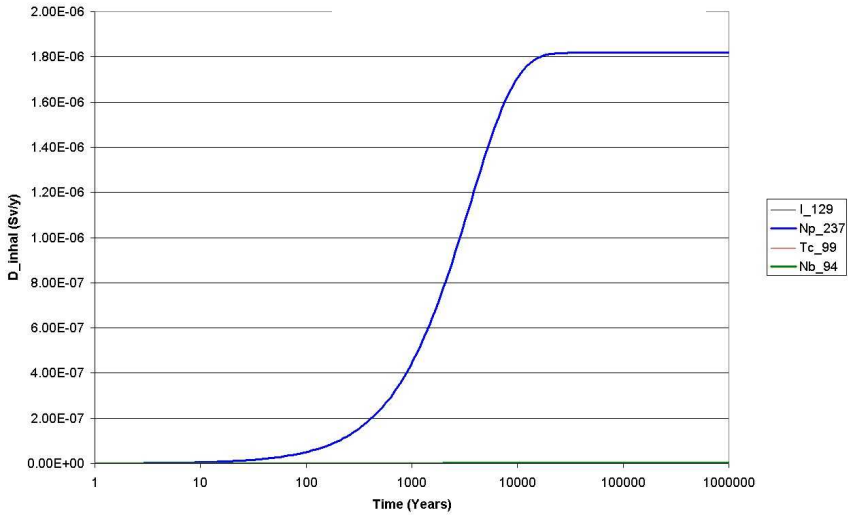
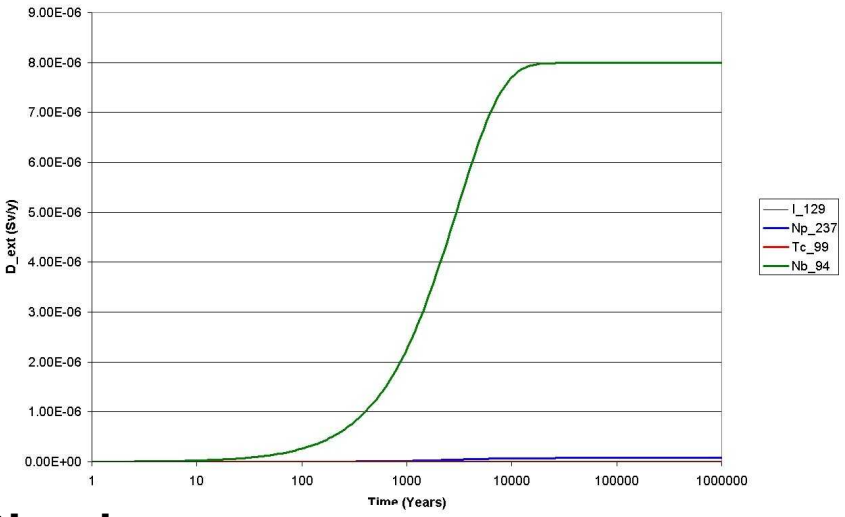
ERB2A Pathway Analysis

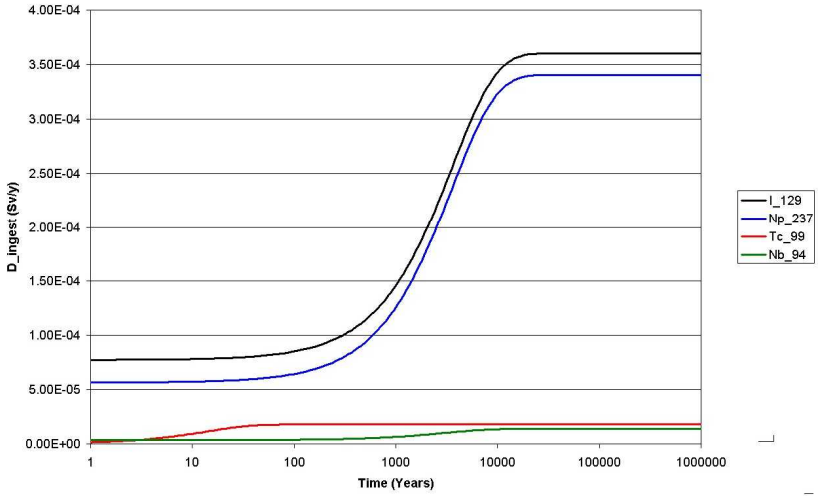
Inhalation Dose



External Exposure Dose



Ingestion dose



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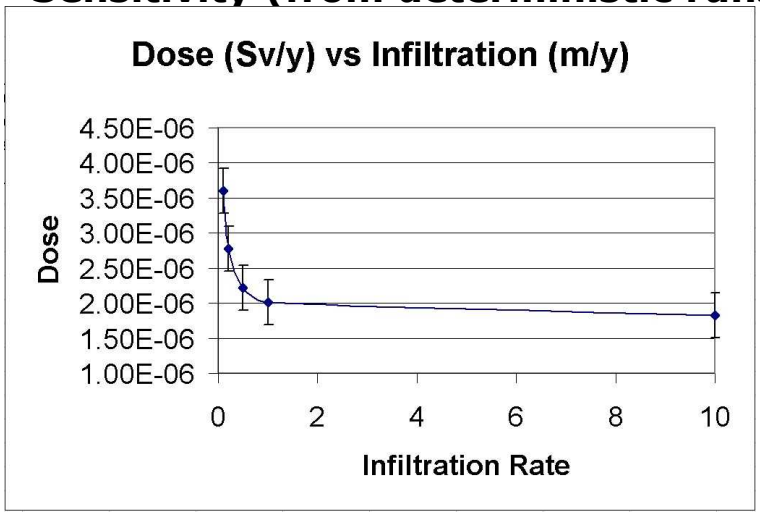
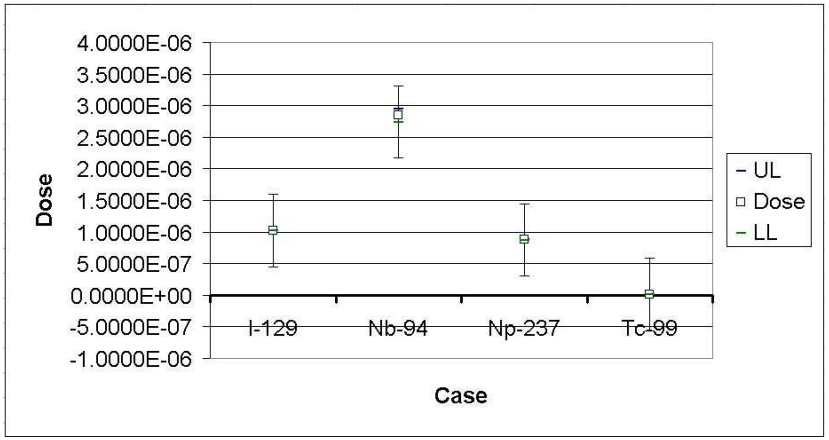
Infiltration – Sensitivity and Uncertainty

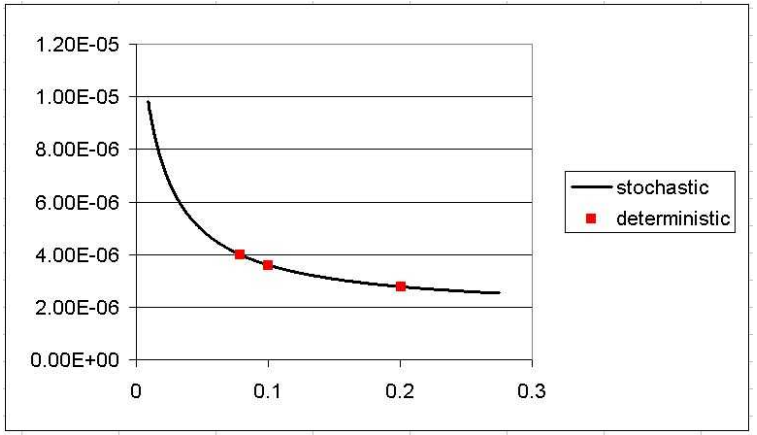
Sensitivity (from deterministic runs)



Uncertainty (probabilistic)



Comparison deterministic vs. probabilistic



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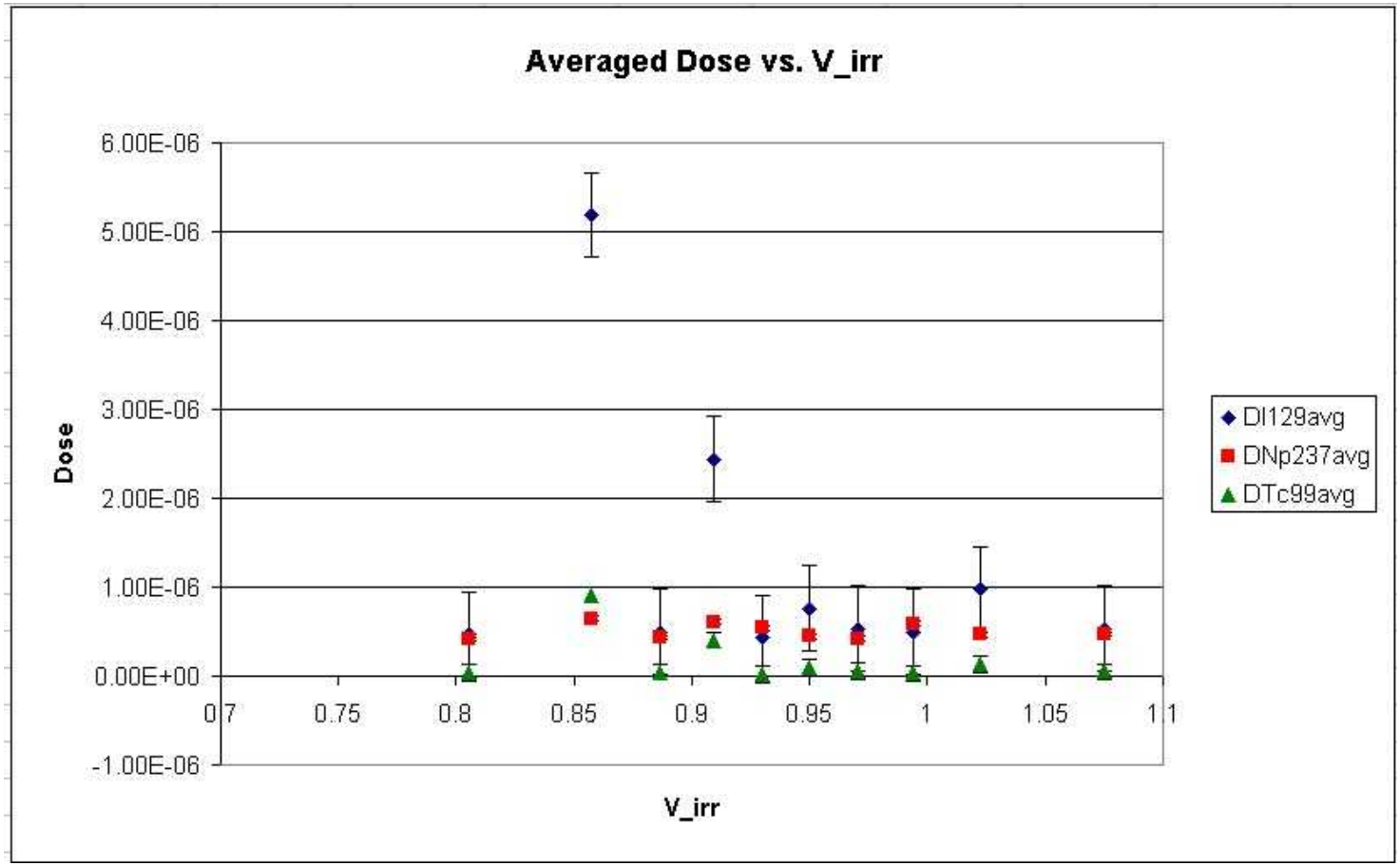
Irrigation - Averaged Dose



All parameters fixed at AMBER ERB2A values, except V_irr.

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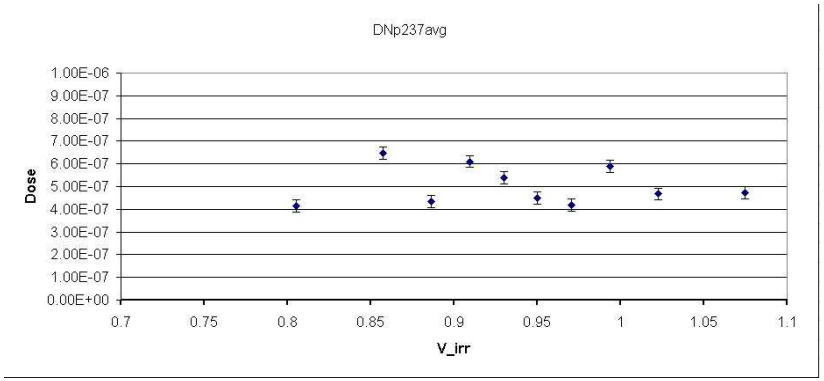
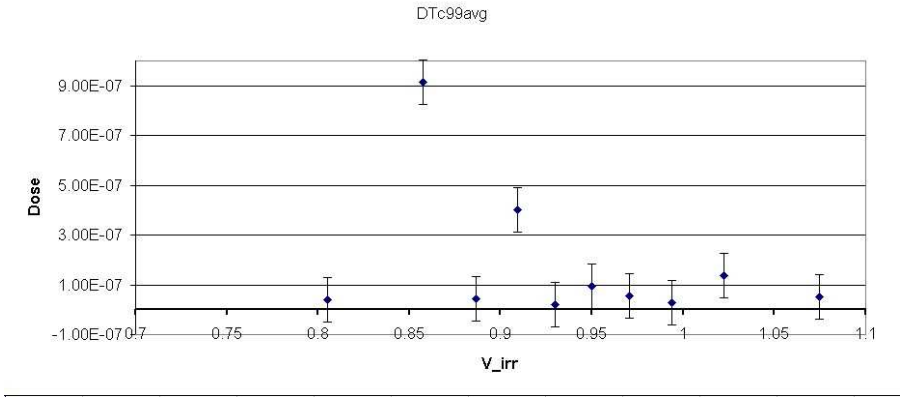
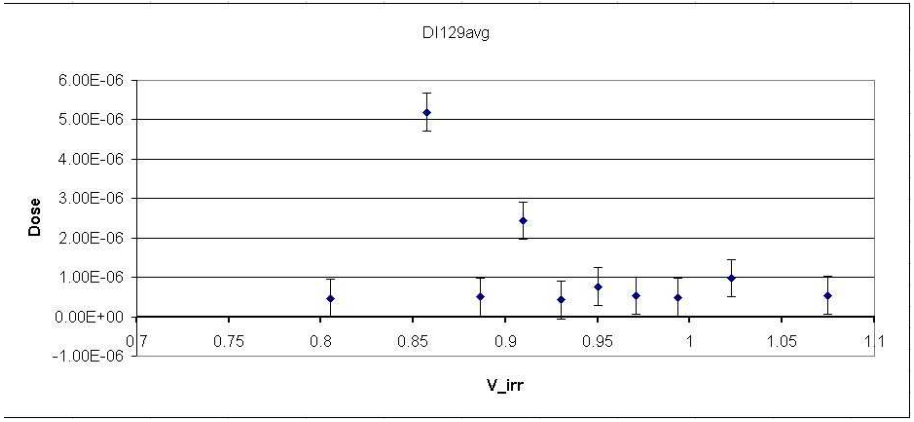
Irrigation - Averaged Dose







All parameters fixed at AMBER ERB2A values, except V_irr.

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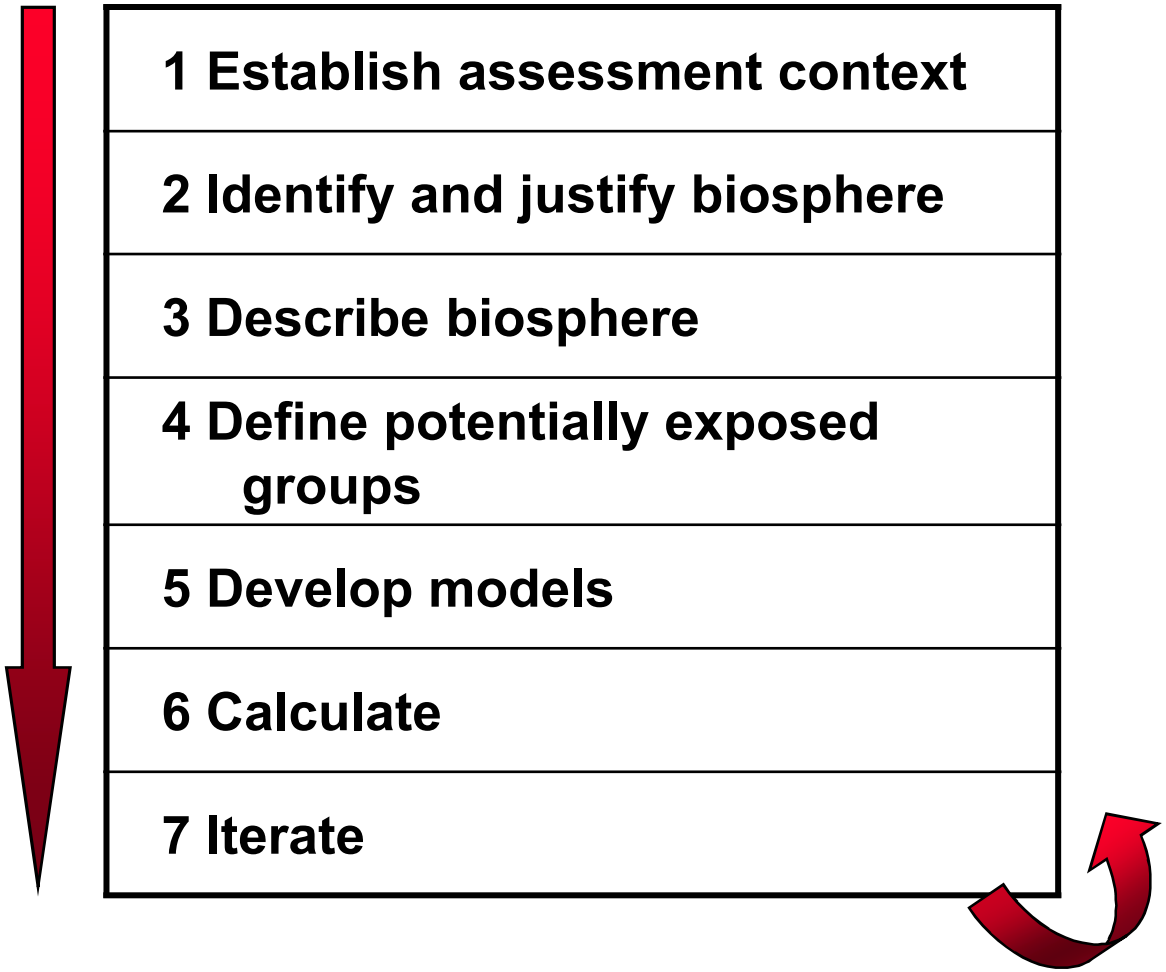
IAEA BIOMASS Methodology



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