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RESRAD-BIOTA Training Course

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Introduction and Course Overview

Introduction of Presenters

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RESRAD-BIOTA Workshop Objective

- For you to leave with a working knowledge of the RESRAD-BIOTA code, for your subsequent use in evaluating and demonstrating radiological protection of biota. We will cover:
  - The technical derivation of DOE's Graded Approach to Biota Dose Evaluation, as it provides the basis for the RESRAD-BIOTA code
  - RESRAD-BIOTA code design, features, and functionality
  - Application of the RESRAD-BIOTA code through implementation of the Graded Approach Framework, highlighting various ways to design your evaluation based on the nature & availability of data
  - Issues when evaluating radiation as a stressor to the environment
  - Instruction, hands-on exercises, and discussion
- Let's also learn from each other

Increasing Interest in Radiation Protection of the Environment

- Revisiting ICRP assumption
- Different exposure pathways
- Site, regulator, and stakeholder interest
- International activity
  - IAEA
  - ICRP
  - Other Countries

ICRP Statements

"…if man is adequately protected then other living things are also likely to be sufficiently protected." (ICRP Pub. 26, 1977)

"The Commission believes that the standards of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk." (ICRP Pub. 60, 1991)

"Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species." (ICRP Pub. 60, 1991)

"…ICRP therefore needs to revise its current system of protection, and particularly, develop a comprehensive approach to the study of the effects on, and protection of, all living matter with respect to the effects of ionising radiation…" (ICRP Pub. 91, 2003)

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Overview of the RESRAD-BIOTA Code

What is RESRAD-BIOTA?

- RESRAD (RESidual RADioactivity) is a suite of computer codes developed at ANL for DOE
- RESRAD was initially developed to derive site-specific soil cleanup criteria
- It was expanded to 9 computer codes
- RESRAD-BIOTA is one of the RESRAD Family of Codes that is being maintained and updated

RESRAD Family of Codes

RESRAD Family of Codes HOME CODES DOWNLOAD TRAINING DOCUMENTS FAQS CONTACT US USER CENTER

The RESRAD family of codes is developed at Argonne National Laboratory to analyze potential human and biota radiation exposures from the environmental contamination of RESidual RADioactive materials. The codes use pathway analysis to evaluate radiation exposure and associated risks, and to derive cleanup criteria or authorized limits for radionuclide concentrations in the contaminated source medium. The RESRAD family of codes is widely used by regulatory agencies, the risk assessment community, and universities in more than 100 countries around the world.

UPCOMING EVENTS

May 19-23, 2025
RESRAD Virtual Training: RESRAD Family of Codes (Five Codes)

Learn More & Register »

RESRAD-ONSITE

For assessing radiation exposures of a human receptor located on top of soils contaminated with radioactive materials

RESRAD-OFFSITE

For assessing radiation exposures of a human receptor located on top of or at some distance from soils contaminated with radioactive materials

RESRAD-BUILD

For assessing radiation exposures of a human receptor in a contaminated building or a building housing contaminated furniture or equipment

RESRAD-RDD

For evaluating human radiation exposures during the early, intermediate, or late phase of response after a radiological dispersal device (RDD) incident

RESRAD-BIOTA

For evaluating radiation exposures of nonhuman biota, including flora and fauna, in a terrestrial or aquatic ecosystem

SQA & DISCLAIMER

RESRAD Software Quality Assurance

Additional User Quality Assurance Requirements

OTHER RESRAD CODES

RESRAD-RECYCLE
RESRAD-BASELINE
RESRAD-CHEM
RESRAD-ECORISK

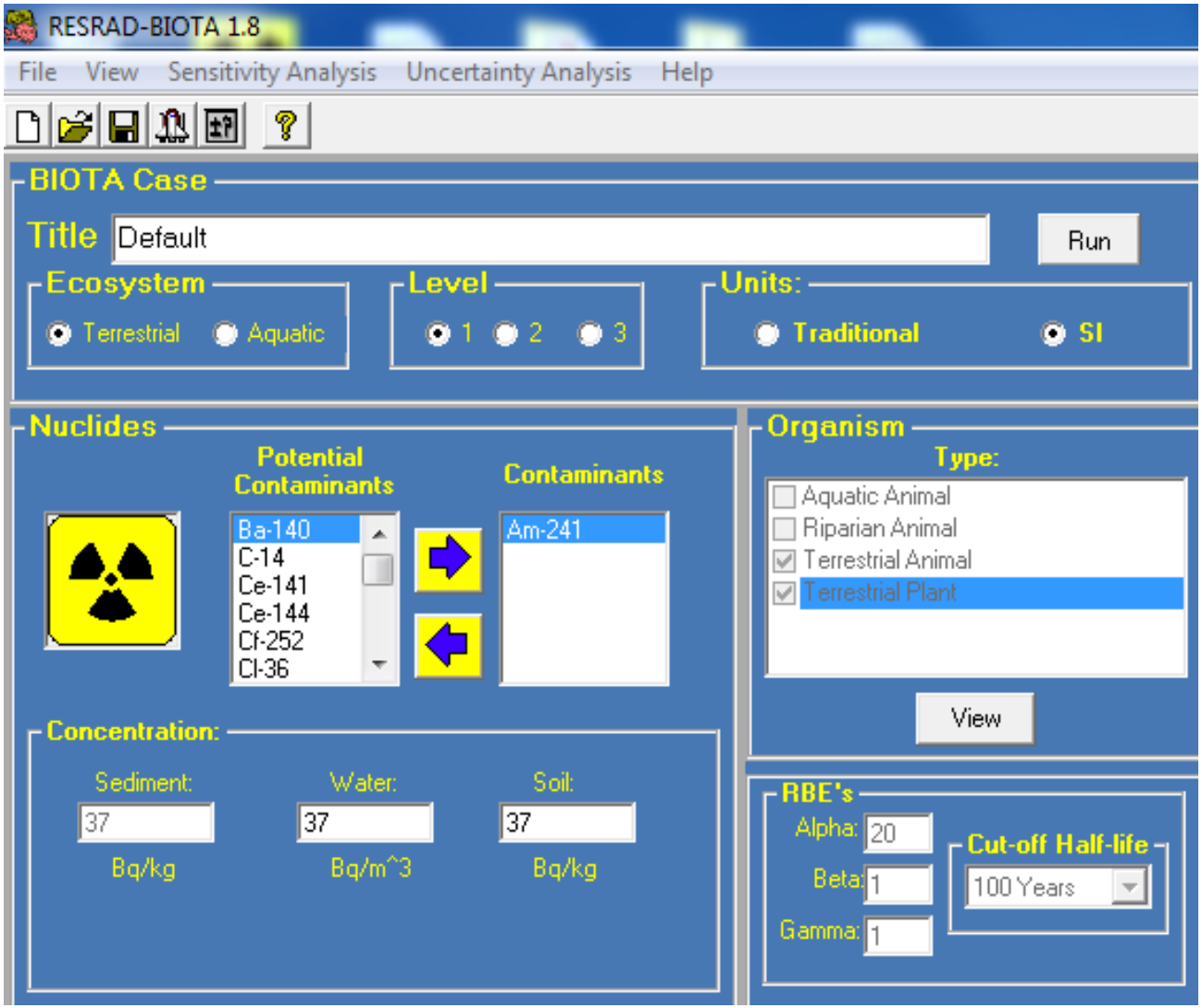
Development of RESRAD-BIOTA

- Code development initiated by DOE in June 2000
- Principally developed and sponsored by DOE since 2000; DOE then formed the ECORAD-Workgroup, an inter-agency group consisting of DOE, the Environmental Protection Agency (EPA), and the Nuclear Regulatory Commission (NRC) to continue code development in collaboration
- RAD-BCG Calculator successfully converted into beta version of RESRAD-BIOTA in 2001
- Added sensitivity analysis capability in 2002
- Generated dose conversion factors for 8 organisms in 2003
- Designed a new user interface with Organism Editor in 2003
- Added food chain model in 2006
- Added probabilistic analysis capability in 2008
- A total of 46 radionuclides in the current database

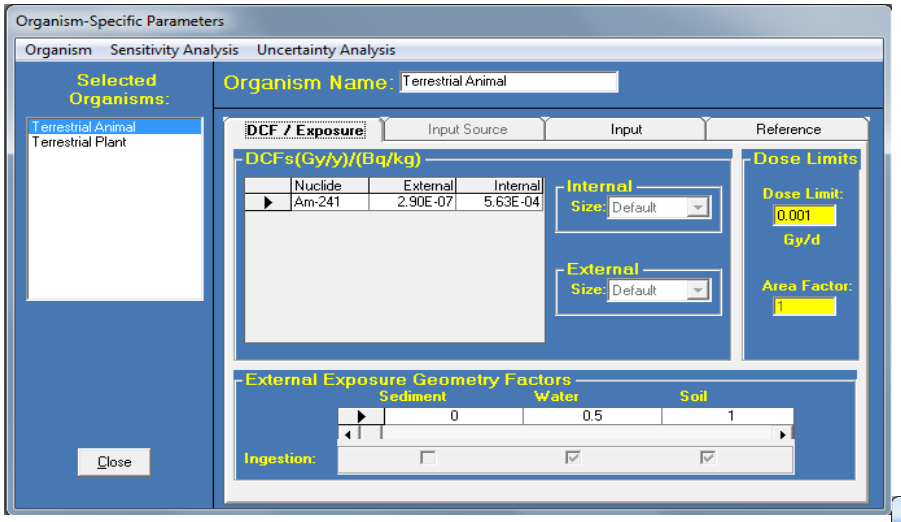
Features of RESRAD-BIOTA

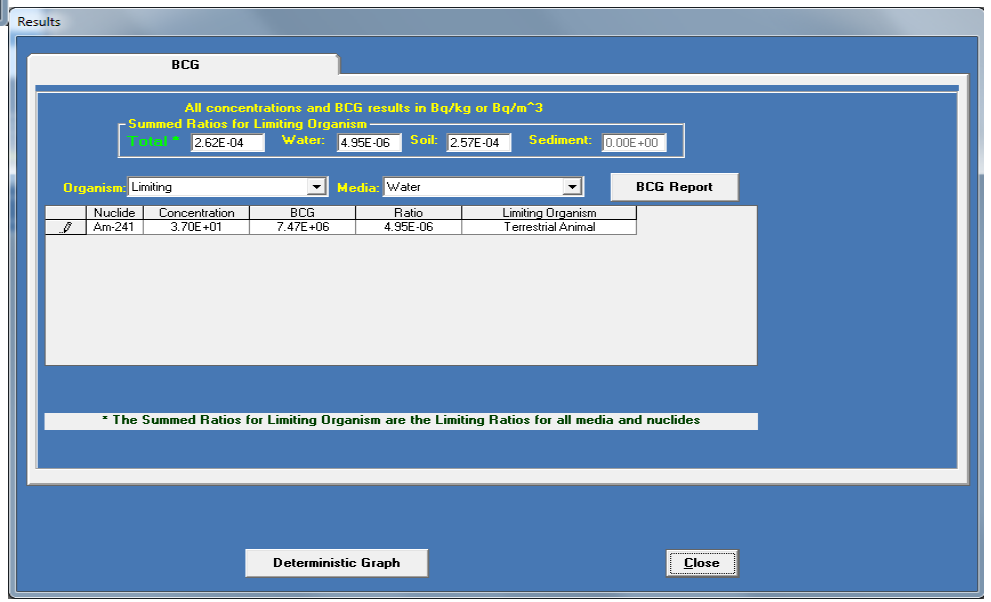
- Has a user-friendly input interface with Help files
- Users can view dose conversion factors (DCFs), dose results, Biota Concentration Guides (BCG) results, etc., and select radiological units
- User can modify lumped parameters (Biv transfer factors and Kd distribution coefficients), dose limits, area factors, radiation weighting factors, DCFs, and allometric parameters, etc.
- Includes DCFs for 8 specific geometries covering a wide range of organisms
- Has Organism Editor and Wizard allowing users to create a new organism
- Has a food chain/web model
- Shows screening results (pass or fail)
- Users can do sensitivity analysis on input parameters
- Users can do probabilistic (uncertainty) analysis on input parameters
- Has text reports (both interactive and HTML) and graphic report (bar charts)
- Import and export data

RESRAD-BIOTA Main Window

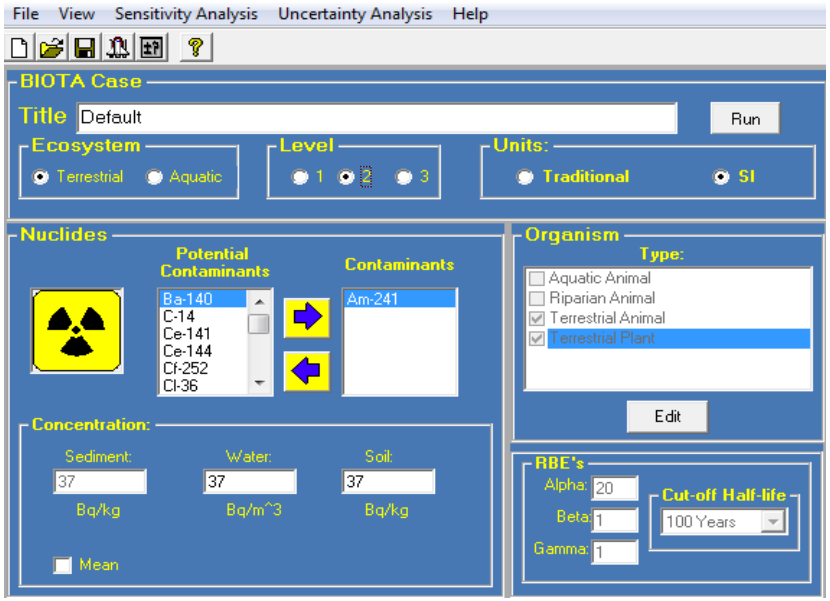


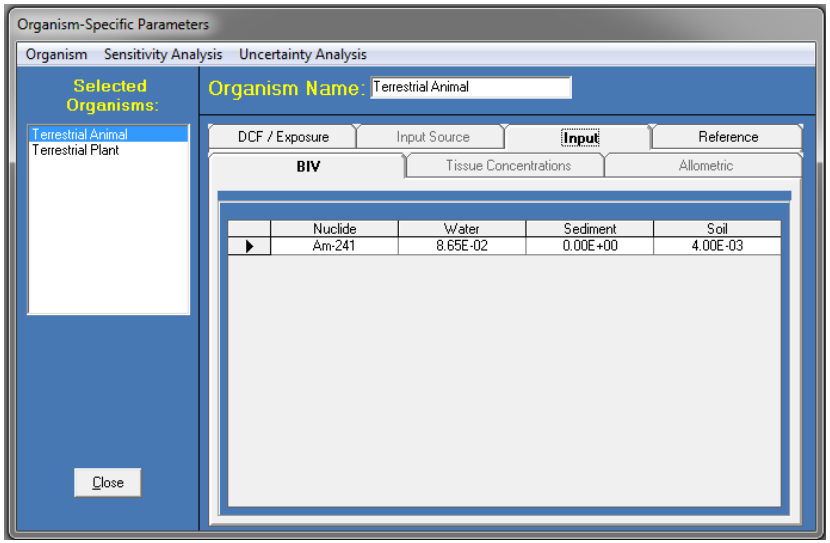
Level 1 Windows

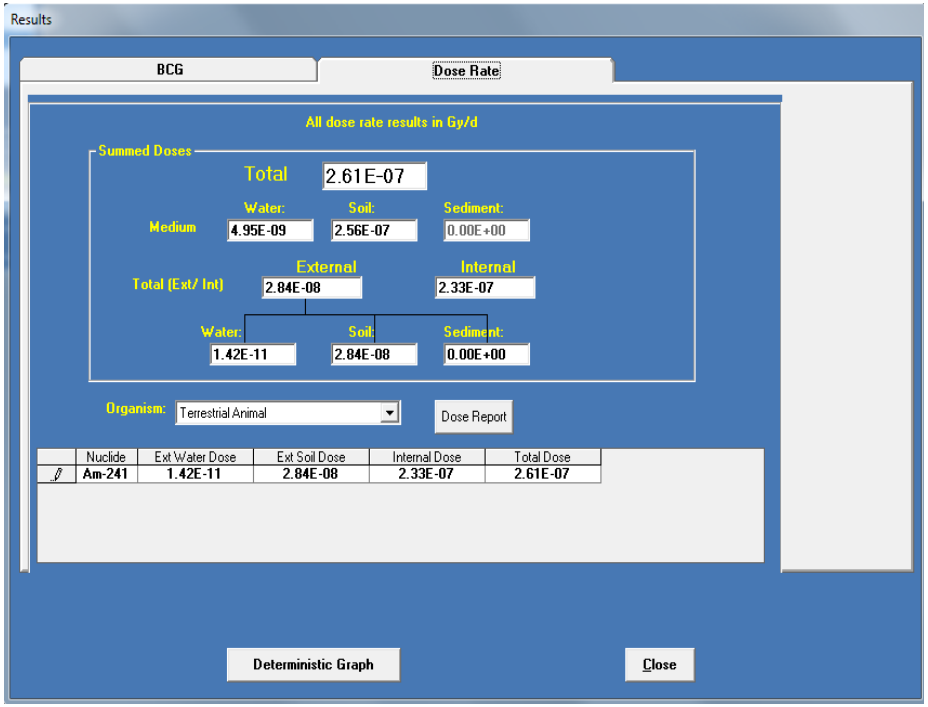




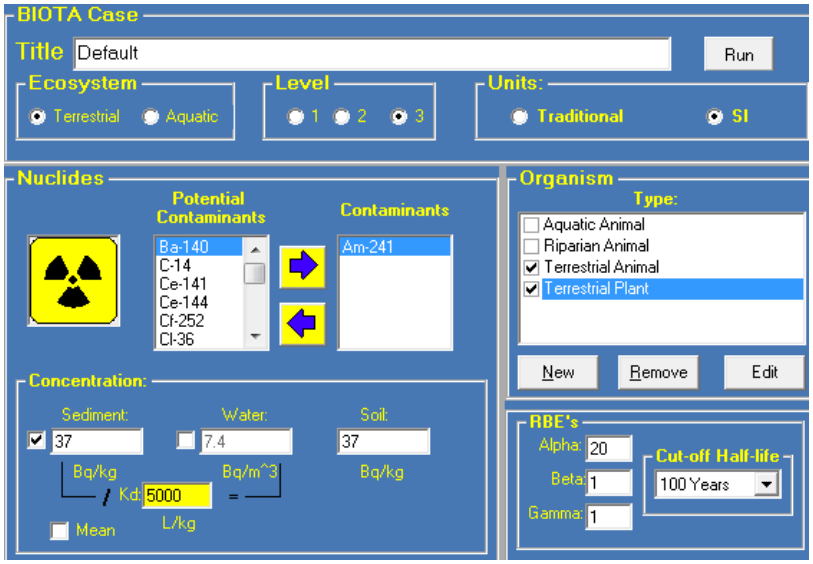
Level 2 Windows

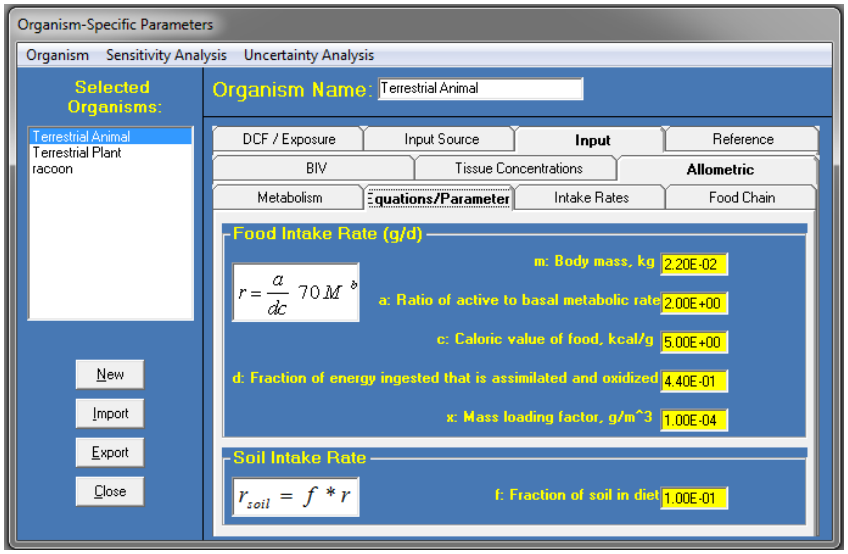


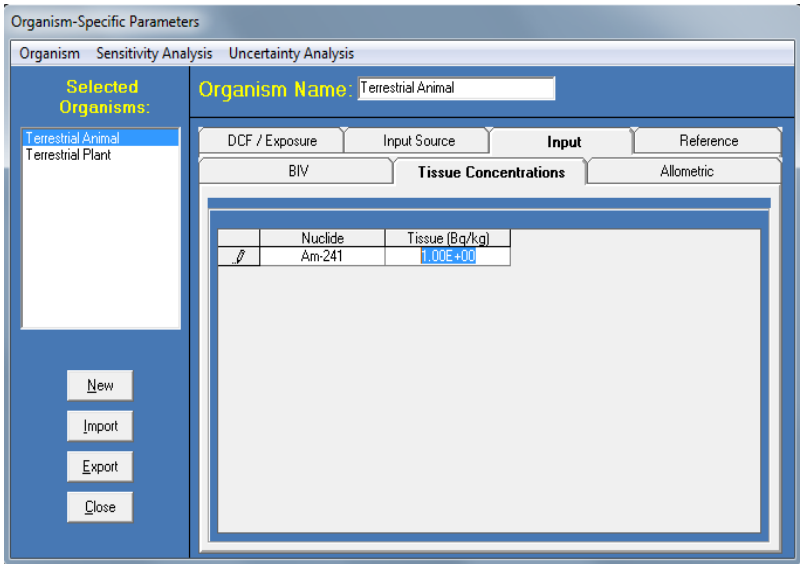


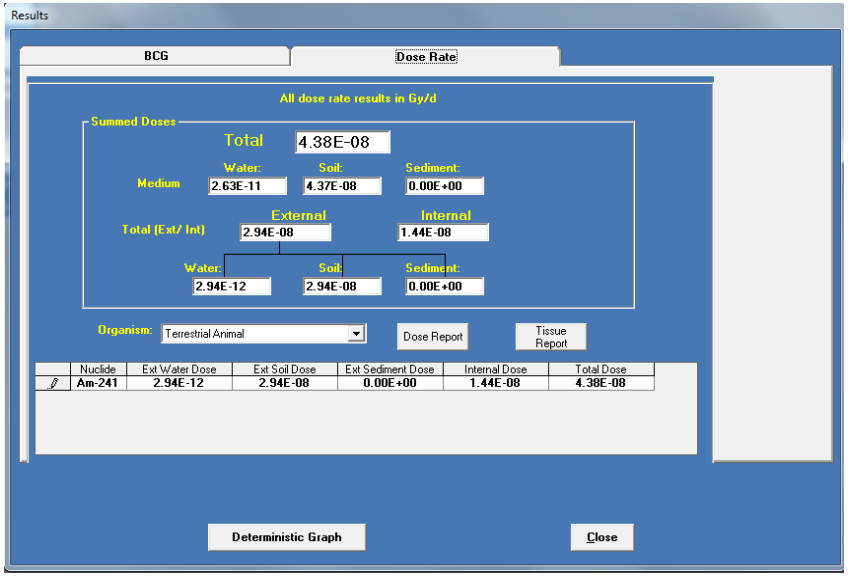


Level 3 Windows

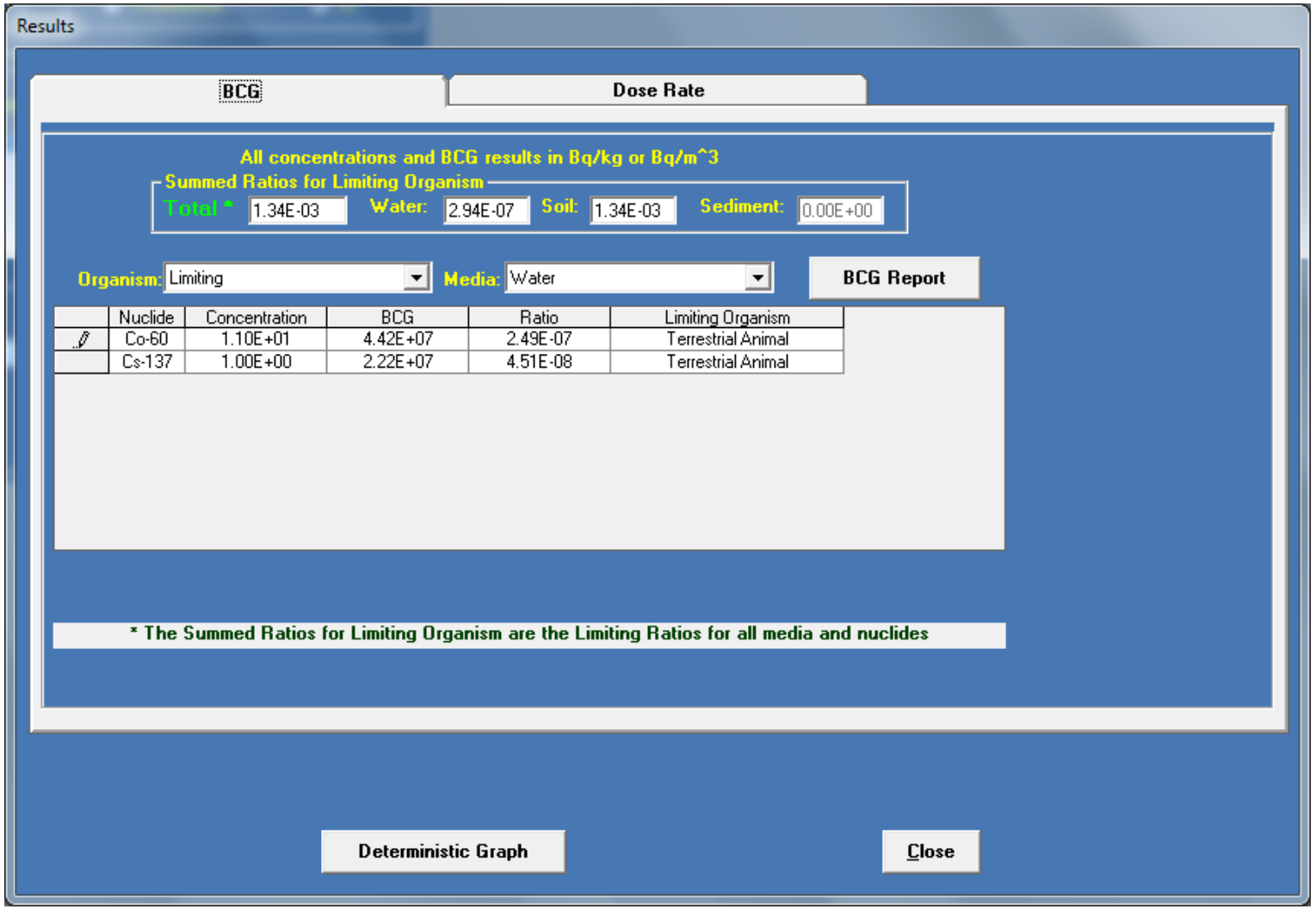




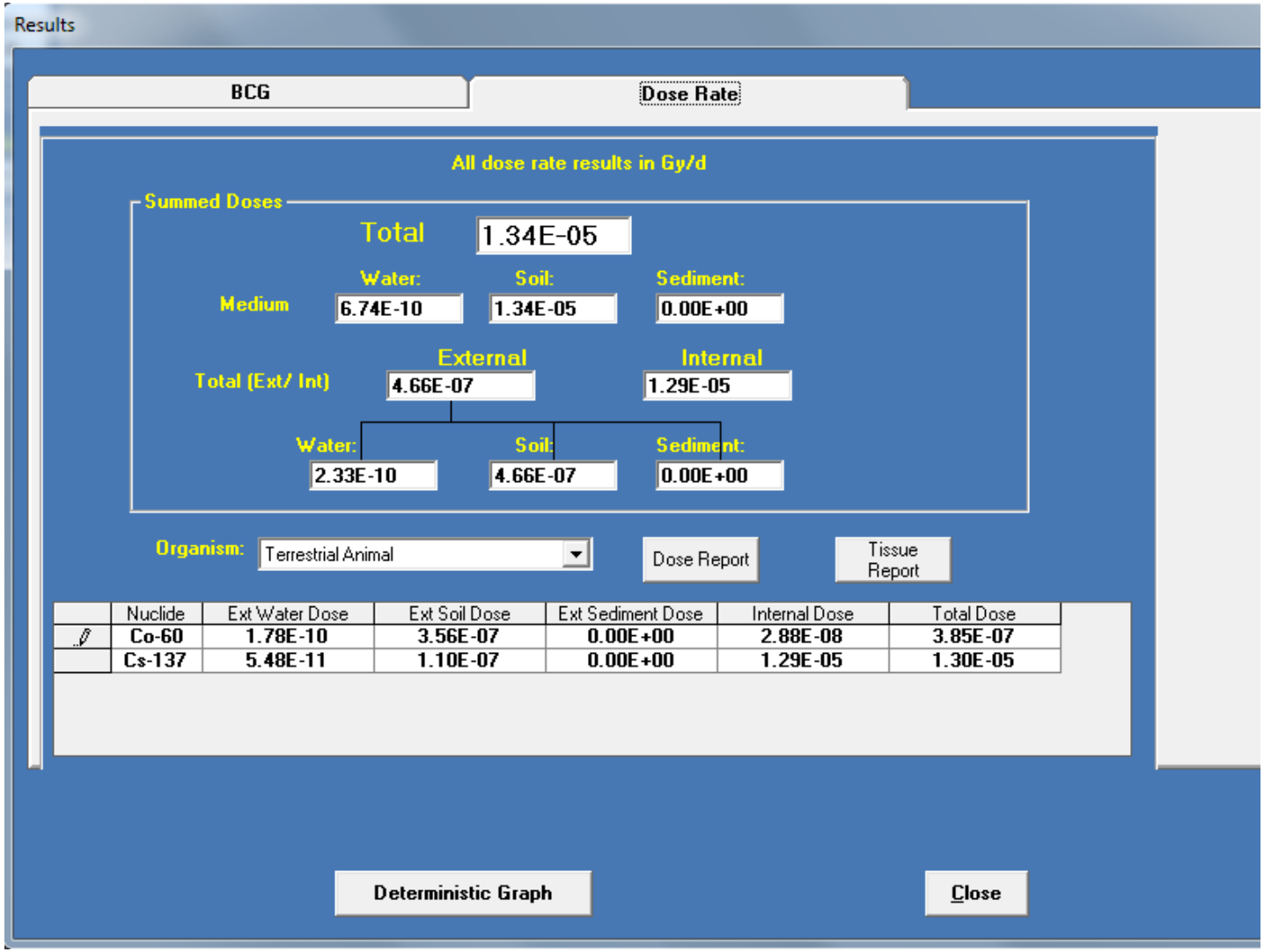




Interactive Report (BCG)



Interactive Report (Dose Rate)



HTML Report

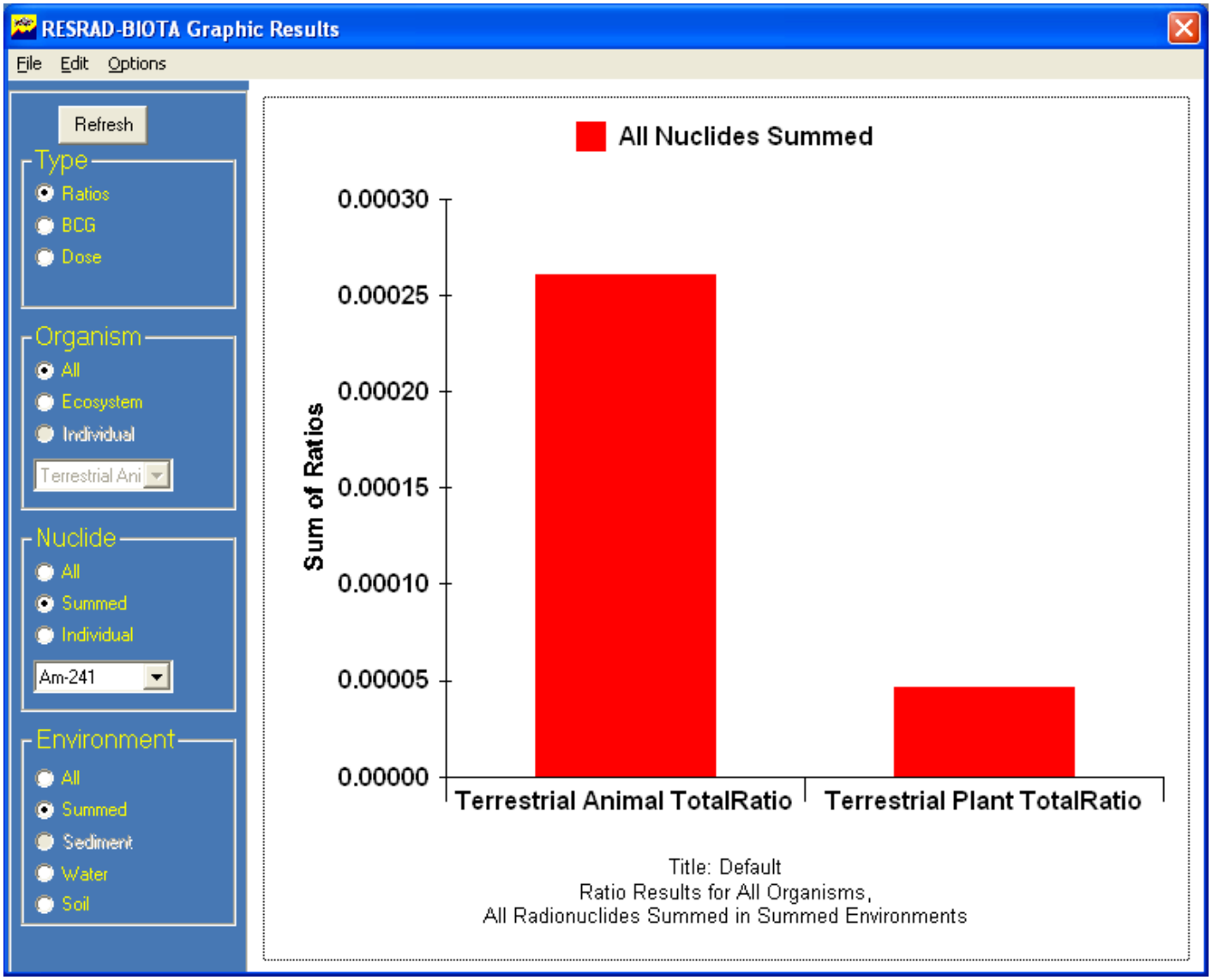
Terrestrial Dose Report for Level 2 in Gy/d

Title: Default

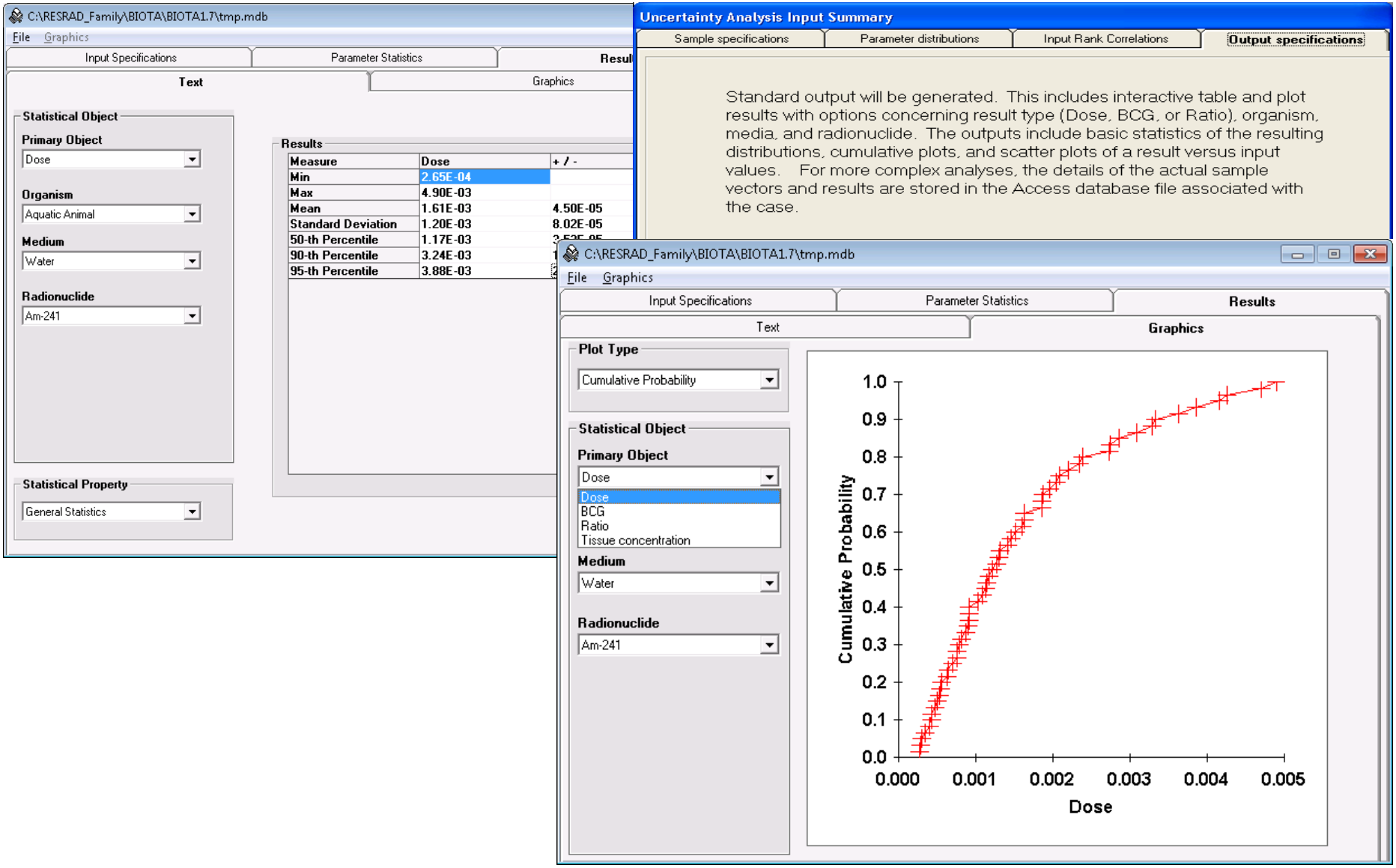
Terrestrial Animal												
Nuclide	External				Internal				Total			
	ext_Wtr	ext_Soil	ext_Sed	ext_Sum	int_Wtr	int_Soil	int_Sed	int_Sum	tot_Wtr	tot_Soil	tot_Sed	tot_Sum
Co-60	1.96E-10	3.56E-08	0.00E+00	3.58E-08	5.30E-11	3.47E-09	0.00E+00	3.53E-09	2.49E-10	3.91E-08	0.00E+00	3.93E-08
Cs-137	5.48E-12	1.10E-08	0.00E+00	1.10E-08	3.96E-11	1.29E-06	0.00E+00	1.29E-06	4.51E-11	1.30E-06	0.00E+00	1.30E-06
Summed	2.01E-10	4.66E-08	0.00E+00	4.68E-08	9.26E-11	1.29E-06	0.00E+00	1.29E-06	2.94E-10	1.34E-06	0.00E+00	1.34E-06

Terrestrial Plant												
Nuclide	External				Internal				Total			
	ext_Wtr	ext_Soil	ext_Sed	ext_Sum	int_Wtr	int_Soil	int_Sed	int_Sum	tot_Wtr	tot_Soil	tot_Sed	tot_Sum
Co-60	1.96E-10	3.56E-08	0.00E+00	3.58E-08	3.32E-12	8.50E-09	0.00E+00	8.50E-09	1.99E-10	4.41E-08	0.00E+00	4.43E-08
Cs-137	5.48E-12	1.10E-08	0.00E+00	1.10E-08	0.00E+00	1.11E-07	0.00E+00	1.11E-07	5.48E-12	1.22E-07	0.00E+00	1.22E-07
Summed	2.01E-10	4.66E-08	0.00E+00	4.68E-08	3.32E-12	1.20E-07	0.00E+00	1.20E-07	2.05E-10	1.66E-07	0.00E+00	1.67E-07

Graphic Results



Probabilistic Analysis Results



Parameter Access vs Level

Parameter	Level		
	1	**2**	**3**
Units	x	x	x
Concentration, K_d Option, DL	x	x	x
View BCG results	x	x	x
View dose results		x	x
Sensitivity		x	x
K_d Modification, Mean Conc. setting		x	x
BIV		x	x
CF,T,f			x
DCF options (RBE, T_{cut})			x
Organism selection			x
Organism addition (W, shape,Base)			x
Organism allometric params			x
Allometric option (org,nuc)			x

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Demonstration of the RESRAD-BIOTA Code

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The Technical Basis Behind the RESRAD-BIOTA Code:

Derivation of the DOE Graded Approach Methodology

Overview

- Historical Context for Radiation Protection of the Environment
- Derivation of the DOE Graded Approach Methodology
- Assumptions,
- Dose Coefficients,
- Parameter Selection,
- Dose Rate Modifiers,
- Allometric Methods,
- Design Features and Flexibility

Evolution of Dose Limits for Biota

- Historical setting:
  - Human limits are dose-based
  - Protection established by examining all exposure pathways

- 1990's DOE considered parallel protection for biota
  - DOE Standard (DOE Order 5400.5):
    - *10 mGy/d (1 rad/d) for aquatic organisms*
    - *Intended to protect **natural populations** if dose to a representative exposed individual is less than the limit.*

Dose Limits for Biota

- Based on NCRP and IAEA findings
- Other standards proposed
  - 10 CFR 834, Subpart F:
    - *400 µGy/hr (1 rad/d) for aquatic animals*
    - *400 µGy/hr (1 rad/d) for terrestrial plants*
    - *40 µGy/hr (0.1 rad/d) for terrestrial animals*

Requirements for Biota Protection

- ***DOE Order 5400.5; (since 1990)*: 400 µGy/hr (1 rad/d) dose limit for aquatic organisms**
- ***Proposed 10 CFR 834, Subpart F; (1995-96)*: Proposed limits of 400 µGy/hr (1 rad/d) for terrestrial plants; 40 µGy/hr (0.1 rad/d) for terrestrial animals. Not codified but represent DOE's recommended terrestrial dose limits**
  - Site and public comments - requests for screening approaches, standardization, flexibility to use site-specific information
- ***DOE Order 450.1; (2003)*: Requires biota protection; environmental monitoring program such that resulting data obtained is sufficient to allow for biota dose evaluation**
- ***DOE O458.1; (2011*): The dose limits for aquatic animal, riparian animal, terrestrial plant, and terrestrial animal are 1 rad/d, 0.1 rad/d, 1 rad/d, and 0.1 rad/d respectively.**
- **Strategic Goal: Incorporate biota dose evaluation into site environmental monitoring and surveillance programs as a good business practice; communicate evaluation results in the annual site evaluation report**

Guiding Principles for Methods Development

- Provide a ***graded approach*** to support multiple needs and users (compliance - to - ecological risk)
- Easy to use and technically sound
- Utilize existing generic and site-specific data
- Applicable to multiple media and biota types
- Draw upon eco-risk concepts and protocols
- Interdisciplinary team approach: involve “users” and “developers”
- Provide leadership in methods development
- ***Be Forward Thinking: Build in flexibility; anticipate regulatory or technical changes***

Demonstrating Protection

- Dose-based biota-protection standards
  - Difficult to demonstrate compliance
- A more practical approach:
  - Derive radionuclide concentration limits for environmental media
  - Protective of all biota
- DOE's biota concentration guides (BCGs)
  - Limiting radionuclide concentrations in soil, sediment, and water

DOE's Graded Approach

1. Data Assembly

2. General Screening

3. Analysis
   - Site Specific Screening
   - Site Specific Analysis
   - Site Specific Biota Dose Assessment

Compare media concentrations with Biota Concentration Guides (BCGs) *(RESRAD-BIOTA Level 1)*

Site-representative parameters *(RESRAD-BIOTA Level 2)*

Kinetic/allometric modeling tool *(RESRAD-BIOTA Level 3)*

Collection of biota using eco-risk protocols

DOE Biota Technical Standard

MODULE 1: Principles and Applications (*users guide*)

- Overview of the graded approach & evaluation process
- Application considerations
- Look-up tables; step-by-step guidance; RAD-BCG Calculator
- Examples

MODULE 2: Detailed Guidance (*links to users guide*)

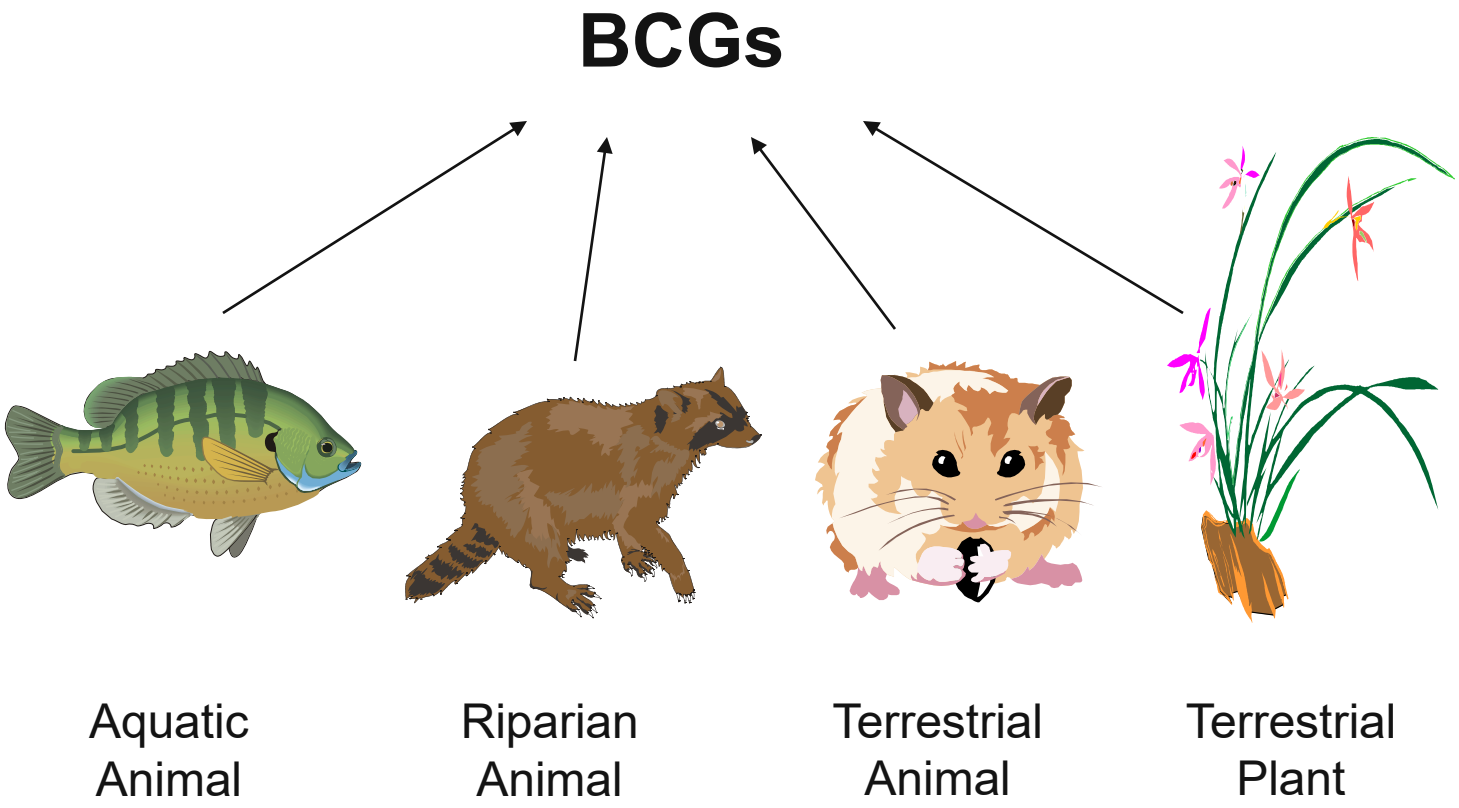
- Radiological ecological risk assessment: tutorial & issues
- Time averaging and spatial variability (contaminants & doses)
- Defining the evaluation area
- Biota sampling design and methods
- Radiation weighting factor for alpha particles
- Evaluation of individuals; special considerations

MODULE 3: Methods Derivation (*links to users guide*)

- Equations and models for deriving BCGs / default parameters

Download: Documents [RESRAD Family of Codes]

Receptors Used in Deriving the Screening Methodology



Basic Screening Methodology

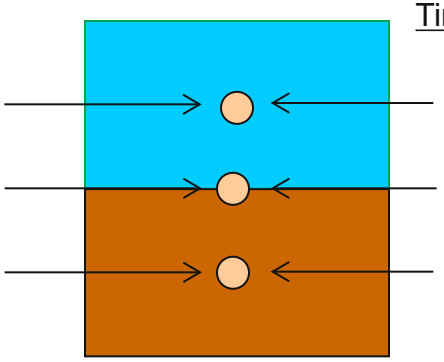
$$\text{BCG} = \frac{\text{Dose Limit}}{\text{Internal Dose} + \text{External Dose}}$$

- Evaluate for unit concentration for single media (e.g., soil)
- Use sum of fractions approach for multiple media (e.g., sediment, water) and radionuclides

Assumptions for External Dose

- Source medium is infinite/semi-infinite in extent and contains uniform concentrations of radionuclides
- Extremely small organism
- DCFs are for an infinite source medium (soil, water, or sediment)
- External exposure geometry factor – for use to multiply DCFs

Terrestrial system	Aquatic system	Geometry	Time fraction
air	water	4 π	0.75
air/soil interface	water/sediment interface	2 π for each medium	0.25
soil	sediment	4 π	0



External exposure geometry factor

Terrestrial system:
0.5 × 0.25 + 1 × 0 = 0.125 for soil

Aquatic system:
1 × 0.75 + 0.5 × 0.25 = 0.875 for water and
0.5 × 0.25 + 1 × 0 = 0.125 for sediment

External Dose Factors

$$\left(1\,\frac{\text{MeV}}{\text{Bq-s}}\right)\cdot\left(1.6\text{x}10^{-13}\,\frac{\text{J}}{\text{MeV}}\right)\cdot\left(\frac{\text{kg Gy}}{\text{J}}\right)\cdot\left(3.156\text{x}10^{7}\,\frac{\text{s}}{\text{y}}\right)$$

$$= 5.05\text{x}10^{-6}\,\frac{\text{Gy/y}}{\text{Bq/kg}}$$

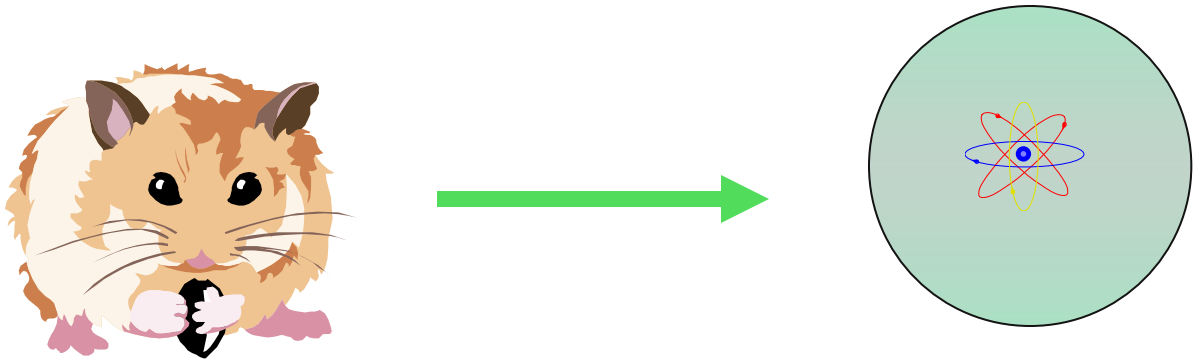
$$(d_{ext})_{sediment}\left(\frac{\text{Gy/y}}{\text{Bq/kg}}\right) = (2.52\text{x}10^{-6})E_{photons\,+\,electrons}\left(\frac{\text{MeV}}{\text{dis}}\right)$$

$$(d_{ext})_{water}\left(\frac{\text{Gy/y}}{\text{Bq/m}^3}\right) = (2.52\text{x}10^{-9})E_{photons+electrons}\left(\frac{\text{MeV}}{\text{dis}}\right)$$

$$(d_{ext})_{soil}\left(\frac{\text{Gy/y}}{\text{Bq/kg}}\right) = (5.05\text{x}10^{-6})E_{photons+electrons}\left(\frac{\text{MeV}}{\text{dis}}\right)$$

Assumptions for Internal Dose

- Extremely large organism
- All decay energies retained in tissue
- Chain-decay progeny included
- Radiation weighting factor included (and modifiable)
- Nuclides uniformly distributed



Internal Dose Factors

$$DCF_{internal,i} =$$

$$\left(\frac{1\text{dis}\cdot s^{-1}}{\text{Bq}}\right)\left(\sum_i\sum_j Y_j E_j Q_j\right)(1.6022\text{E}-13\ \text{J MeV}^{-1})(3.1536\text{E}07\text{s}\cdot y^{-1})\frac{1\text{Gy}}{1\text{J}\cdot\text{kg}^{-1}}$$

- Where the following terms apply:
  - $DCF_{Internal,i}$ = Gy/y per Bq/kg of wet tissue for radionuclide i;
  - Y_j = yield (abundance) of radiation j per disintegration of nuclide i;
  - E_j = energy (MeV) of radiation j for nuclide i; and
  - Q_j is the radiation weighting factor (quality factor) for radiation j of nuclide i.

Deriving Limiting Concentrations

$$BCG = \frac{DL}{DCF_{internal} \cdot LP + DCF_{external}}$$

$$Bq \cdot kg^{-1} = \frac{Gy \cdot y^{-1}}{Gy \cdot y^{-1}/Bq \cdot kg^{-1}}$$

- $DCF_{internal}$ (Gy y^{-1}/ Bq kg^{-1}) is the dose conversion factor for radionuclides in the tissue of the organism;
- LP is a parameter which relates radionuclide concentration in the media external to the organism to its internal tissues;
- $DCF_{external}$ (Gy y^{-1}/ Bq kg^{-1}) is the dose conversion factor for radionuclides in the media external to the organism;

Lumped Parameters

$$LP = \frac{Bq \cdot kg^{-1}\ in\ plant\ or\ animal\ tissues(wet\ weight)}{Bq \cdot kg^{-1}\ in\ soil\ or\ sediment(dry\ weight)} = \frac{Bq \cdot kg^{-1}}{Bq \cdot kg^{-1}}$$

$$LP = \frac{Bq \cdot kg^{-1}\ in\ plant\ or\ animal\ tissues(wet\ weight)}{Bq \cdot m^{-3}\ in\ water} = m^3 \cdot kg^{-1}$$

- Measures degree of radionuclide transport in an ecosystem
- Sometimes called
  - Concentration ratio
  - Concentration factor
  - Transfer factor, or
  - Wet-weight concentration ratio (**Biv**)

Lumped Parameter Dataset

A Qualitative Assessment of Availability of Lumped Parameters for Vertebrate Animals in the Technical Literature					
	Soil	Plant	Herbivore	Omnivore	Carnivore
Plant	R				
Herbivore	L	R			
Omnivore	S	L	S		
Carnivore	S	S	S	S	S

N/A = not applicable R = Reasonable data set
L = Limited data set S = Scarce to non-existent data

Addressing Data Gaps

- Lumped Parameters (LPs)
  - Empirical data
  - Product approach
  - Calculational method called “kinetic/allometric”
- Lessons learned in method development:
  - Less data available than we originally thought
  - Continuously “reality checking” with site applications

Kinetic Approach, Internal Exposure

Intake Rate → **Body Burden** → Loss Rate (through biological and radioactive decay)

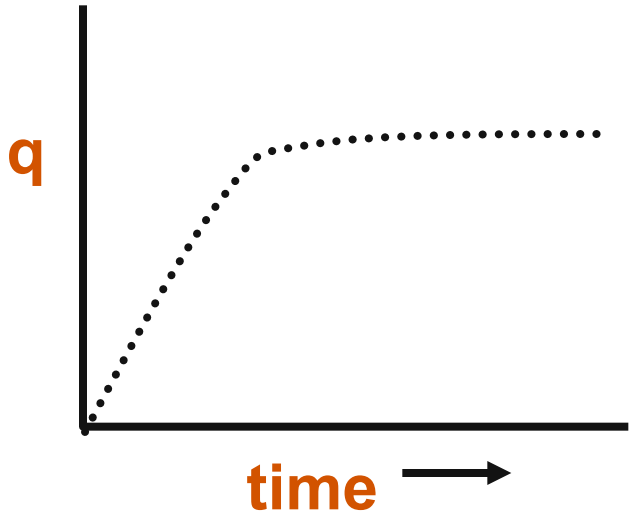
$$\frac{d(Body\ Burden)}{dt} = Intake\ rate\ - K_{loss}\ \times (Body\ Burden),$$

$$Body\ Burden = \frac{Intake\ rate}{K_{loss}}(1\ -\ e^{-K_{loss}\times t}),$$

$where\ K_{loss} =$ Loss rate constant, $and\ t\ =$ exposure time.

Kinetic Approach, Body Burden Estimates

- Function of:
  - Body mass
  - Intake rate
  - Loss rate
  - Exposure time
- Need to address:
  - varying mass
  - intake
  - exposure period



Activity concentration in the organism = Body Burden/Mass

Allometric Relationships

- Cross-species relationships
  - $Y = aX^b$
  - Empirically obtained
  - Derived from energy/nutrient transport limitations
- Mass and Metabolic Rate
  - $M^{3/4}$ (Ingestion, Inhalation)
  - $M^{1/4}$ (Life-span)
  - aM^x (biological elimination rate)
- Mass and Home Range
  - $M^{\sim 3/4}$ (Defining exposure areas)

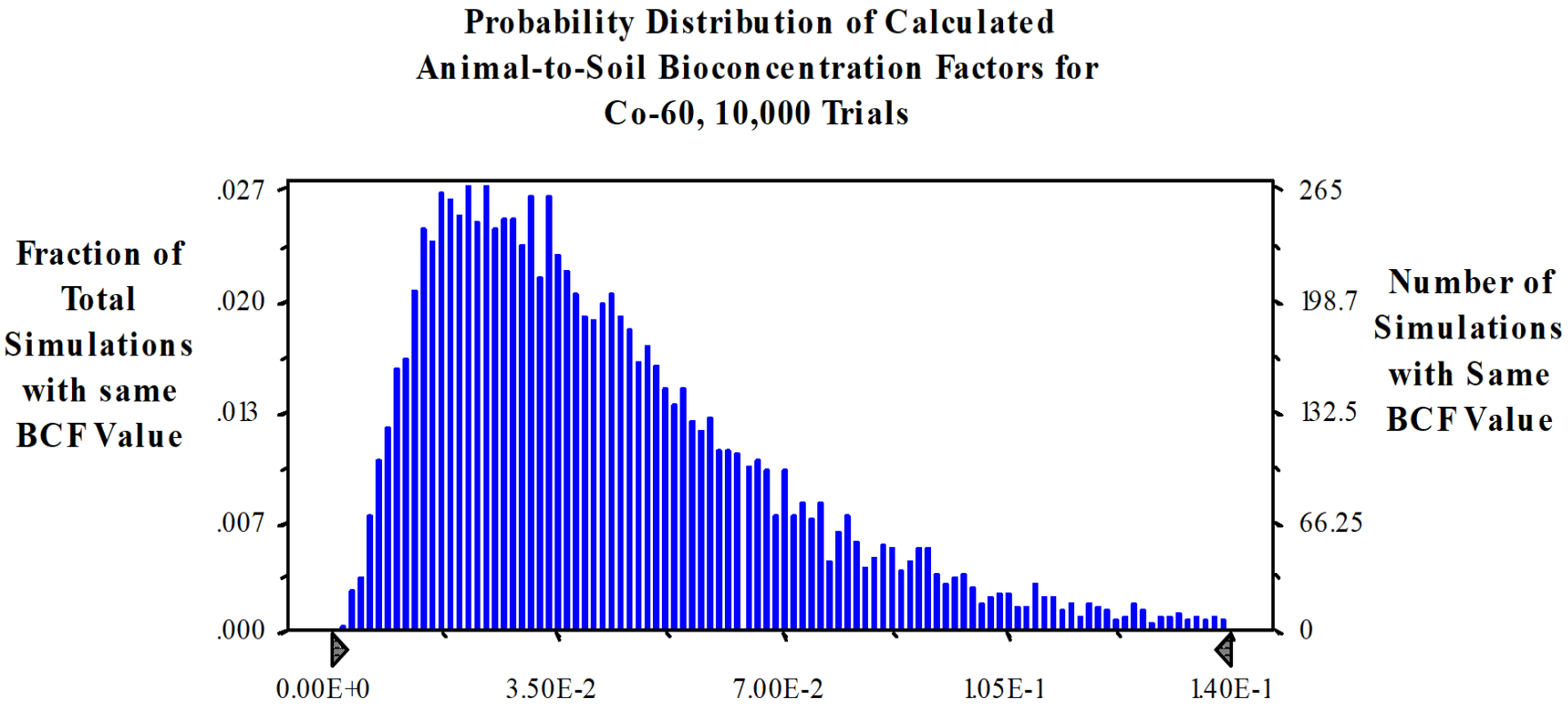
Combining Kinetic & Allometric

- Allows prediction of body burden
  - for any body mass
  - lifespan
  - loss rate
- Can be tailored to specific species
- Stochastic analysis used to ground truth approach and compare to “lumped” parameters
- Intake is considered to come from four routes
  - Ingestion of food
  - Ingestion of soil/sediment
  - Ingestion of water
  - Inhalation of re-suspended soil

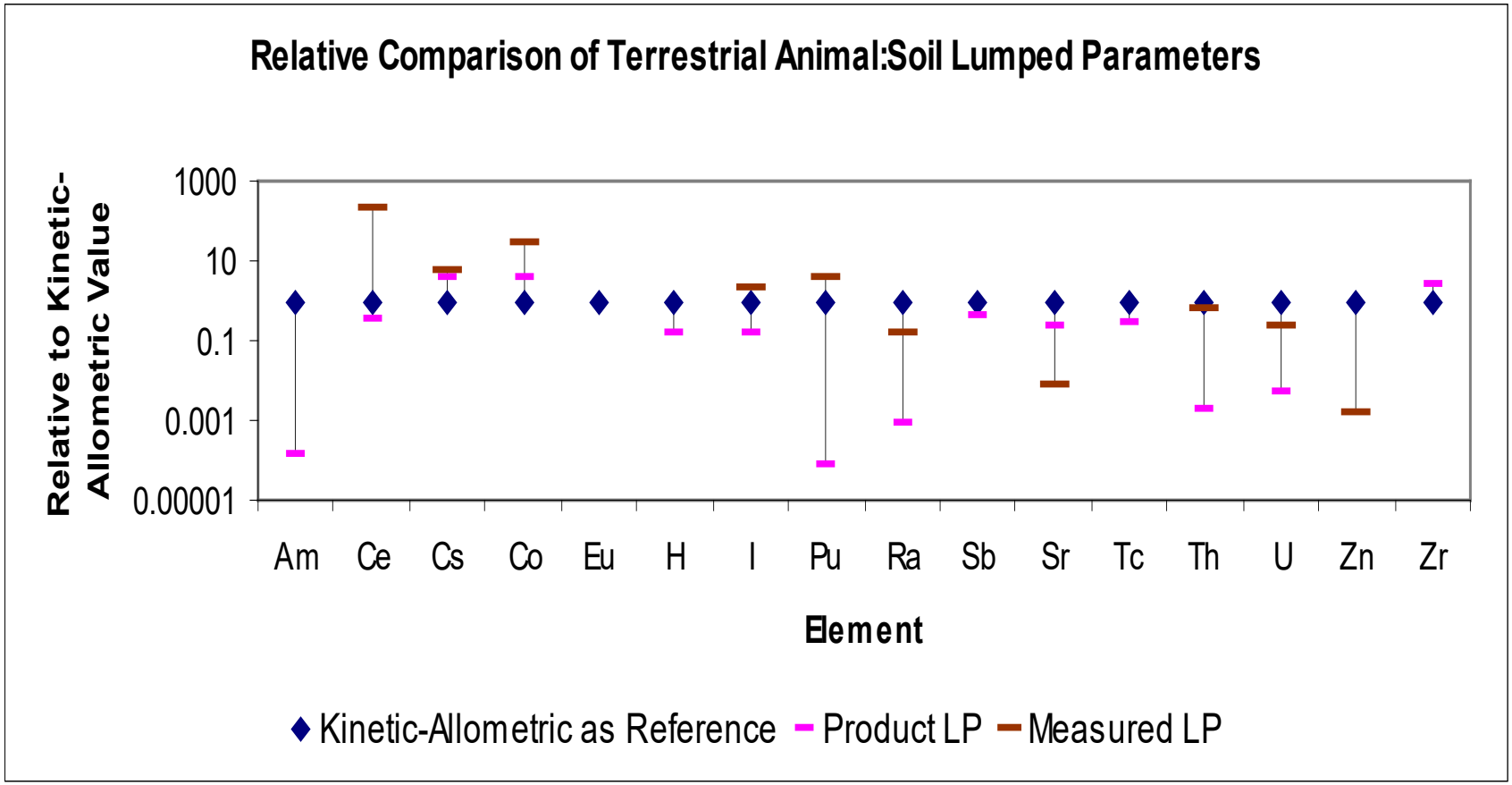
Combining Kinetic & Allometric – cont.

- Lumped parameter calculation using probabilistic analysis
- All parameters were assigned distributions,
- 10,000 trials run,
- 95^{th} percentile value selected

Lumped Parameter (LP) Output Distributions



Assessment of LP Values



Internal Tissue Concentration

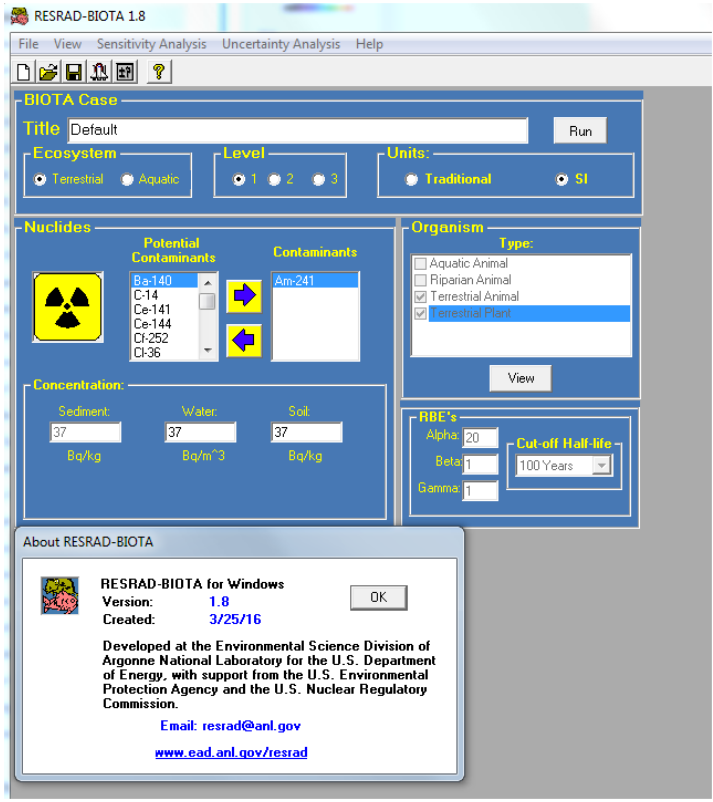
- General Screening
  - Empirically-derived lumped parameter (LP)
    - *Concentration Ratios (Bivs)*
    - *Natural integrators of mechanisms to internal dose*
- Site-Specific Screening
  - Select LP representative of site receptors
- Site-Specific Analysis
  - Kinetic/allometric model
    - *intake rates via ingestion (food/soil/sediment/water) and inhalation*
    - *fraction assimilated and loss rates (decay; bio-elimination.)*

Implementation of Method

- Old Companion Software Tool: RAD-BCG Calculator
- New Companion Software Tool: RESRAD-BIOTA
  - Specifically designed to be totally consistent with the DOE graded approach phases.
  - RESRAD-BIOTA (RRB) level 1 corresponds to general screening;
  - RRB level 2 equals site-specific screening, and
  - RRB level 3 equals site-specific analysis.
  - All references to RAD-BCG Calculator can be mapped to the three levels of the RESRAD-BIOTA code.
  - All chapters and explanation in the Tech. Std.
    - *(e.g., Tech Std Chapter 6 is general screening;*
    - *Chapter 7, Section 7.1 is site-specific screening;*
    - *Section 7.2 is site-specific analysis;*
    - *Module 3 provides detailed discussion of methods derivation*
  - RAD-BCG Calculator will continue to be available for those who are comfortable with that and wish to continue using it.

RESRAD-BIOTA: Key Features

- Duplicates DOE Graded Approach process & BCGs
- Retains flexibility to modify organism exposure profile, parameters, dose limits, allometric relationships
- Like the Graded Approach, the code implements primary and secondary reference organism concepts
- Organism Wizard allows users to configure their own “secondary” organisms
- Includes DCFs for 8 specific geometries covering a wide range of organisms
- Sensitivity and uncertainty analysis
- Simple food chain model
- Import and export data



Conclusions & Recommendations

- Methodology
  - Utilizes available data
  - Conservative approach works; with flexibility to incorporate site-specific information
  - Good compliance tool
  - Equations and framework support its application in eco-risk assessments
  - Provides a complete evaluation framework, from general screening employing BCGs to site-specific analysis.

Conclusions & Recommendations (Cont'd)

- Adaptable
  - Can address standards other than 10 mGy per day
  - Different weighting factors
  - Allows use of site and organism-specific input data
- Represents a cost-effective technique that is protective but doesn't require exhaustive in-depth assessments
  - Screening provides a "place to start and analysis path forward." Detailed organism-specific dose evaluations can be performed but are not always needed.
- Applications, potential/intended use, and considerations discussed in DOE-STD-1153-2002
  - See Module 1, Section 3, Table 3.1 for additional information.

Conclusions & Recommendations (Cont'd)

APPLICATIONS	INTENDED / POTENTIAL USE	CONSIDERATIONS
Types of Receptors		
Populations of plants and animals	This is the primary intended use.	
Individual plants and animals, including threatened and endangered species, and commercially or culturally valued species	Equations used within the graded approach are technically sound for application to individual organisms. Applying dose limits intended for the protection of populations to evaluations of individuals may require further consideration.	Use of effects endpoints/dose limits appropriate for protection of the individuals being evaluated; and/or application of safety factors, conservative exposure assumptions, and parameter values. Dose evaluations should be performed under the provisions of the applicable Federal and/or state statutes or regulations for rare and endangered species.

Conclusions & Recommendations (Cont'd)

APPLICATIONS	INTENDED / POTENTIAL USE	CONSIDERATIONS
Types of Exposure		
Chronic	The methodology assumes chronic exposure and equilibrium conditions.	
Acute		The methodology is not intended to be used for assessing acute exposures.
Accidents	Could be used to provide an indication of long-term "recovery" or health of the population over time following an accident. Equations and models used within the graded approach are technically sound for this application.	Accidents typically result in short-term, acute exposures for which the methodology is not intended. However, it can be applied for assessing long-term exposures due to accidents.
Types of Environments		
Fresh water, coastal, and marine environments	The methodology is intended to be applied to fresh water environments, and can be applied to coastal and marine environments.	Care must be taken when selecting parameter values (e.g., receptor lumped parameters; K_d values), as fresh water, coastal, and marine equilibrium chemistry differ considerably.
Terrestrial environments	The methodology is intended to be applied to terrestrial environments.	
Compliance / Impact Assessment		
Demonstration that DOE activities are in compliance with biota dose limits	This is a principal DOE application of the graded approach.	

Conclusions & Recommendations (Cont'd)

- Technical Standard provides practical guidance on key application issues
- BCG values have been "groundtruthed" and are reasonable
- Methodology
  - Sensible, flexible, and functional

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Sensitivity Analysis Feature

Parameter Access vs Level

Parameter	Level		
	1	**2**	**3**
Units	x	x	x
Concentration, K_d Option, DL	x	x	x
View BCG results	x	x	x
View dose results		x	x
Sensitivity		x	x
K_d Modification, Mean Conc. setting		x	x
BIV		x	x
CF,T,f			x
DCF options (RBE, T_{cut})			x
Organism selection			x
Organism addition (W, shape,Base)			x
Organism allometric params			x
Allometric option (org,nuc)			x

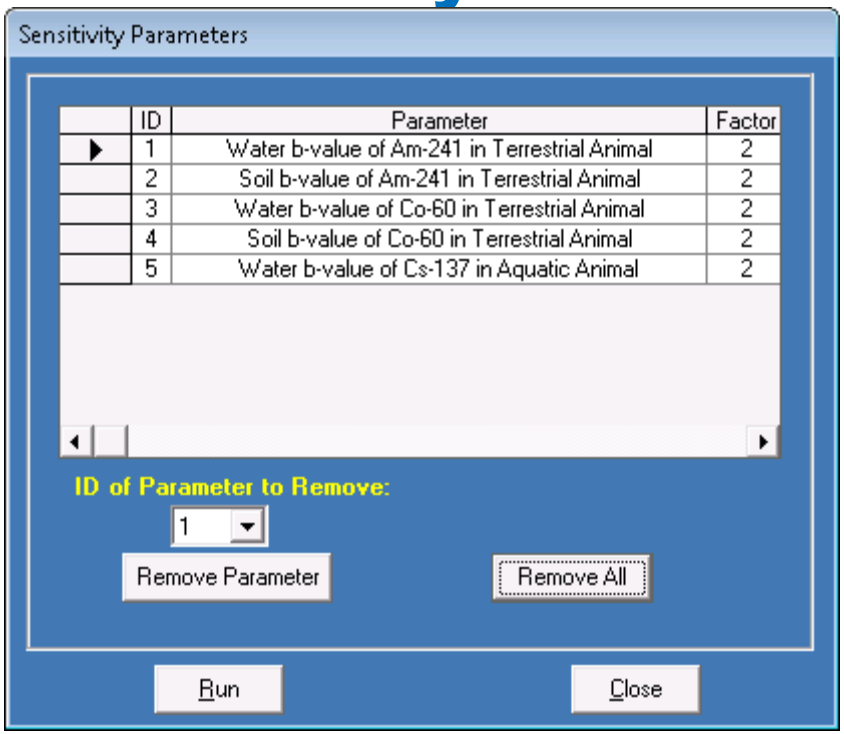
Design for Sensitivity

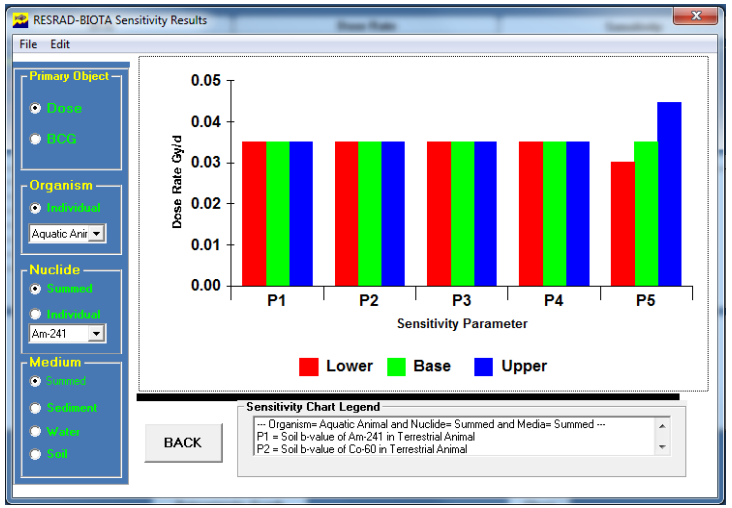
- Input: “F9” or “Sensitivity Analysis” Menu
- Calculation:
  - Multiply and divide parameter by factor (default: 2)
  - Save results
  - Calculate $(R_{high} – R_{low}) / (2 * R_{base})$
- Display Results (graphics similar to RESRAD-BUILD)
- Manage Sensitivity
  - Ability to delete
  - Ability to save
- Note:
  - One definition of sensitivity is S = dR/R / dP/P
  - With the default factor of 2 the calculation returns 0.75*S

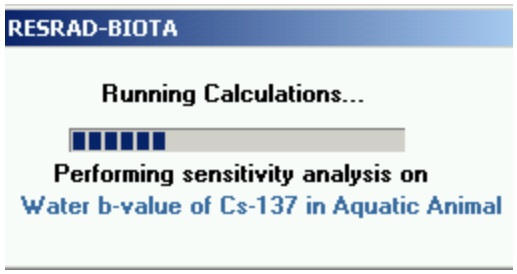
Sensitivity Comparison

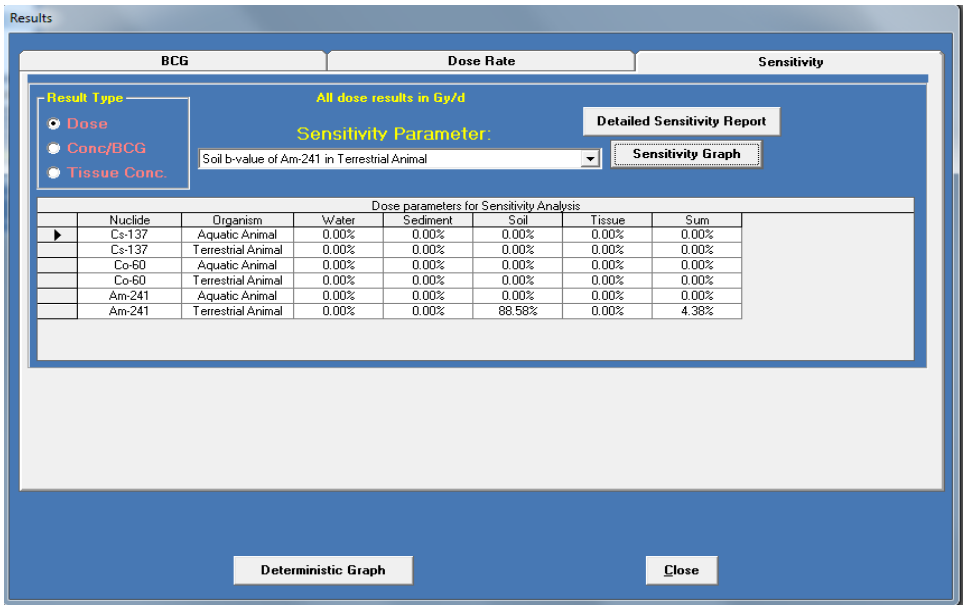
	RESRAD-ONSITE	RESRAD-BIOTA
Time	Yes	No
Sensitivity Values	No	Yes
Sensitivity Graphs	Yes	Yes
Ability to do >5	No	Yes
User control over factor	Yes	Yes

Sensitivity User Interface









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The Technical Basis Behind the RESRAD-BIOTA Code:

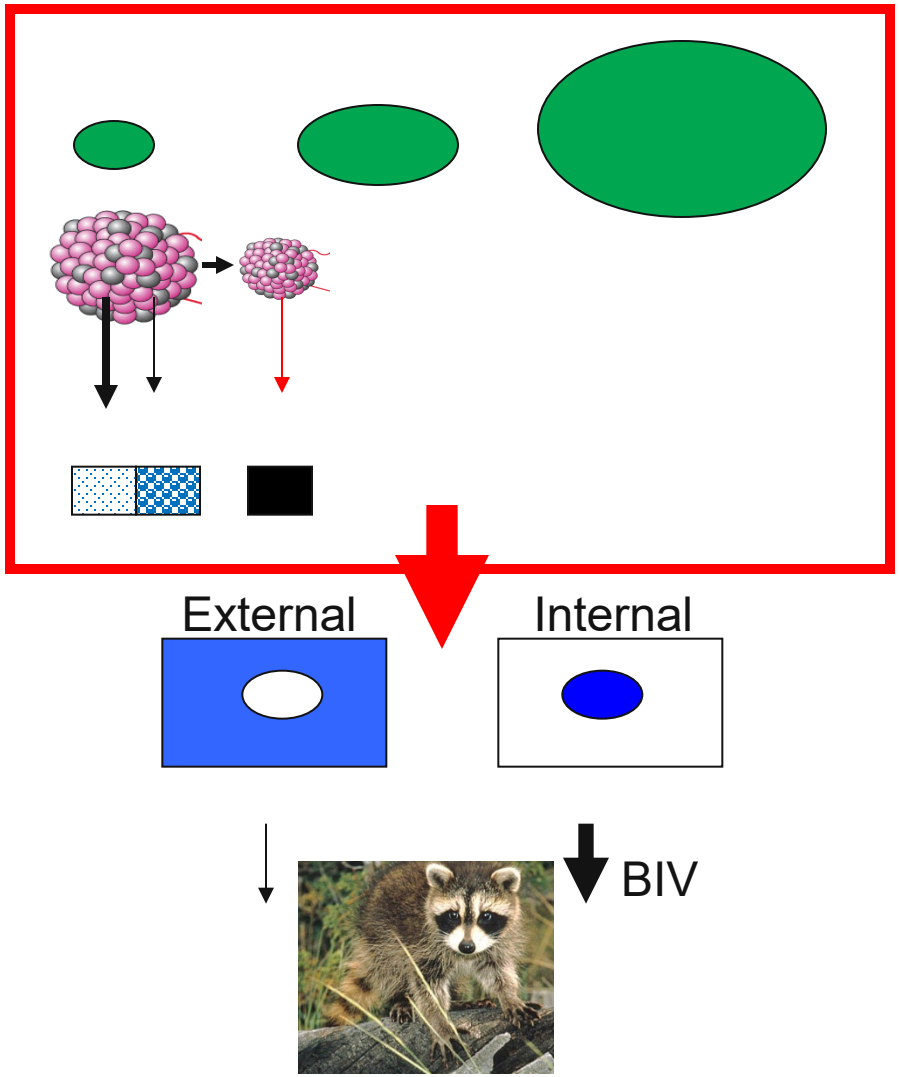
Derivation of Dose Conversion Factors for Specific Organism Geometries

Objective

- To develop a set of organism geometries that span the expected range of organism sizes that would be of utility in evaluating radiation doses to user-selected receptors
- Develop geometry-specific internal and external DCFs for application in the site-specific analysis phase of the Graded Approach methodology / RESRAD-BIOTA (level 3)
- Geometry size-specific DCFs will generally be less conservative:
  - DCF from external radiation changes the most for beta and low energy gamma emitters (lowest for large animals)
  - DCF from internal radiation changes the most for high energy gamma emitters (lowest for small animals)
  - Doses sensitive to size for
    - *Large Biv organisms with high energy gamma emitters*
    - *Low Biv organisms with beta and low energy gamma emitters*
  - Doses insensitive to size for alpha emitters

Approach

- Select sizes of various organisms (Done through consensus process by the ECORAD-WG to ensure multi-agency agreement)
- Select nuclides from truncated decay chains
- Compile decay energies
- Calculate absorbed fraction as a function of energy and radiation type
- Combine calculations of size, nuclides, and absorption fraction to derive DCF's
- Compare with other's calculations



Organism Geometries in RESRAD-BIOTA

Model Geometry No.	Mass Category (Kg)	Example Receptors	Specific Geometry Dimensions (cm)	Specific Mass (Kg)
1	1E-5	Fish egg*, Fish (larvae), Plant root (meristem), Plant seed, Plant shoot (meristem)	0.2 x 0.2 x 0.2	4.2E-6
2	1E-3	Fish (young-of-year) Molluscs*, Plant seedling, Tadpoles	2.5 x 1.2 x 0.62	1E-3
3	1E-2	Fathead minnow, Frogs, Hispid cotton rat, Sculpins, Shrews, Voles, White-footed Mouse*	10 x 2 x 2	2.1E-2
4	1	Black bass, Large fish* Suckers	45 x 8.7 x 4.9	1
5	1E1	Beaver, Carp, Catfish (Channel and Blue), Coyote, Fox (red or grey), Raccoon*, Striped bass	50 x 26 x 13	8.8
6	1E2	Mule deer, White-tailed deer*	100 x 42 x 33	72.6
7	5E2	Elk*	270 x 66 x 48	447.9
8	1E3	Grizzly bear*	220 x 100 x 100	1150

Assumptions in the Derivation of DCFs

- Uniform concentration in source medium and exposed organism
  - Internal DCFs for BIOTA are not like human DCFs where metabolic characteristics are included
- Source medium infinite in extent
- Exposed organisms of eight sizes
- Absorbed fraction unity for alpha for all geometries (internal dose)
- External and Internal Dose Coefficients include contribution of progeny (cut-off half-life <6 months or <100 years)

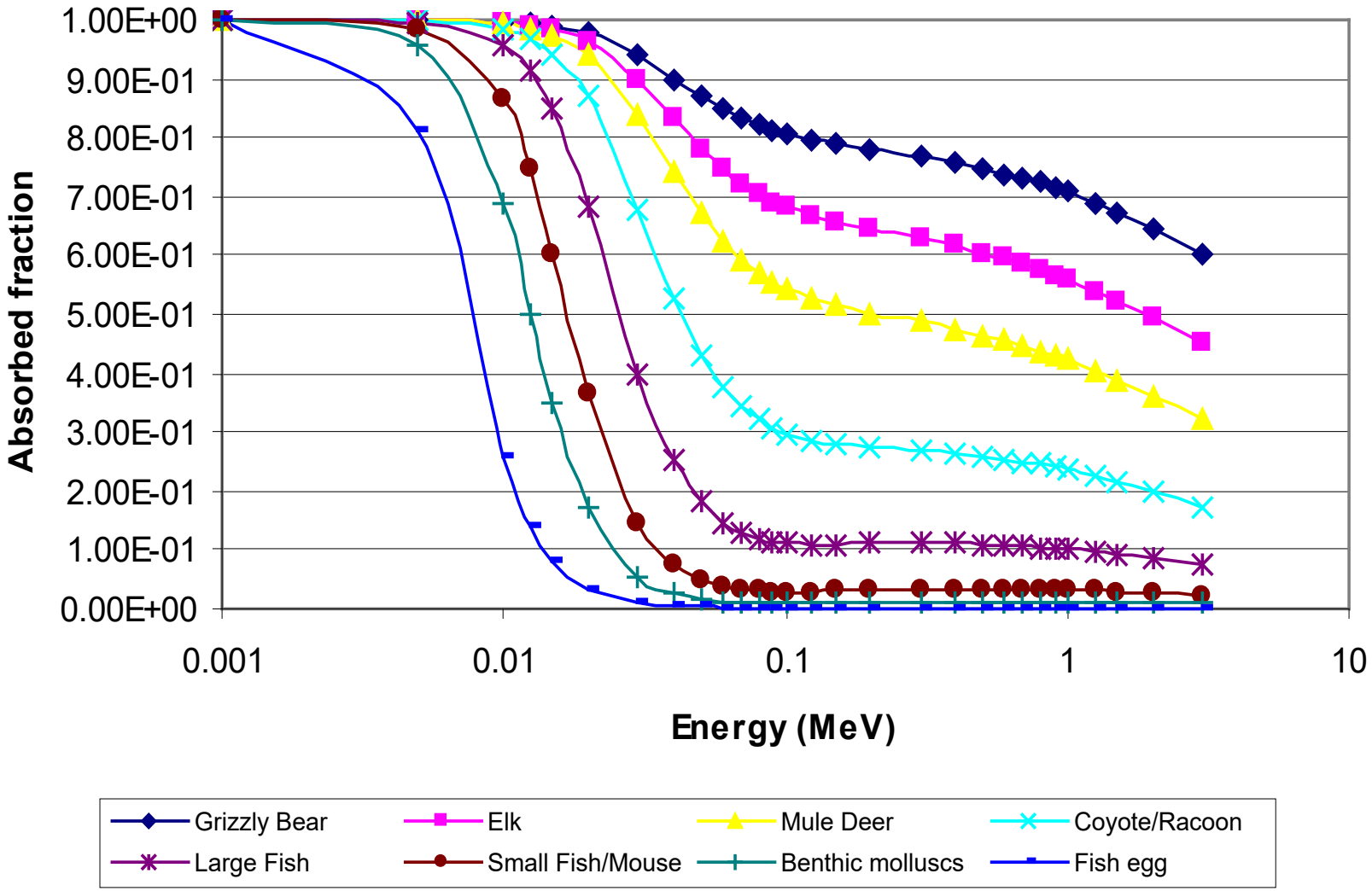
Associated Radionuclides in DCFs

Nuclide	Cut-off Half-life 180 days	Cut-off Half-life 100 years
Ce-144	Pr-144, Pr-144m (1.78%)	Pr-144, Pr-144m (1.78%)
Cs-137	Ba-137m (94.6%)	Ba-137m (94.6%)
Ra-226	Rn-222, Po-218, Pb-214 (99.98%), At-218 (0.02%), Bi-214, Po-214 (99.98%), Tl-210 (0.02%)	Rn-222, Po-218, Pb-214 (99.98%), At-218 (0.02%), Bi-214, Po-214 (99.98%), Tl-210 (0.02%), Pb-210, Bi-210, Po-210
Ra-228	Ac-228	Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212 (64.07%), Tl-208 (35.93%)
Sb-125	Te-125m(22.8%)	Te-125m(22.8%)
Sr-90	Y-90	Y-90
Th-232		Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212 (64.07%), Tl-208 (35.93%)
U-235	Th-231	Th-231
U-238	Th-234, Pa-234m (99.8%), Pa-234 (0.33%)	Th-234, Pa-234m (99.8%), Pa-234 (0.33%)
Zr-95	Nb-95, Nb-95m (0.7%)	Nb-95, Nb-95m (0.7%)
Ba-140	La-140	La-140
Cm-242		Pu-238

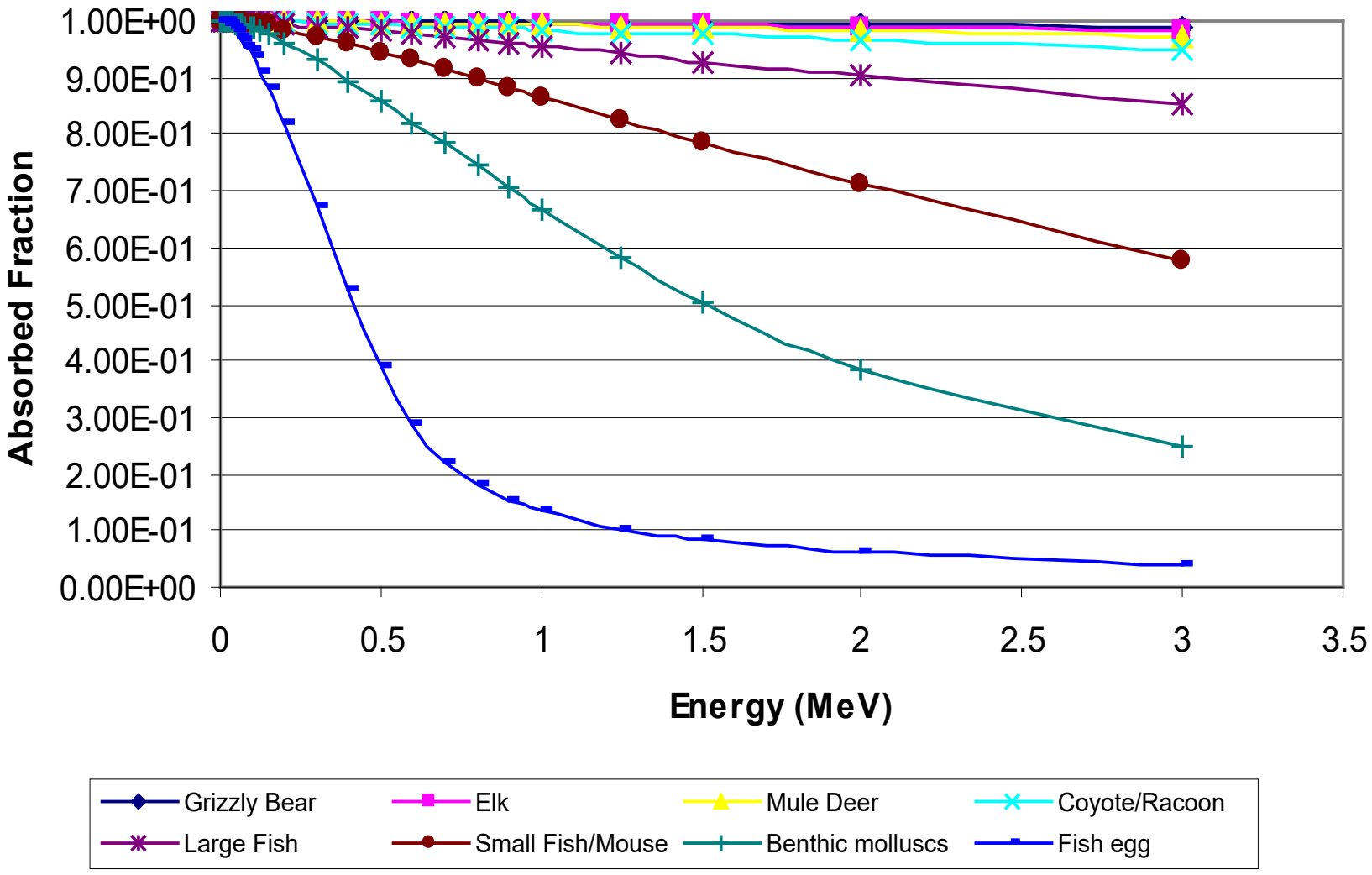
Procedure for Deriving DCFs

- Calculate absorbed fractions for photons and beta particles (electrons) of different energies for different organisms (dimensions) using MCNP
- Calculate effective absorbed beta and photon fraction for each radionuclide
- The absorbed fraction for alpha radiation for all geometries is assumed unity
- Absorbed fractions for default geometry is also calculated. Default geometry is infinitely large for internal DCF and infinitesimally small for external DCF
- Comparison of absorbed fractions with available data
- Calculate internal and external DCFs

Photon Absorbed Fractions for Different Organisms

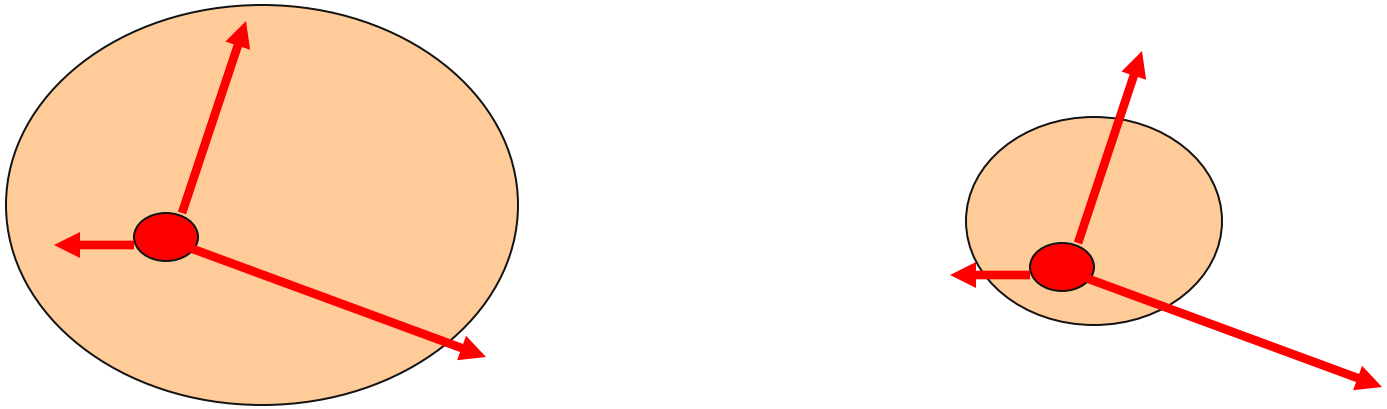


Electron Absorbed Fractions for Different Organisms



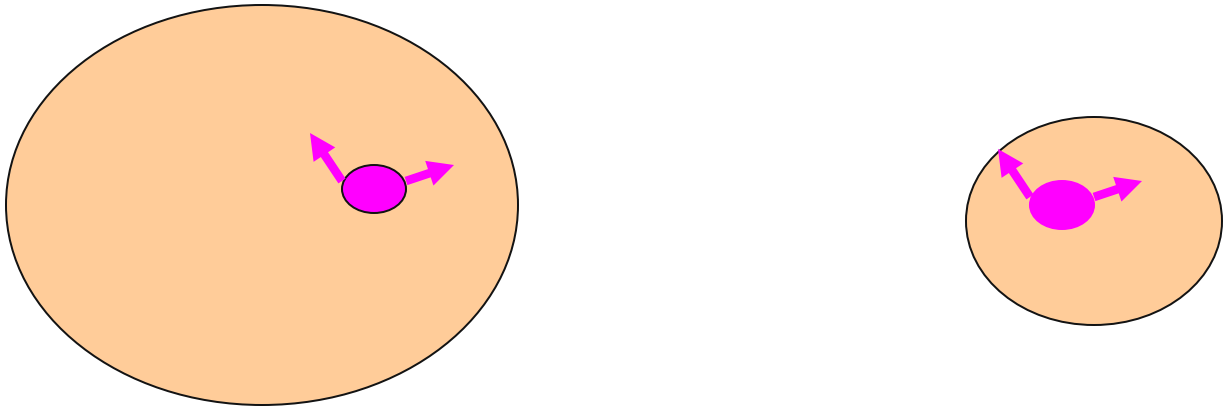
Internal Energy Deposition due to High Energy Gamma Radiation

Large difference in fraction of energy deposited in organism



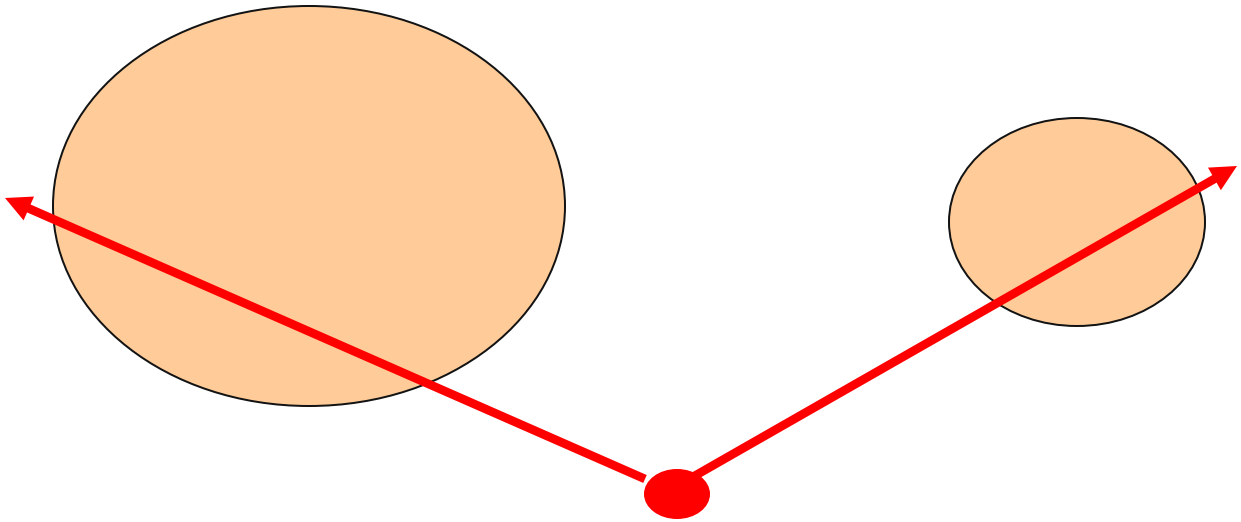
Internal Energy Deposition due to Beta or Low Energy Gamma Radiation

Little difference in fraction of energy deposited in organism



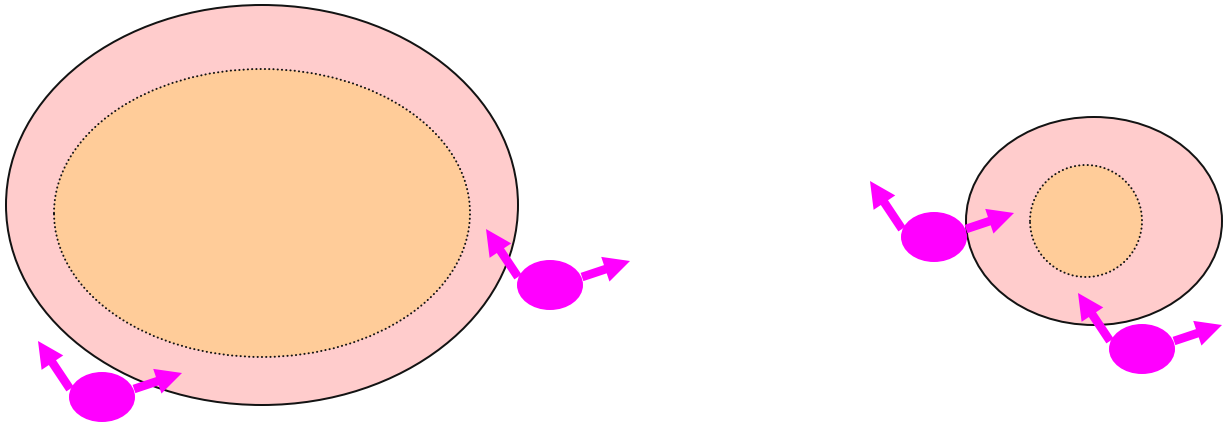
Energy Deposition due to External High Energy Gamma Radiation

Little difference in energy (per mass) deposited in organism



Energy Deposition due to External Beta or Low Energy Radiation

Large difference in energy (per mass) deposited in organism



Comparison of Absorbed Fractions from MIRD Calculations for Uniform Distribution of Activity

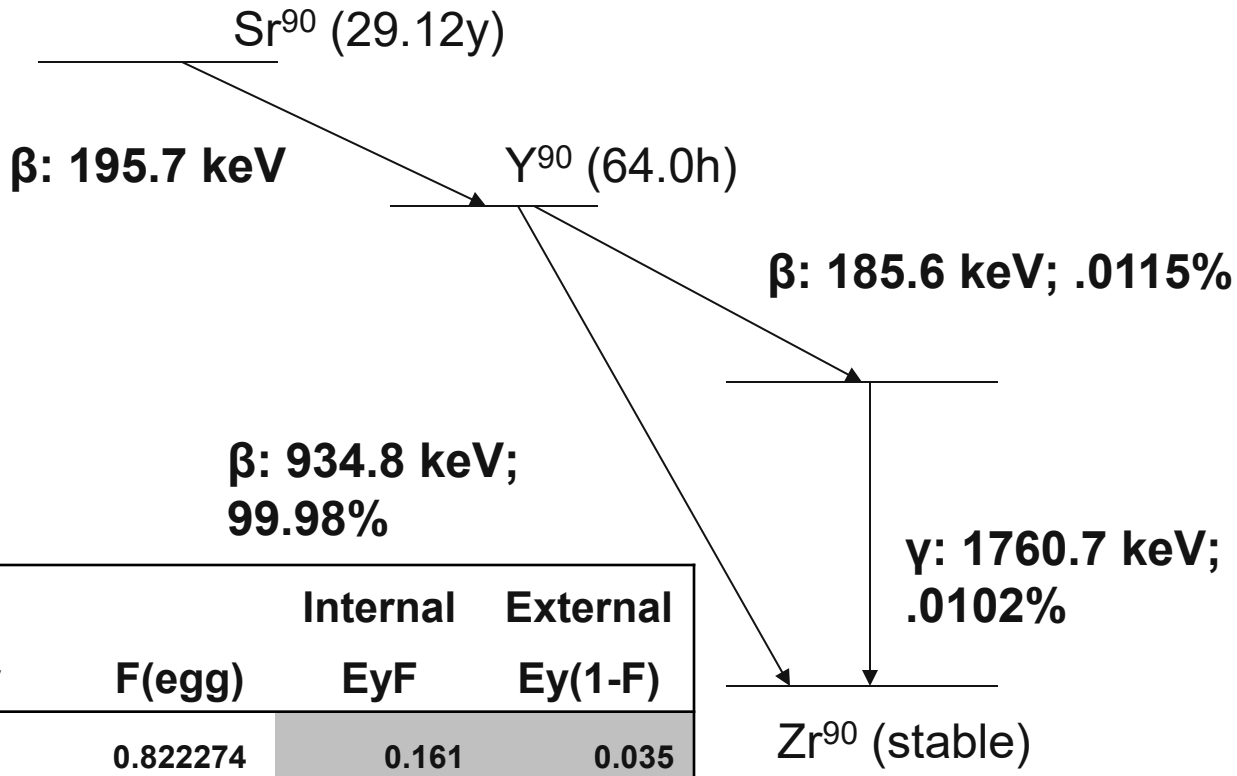
Energy (MeV)	MIRD (8)_0.1 Kg	ANL_0.1 Kg	MIRD(3)_1 Kg	ANL_1 Kg
0.02			7.9E-01	7.9E-01
0.03	3.1E-01	2.9E-01	5.2E-01	5.2E-01
0.04	1.7E-01	1.6E-01	3.4E-01	3.4E-01
0.06	8.7E-02	8.5E-02	2.1E-01	2.1E-01
0.08	7.0E-02	6.9E-02	1.7E-01	1.7E-01
0.1	6.7E-02	6.5E-02	1.6E-01	1.6E-01
0.16	6.6E-02	6.6E-02	1.5E-01	1.5E-01
0.364	7.2E-02	7.0E-02	1.5E-01	1.5E-01
0.662	7.0E-02	6.8E-02	1.5E-01	1.5E-01
1.46	6.1E-02	5.9E-02	1.3E-01	1.2E-01
2.75	5.0E-02	4.9E-02	1.1E-01	1.0E-01

DCF Methodology

$$DCF(org, nuc, type, t_{cut}) = \sum_{n \in Chain} Y_{nuc,n,tcut} \bullet \left(\sum_{r \in type,n} kE_r y_r f_{type}(E_r, org) \right)$$

- Y = Nuclide yield
- n = number of nuclides (parent + associated)
- type = electron, photon, alpha
- k = 5.04E-6 (unit conversion factor) (Gy/y per Bq/kg) per (MeV/Bq-s)
- E = energy in MeV
- r = radiation identification
- y = radiation yield
- $f_{type}(E_r,org)$ =
    - Fraction absorbed (F) for internal DCF
    - (1-F) for external DCF
    - 1 for both internal and external for default organisms

Example:



Nuclide	E(MeV)	y	F(egg)	Internal EyF	External Ey(1-F)
Sr-90	0.1957	1	0.822274	0.161	0.035
Y-90	0.9348	0.9998	0.14656	0.137	0.797
Y-90	0.1856	0.000115	0.835314	0.000	0.000
Y-90	1.7607	0.000102	0.073066	0.000	0.000
Sum				0.298	0.832
* 5.04E-6				1.5E-06	4.2E-06

Maximum Variation in Internal and External DCFs in Different Organisms

Ratio	Internal (Default/Fish eggs)	External (Default/Grizzly Bear)
1.0-1.1	Am-241, Cm-242, Cm-244, Cs-135, H-3, Pu-239, Ra-226, Ra-228, Tc-99, Th-232, U-233, U-234, U-235, and U-238	none
>1.1-10	Ba-140, Ce-141, Ce-144, Co-58, Cr-51, Cs-137, Eu-152, Eu-154, Eu-155, I-129, I-131, Sb-125, and Sr-90	Ba-140, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Eu-152, Eu-154, Eu-155, I-131, Ra-226, Ra-228, Sb-125, Se-75, Zn-65, and Zr-95
>10-100	Co-60, Cs-134, Se-75, and Zr-95	Am-241, Ce-141, Ce-144, I-129, and U-235
>100-1,000	Zn-65	Pu-239, Sr-90, Th-232, U-233, U-234, U-238, Cm-242, Cm-244,
>1,000	none	Cs-135, H-3, and Tc-99

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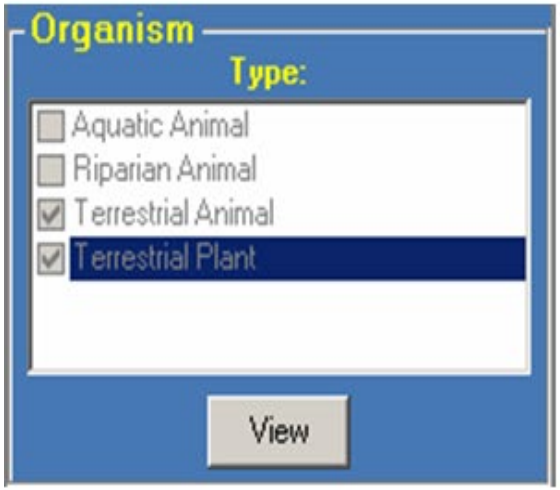
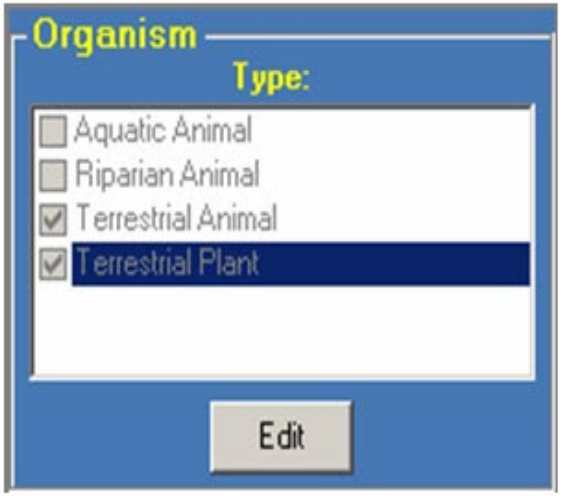
Organism Editor & Wizard Feature

Organism Options

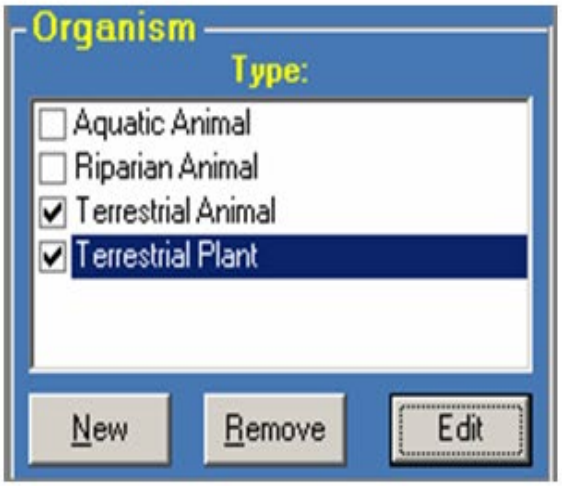
Level 1



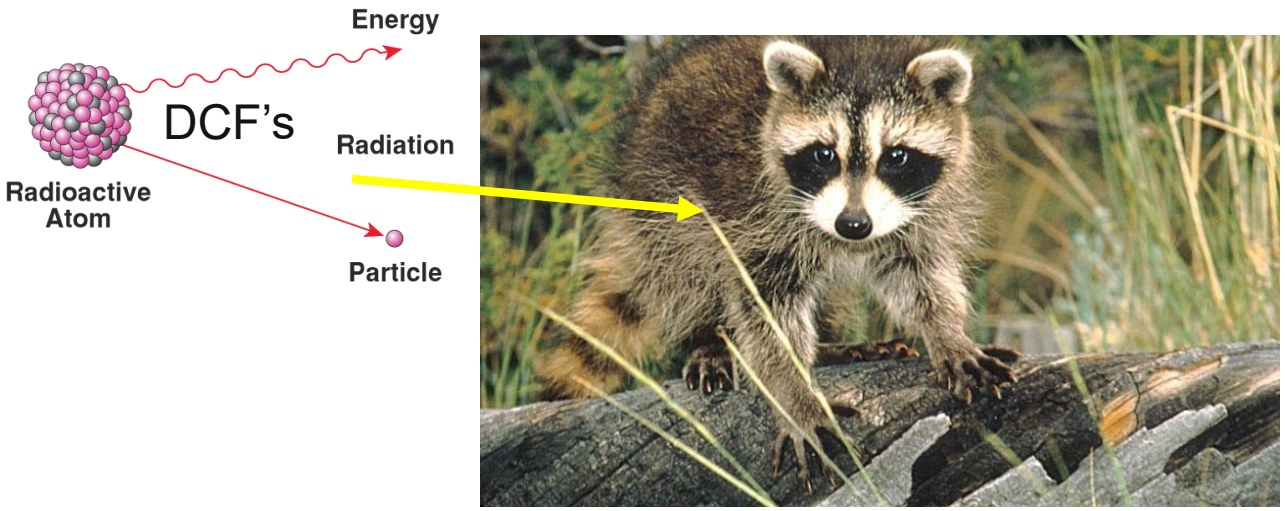
Level 2



Level 3



Organism Specification



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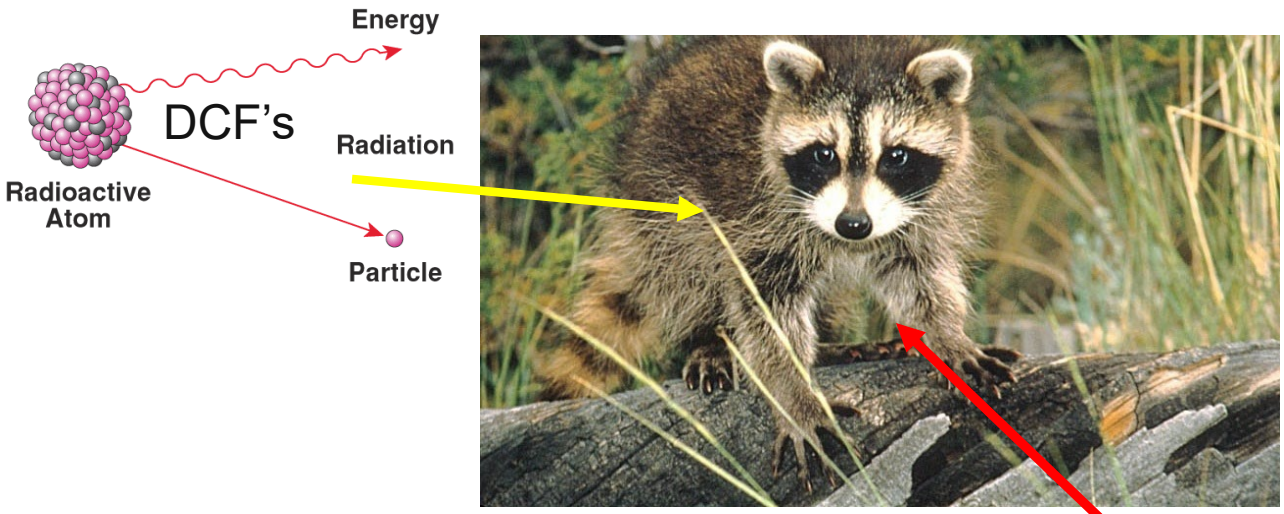
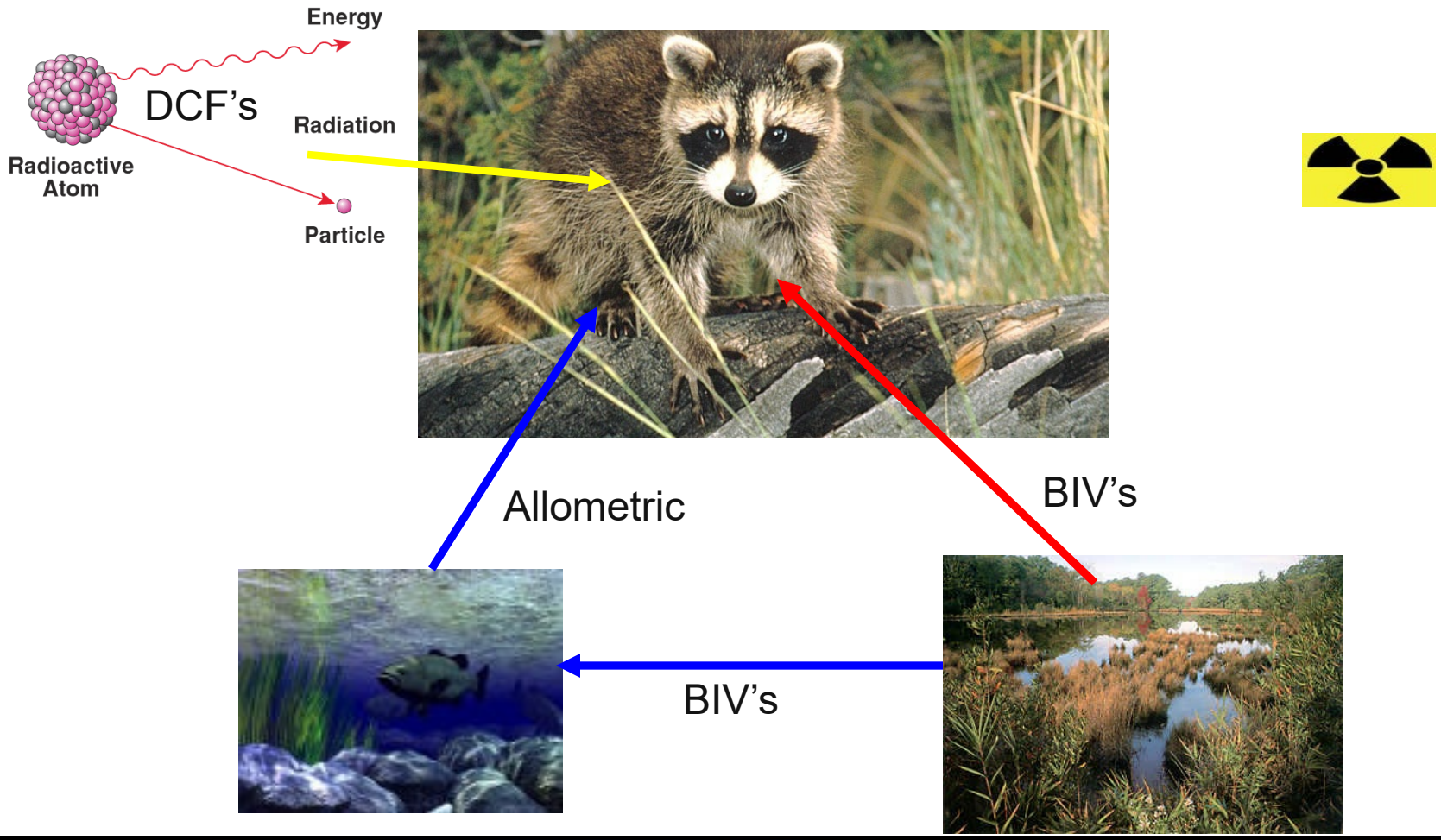
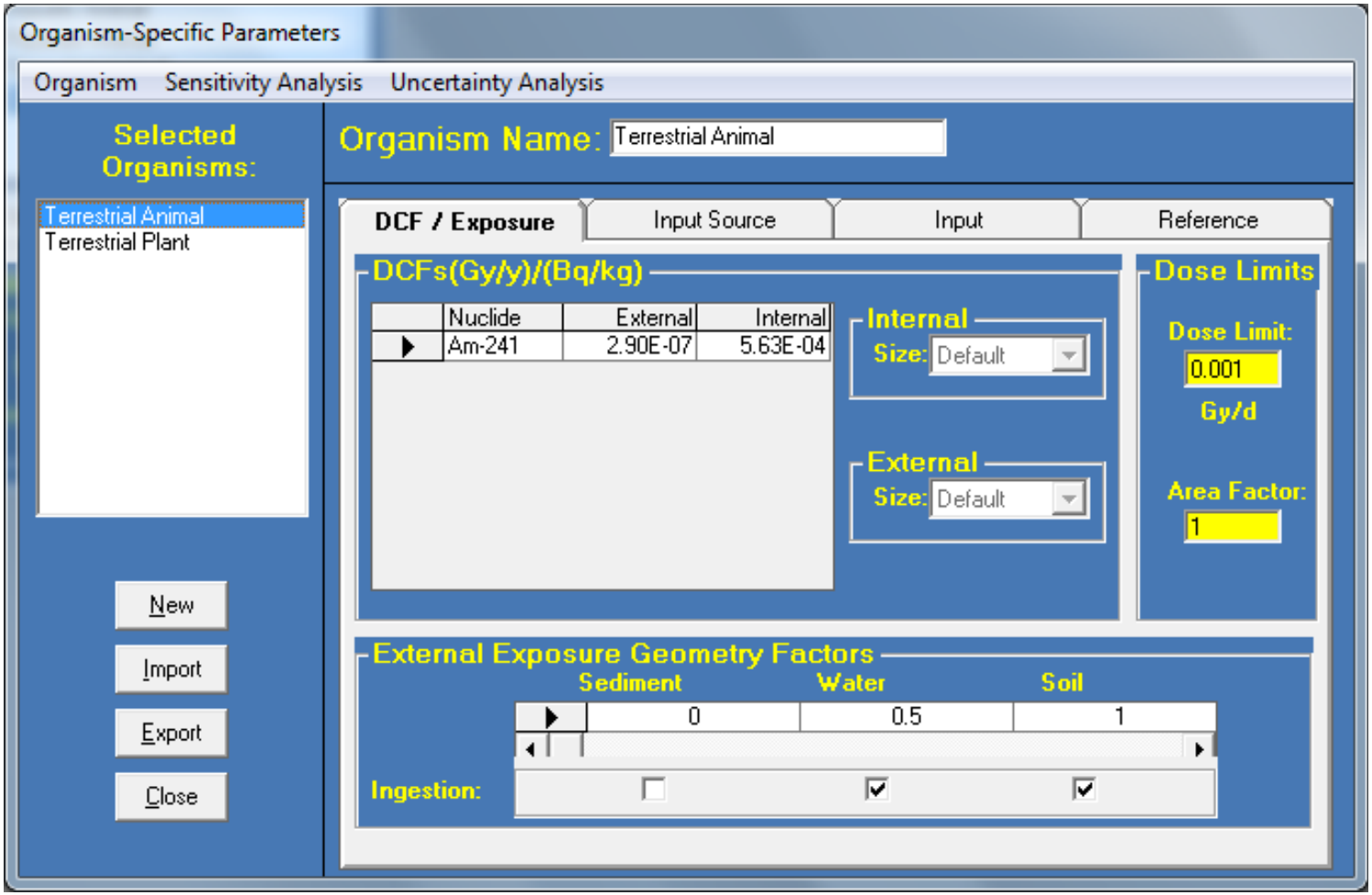


BIV's

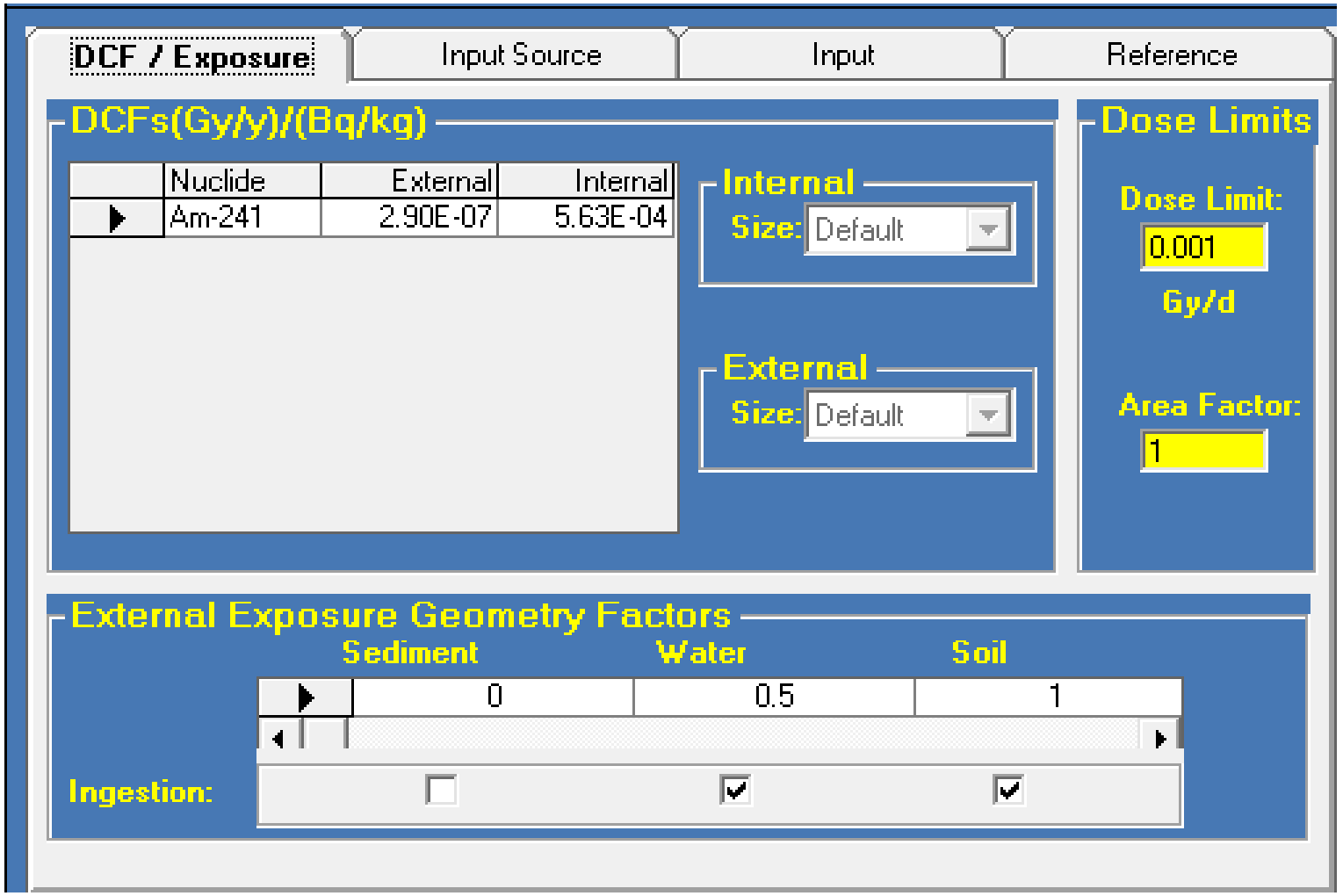
Organism Specification



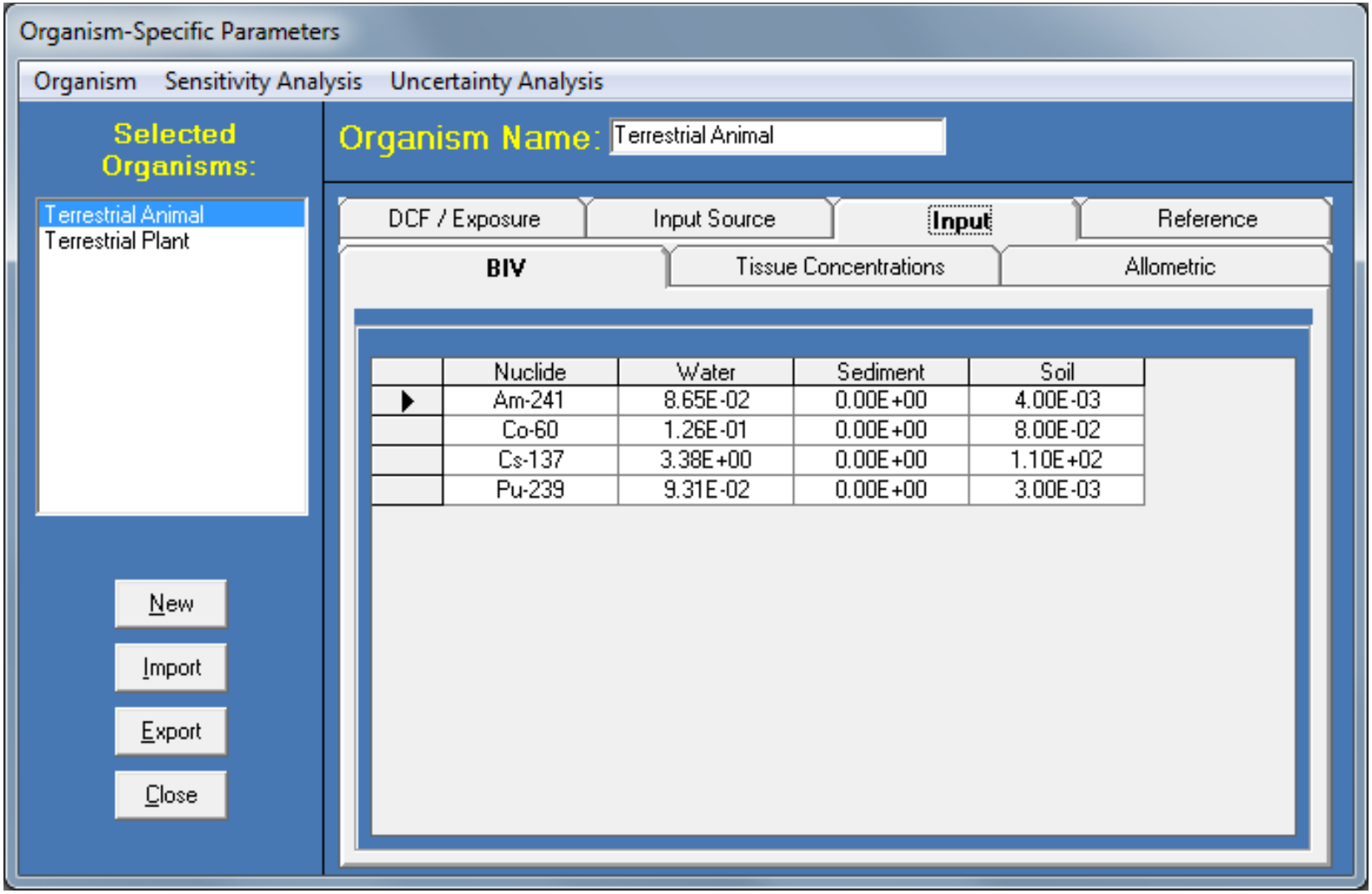
Organism Editor



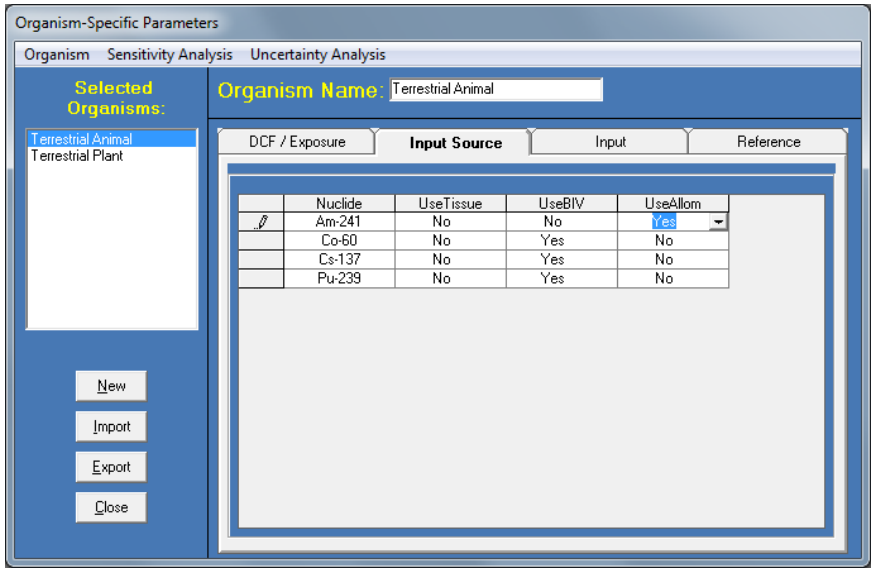
Organism – DCF & Exposure

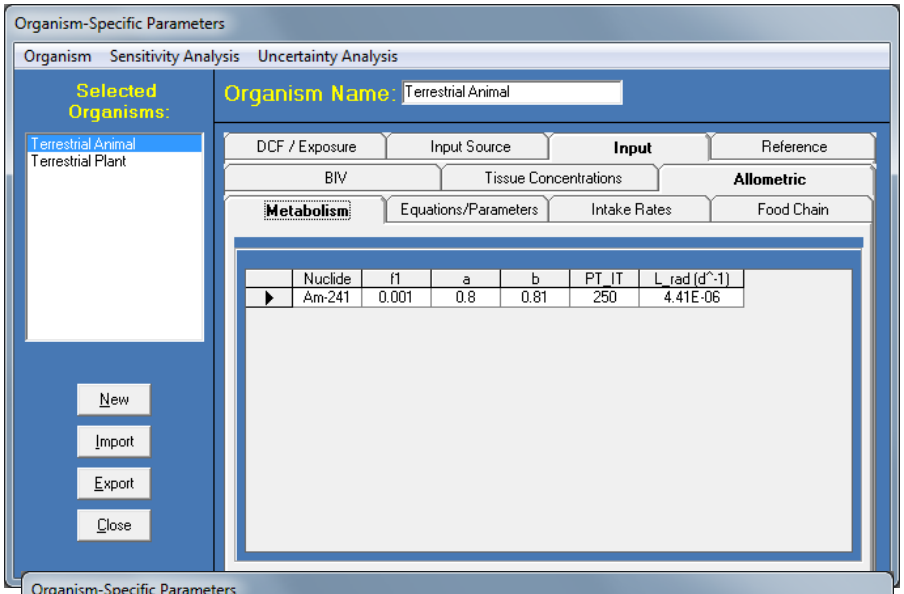


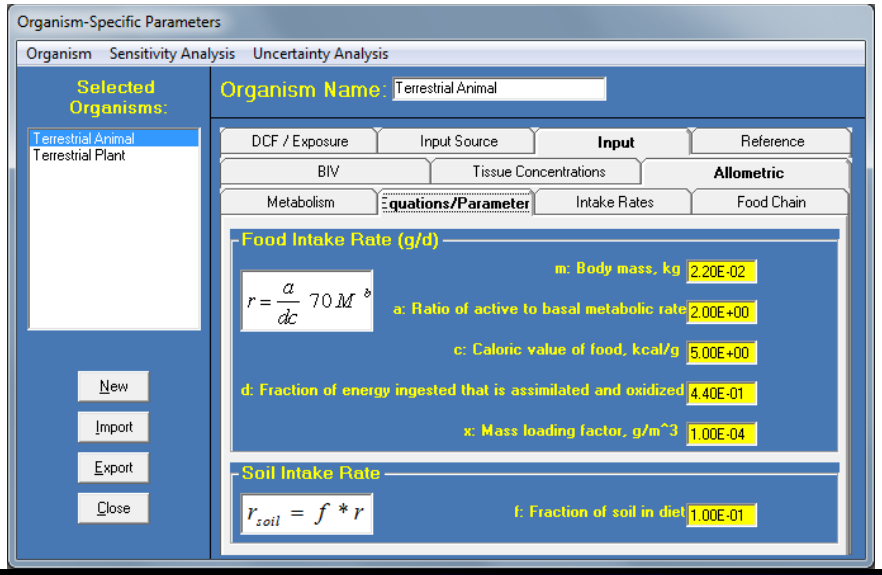
Organism- Biv's

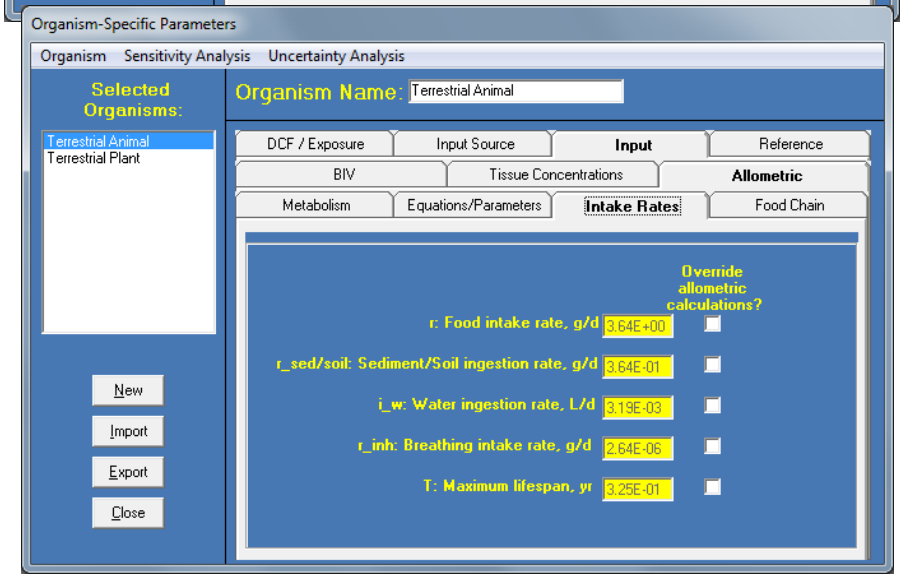


Organism - Allometric

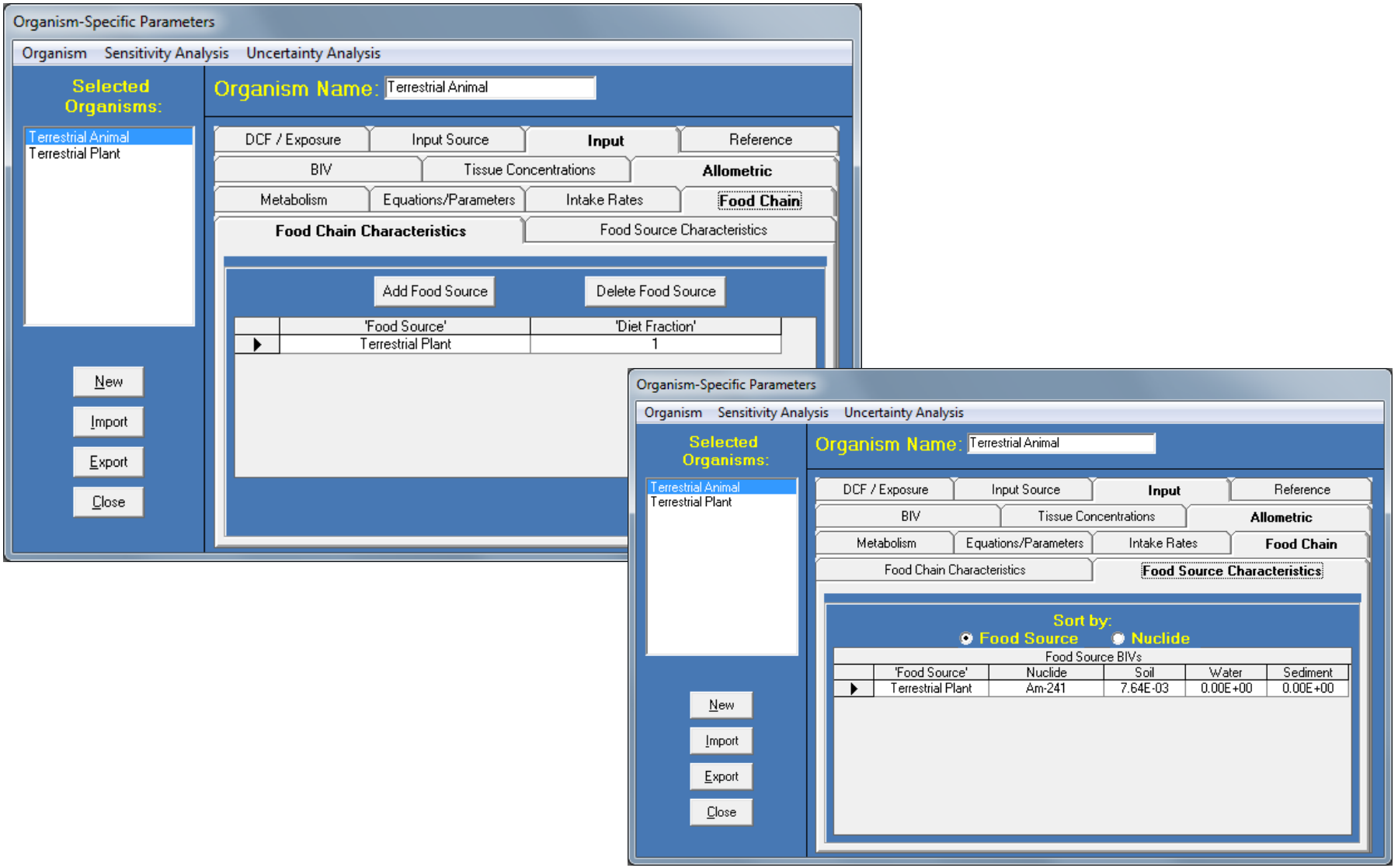




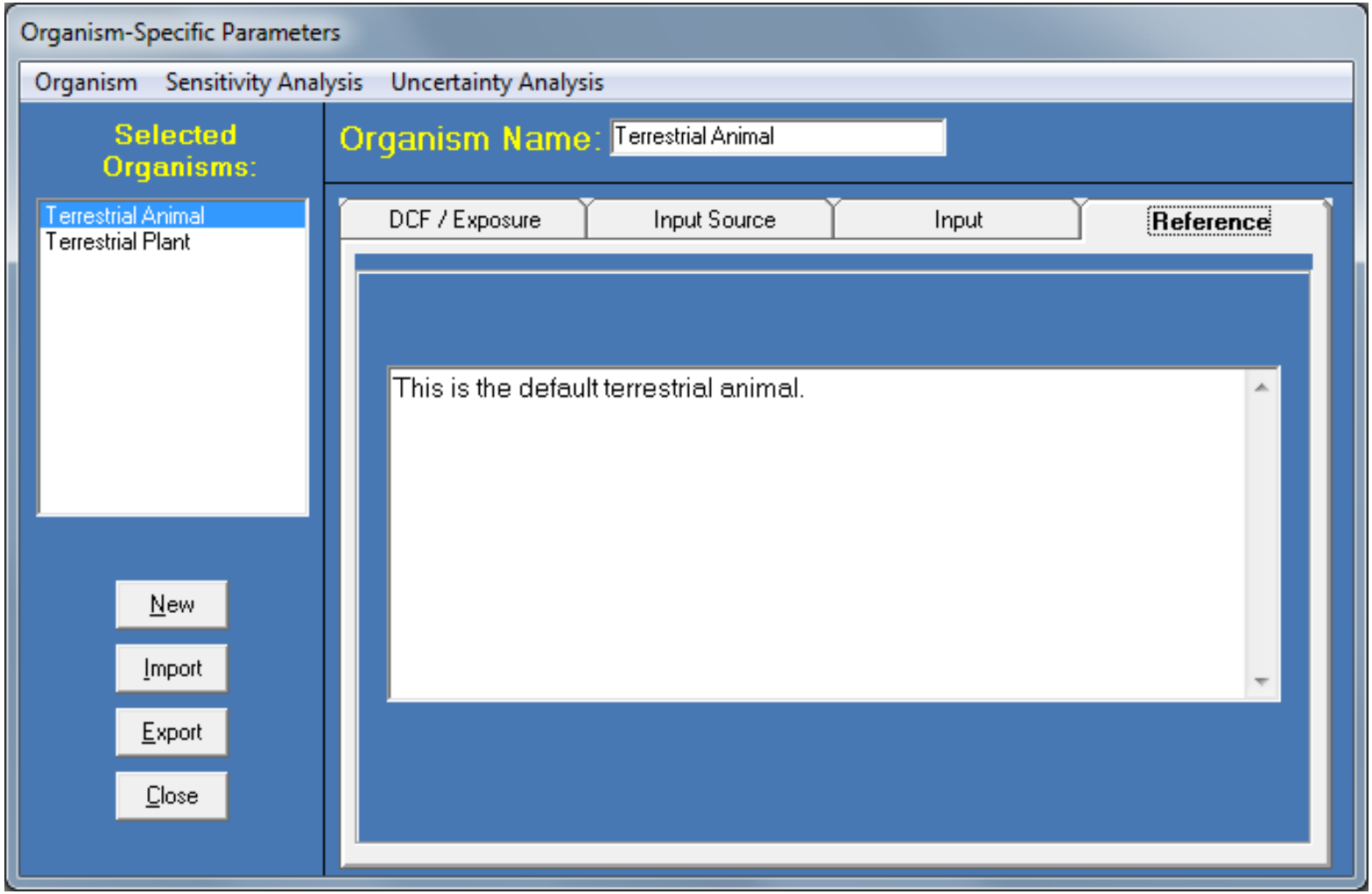




Organism – Allometric - Food Chain



Organism - Reference

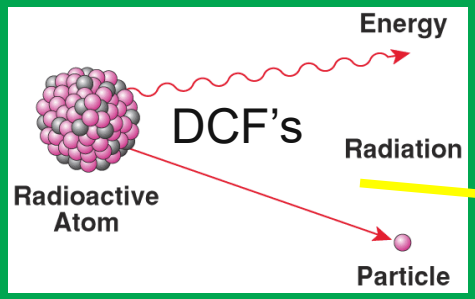


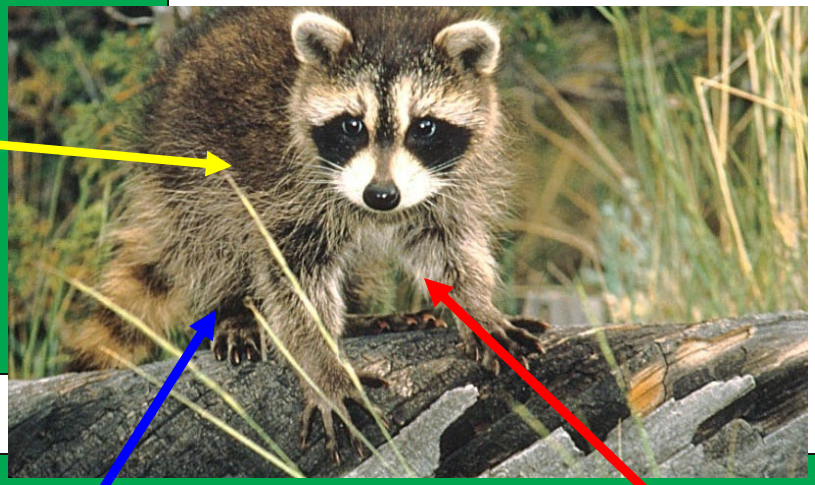
The Wizard

The Chimera was a fire-breathing monster with the head of a lion, body of a goat and tail of a serpent. It killed and ate human beings until it was killed by Bellerophon who was riding the winged horse Pegasus.

Organism Specification

Size





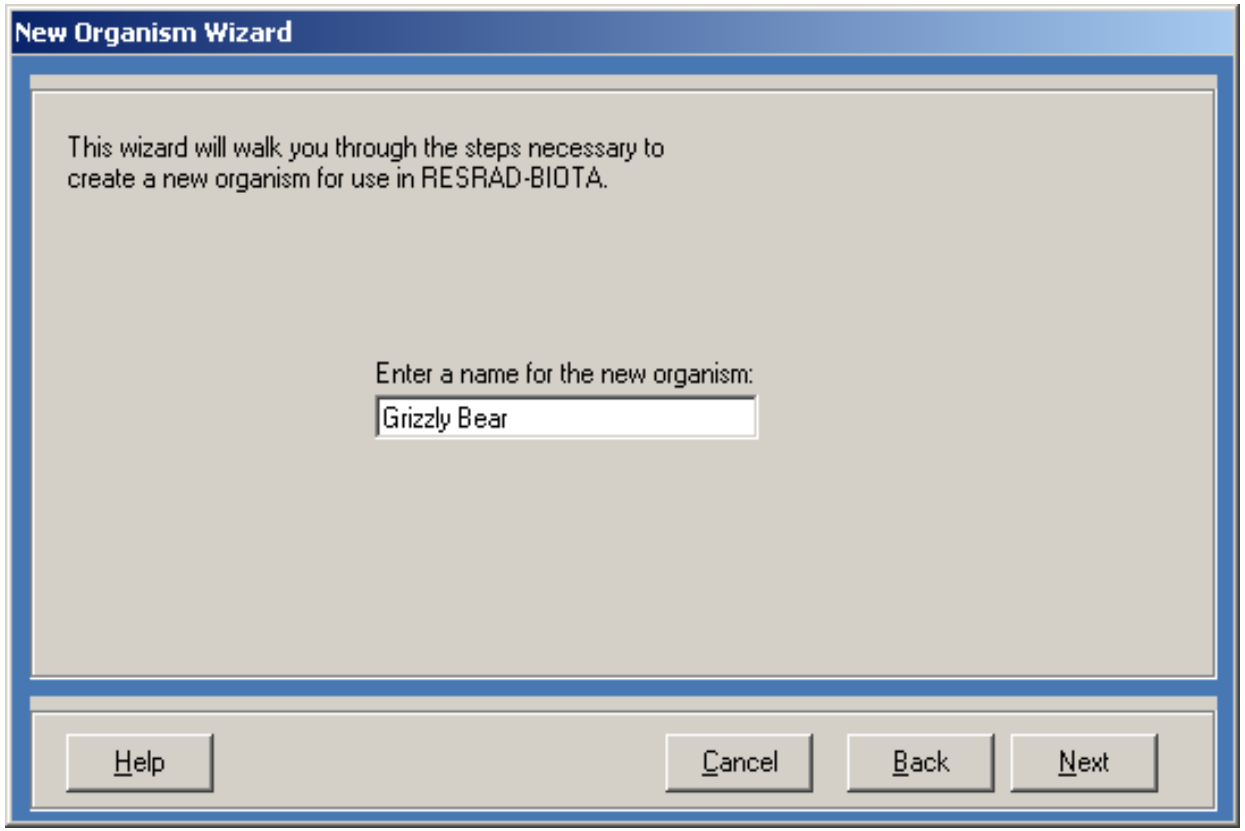
Interaction with Environment

Allometric

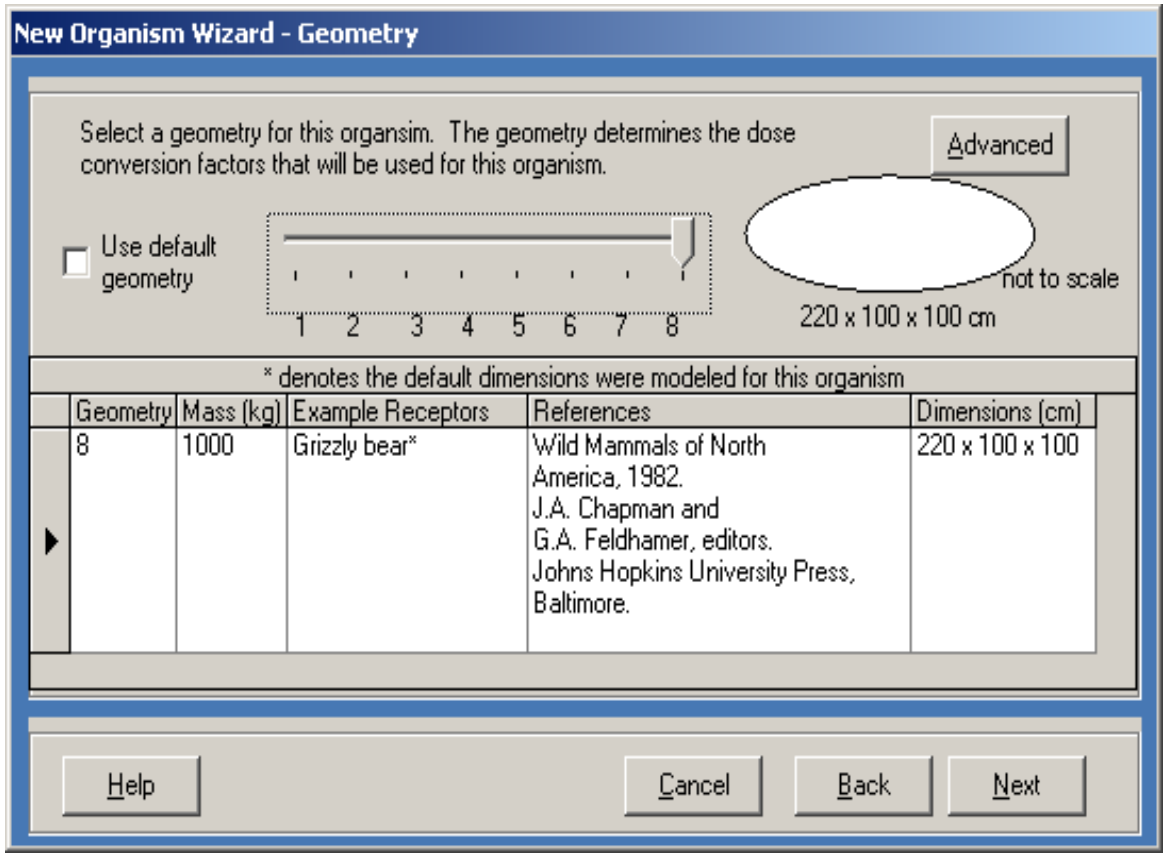
Biv's

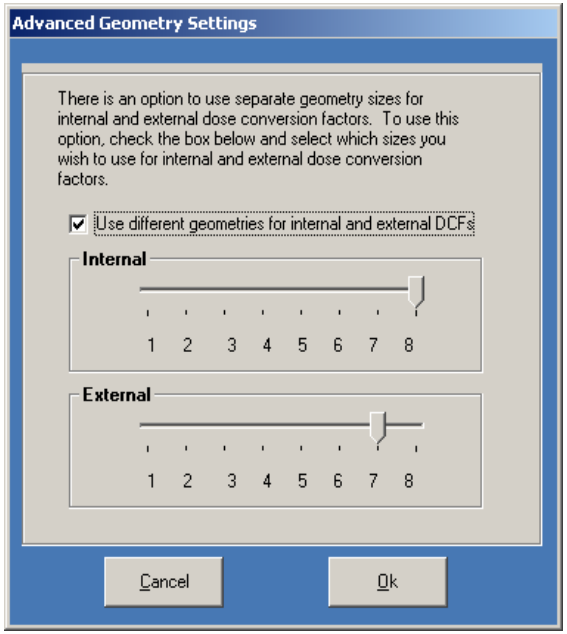
Biv's

Organism Wizard

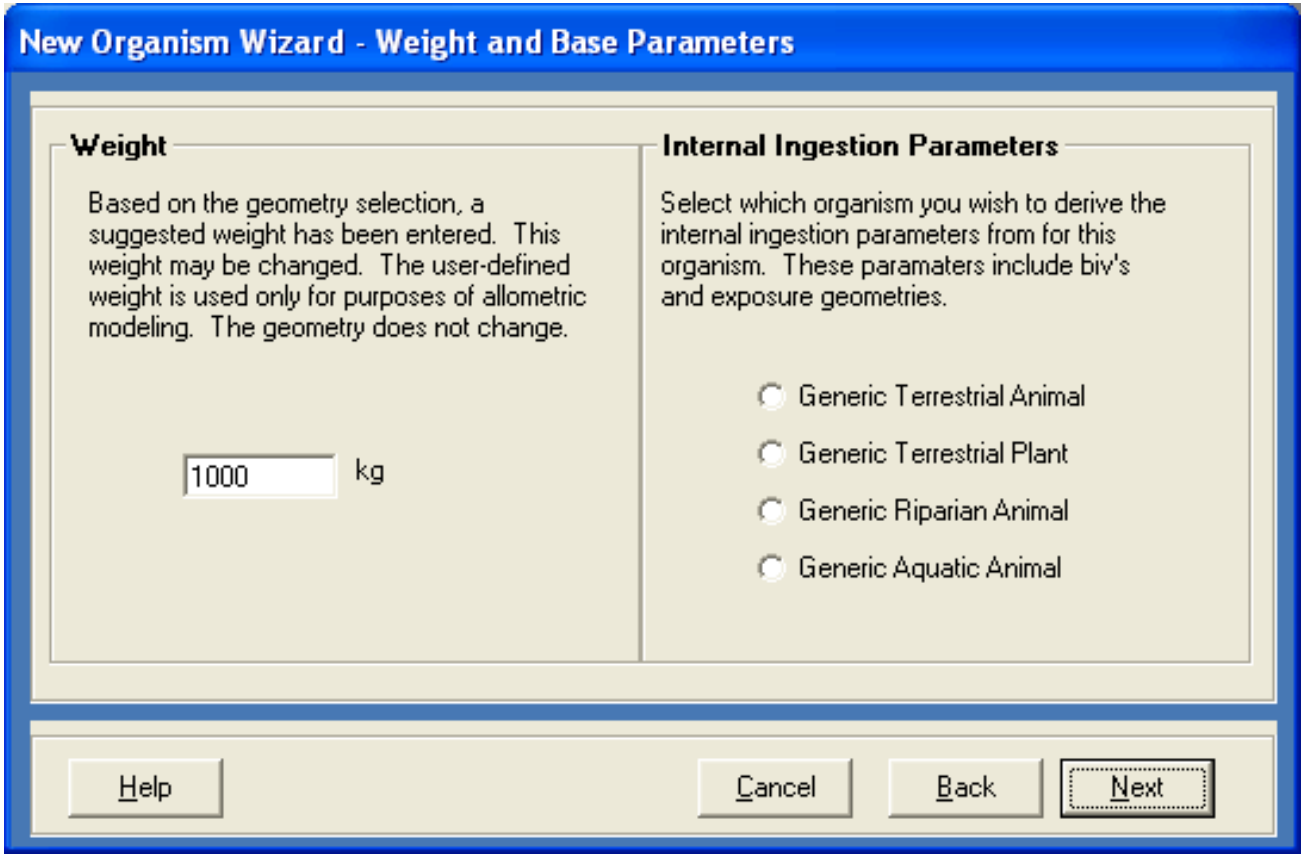


Organism Wizard

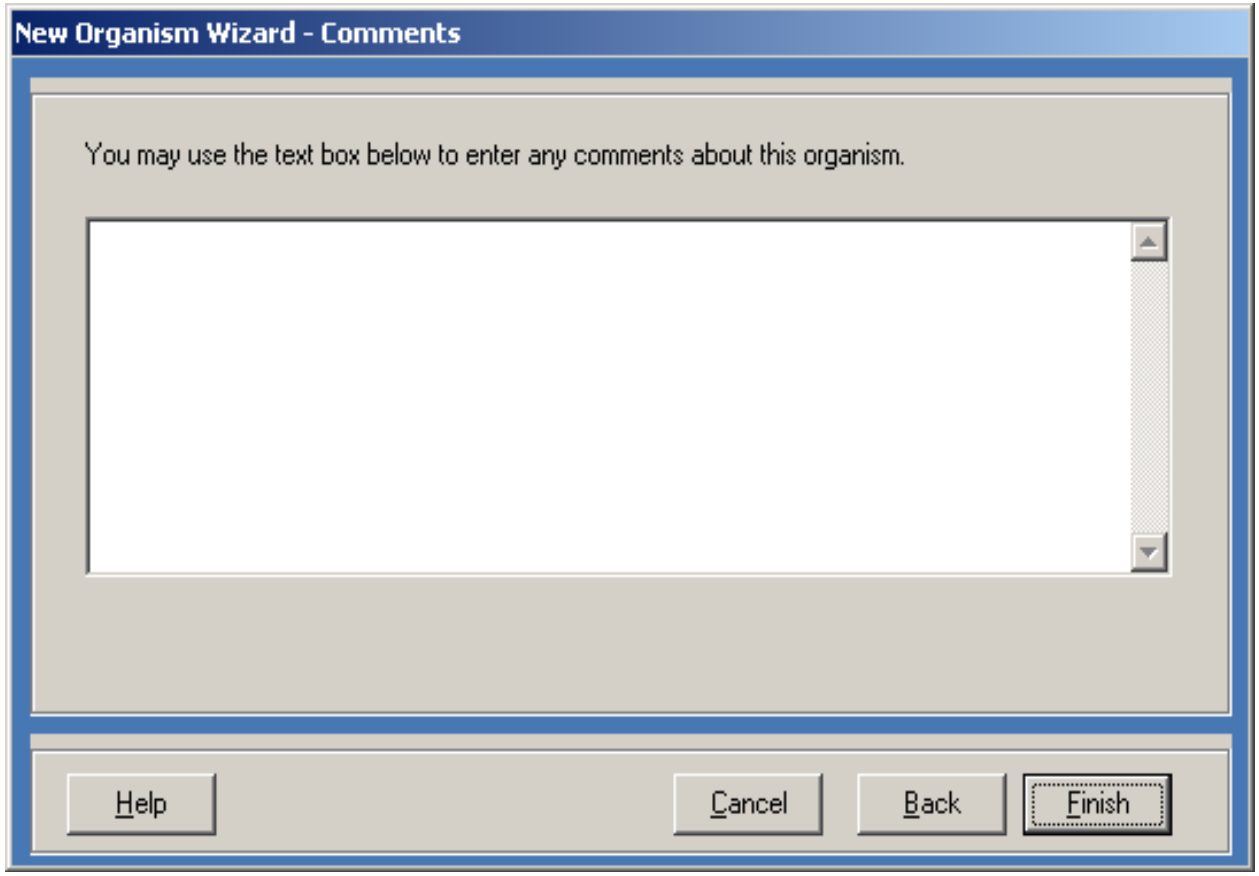




Organism Wizard



Organism Wizard



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Data Import/Export Feature and Graphics & Reports

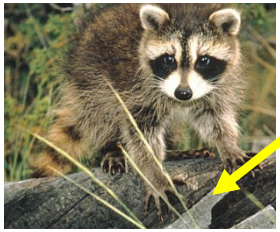
Import & Export

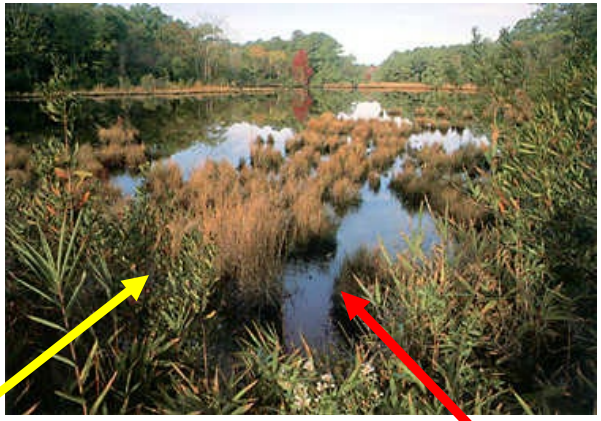
- Organism can be saved (exported) and retrieved (imported) independently of case file.
- Files can be emailed or later posted on the web site (for exchange with other users).
- Please remember to document assumptions and data references

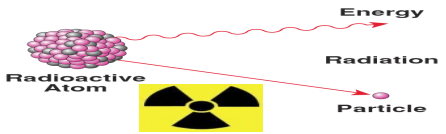
Results

- Interactive Report
- Graphs
- HTML report
- (Database)

Biota Relationships







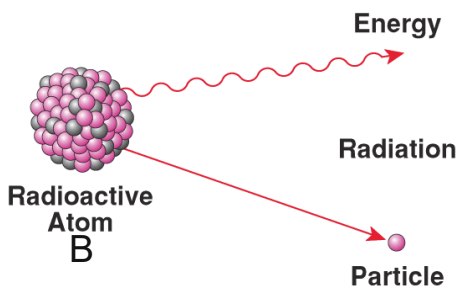
Bivs

Concentrations

A

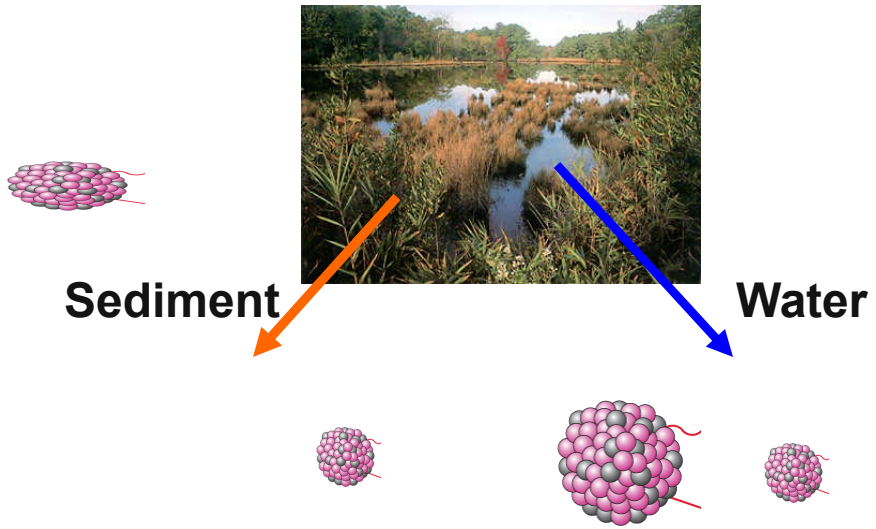
DCFs

Dose Limits



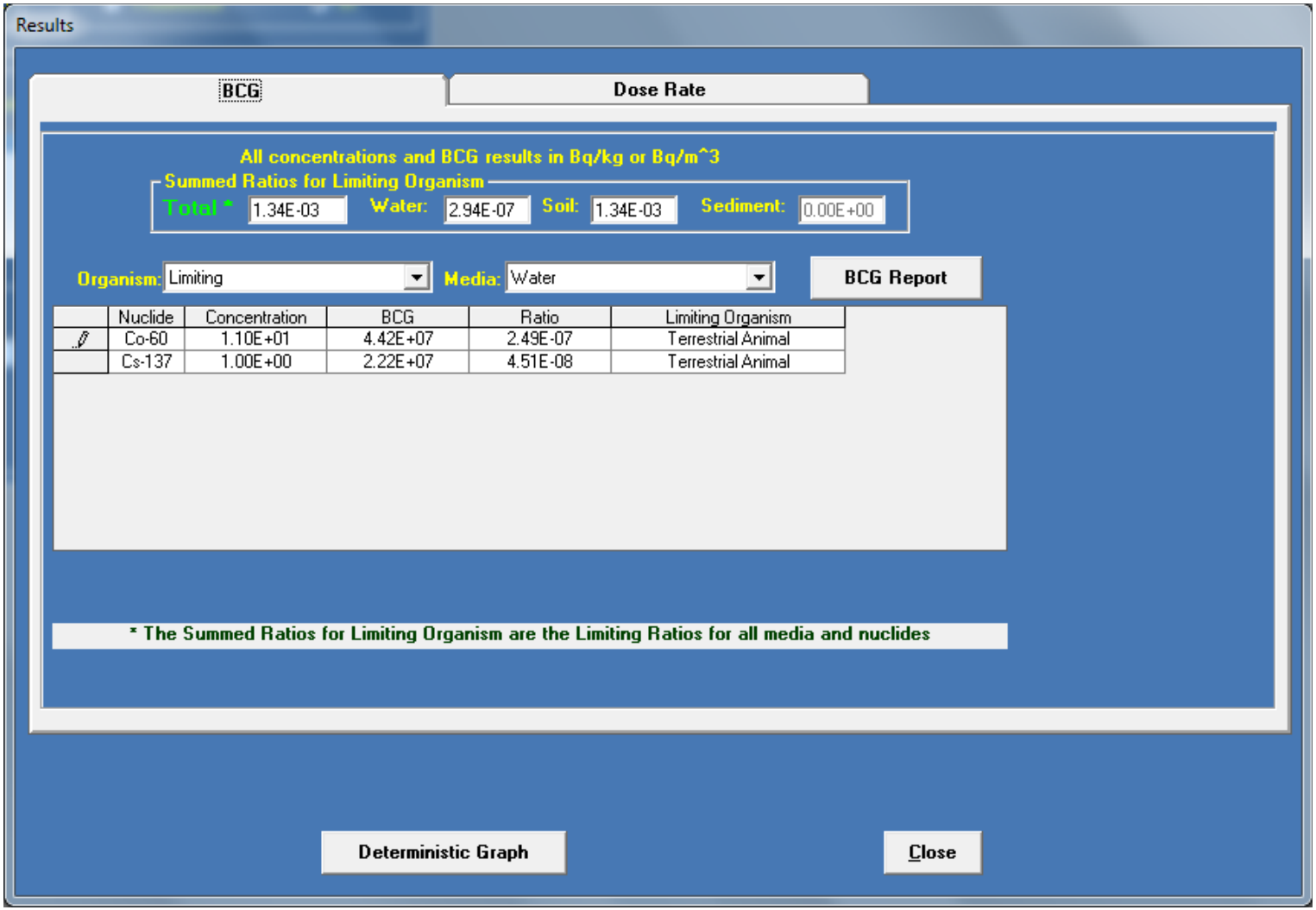
BCG Results

- For each media:
- For each radionuclide:
- Determine organism with highest Dose to Dose Limit ratio

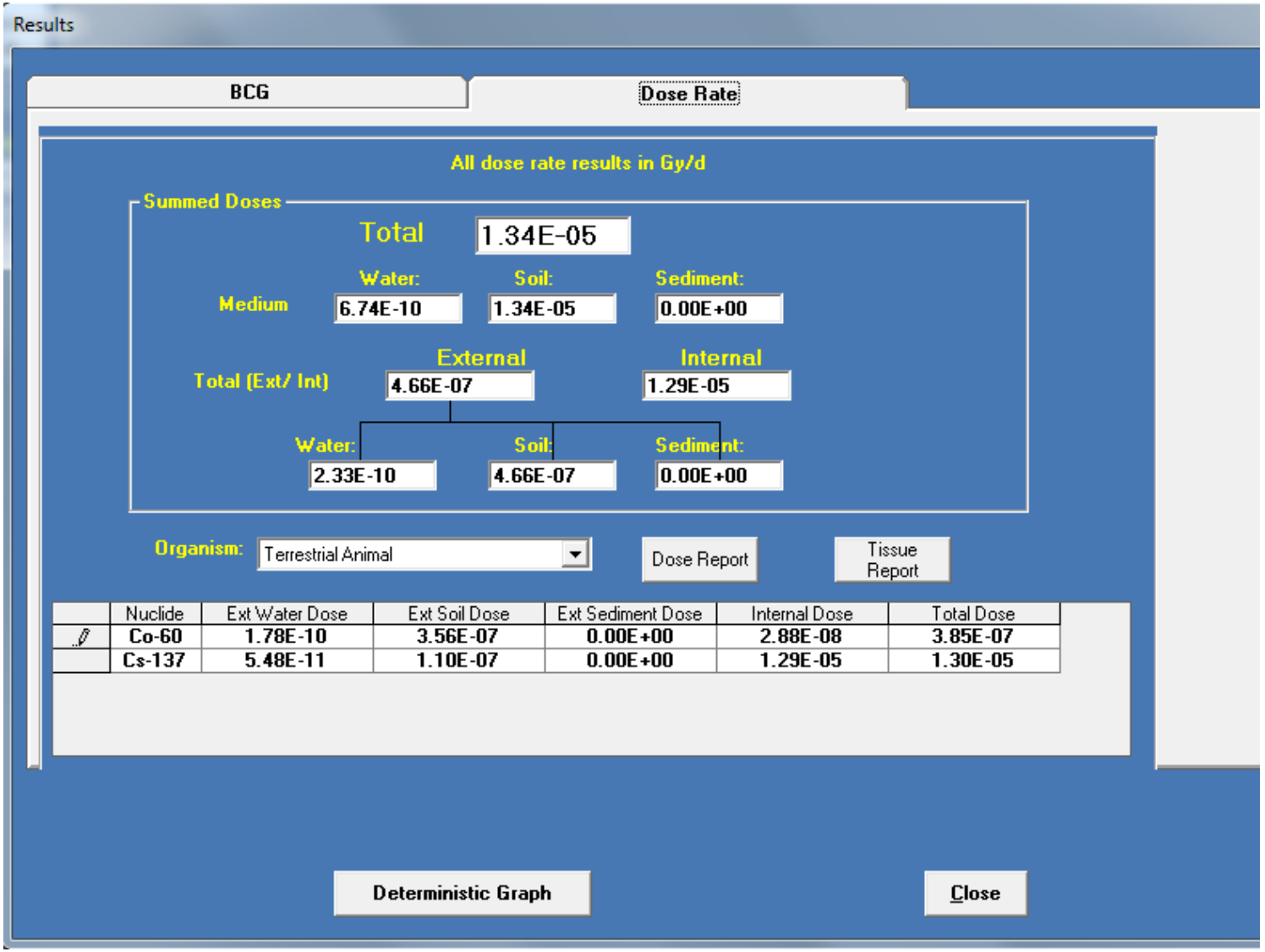


.4	.2	**.9**	.1
.1	**.3**	.8	**1.2**

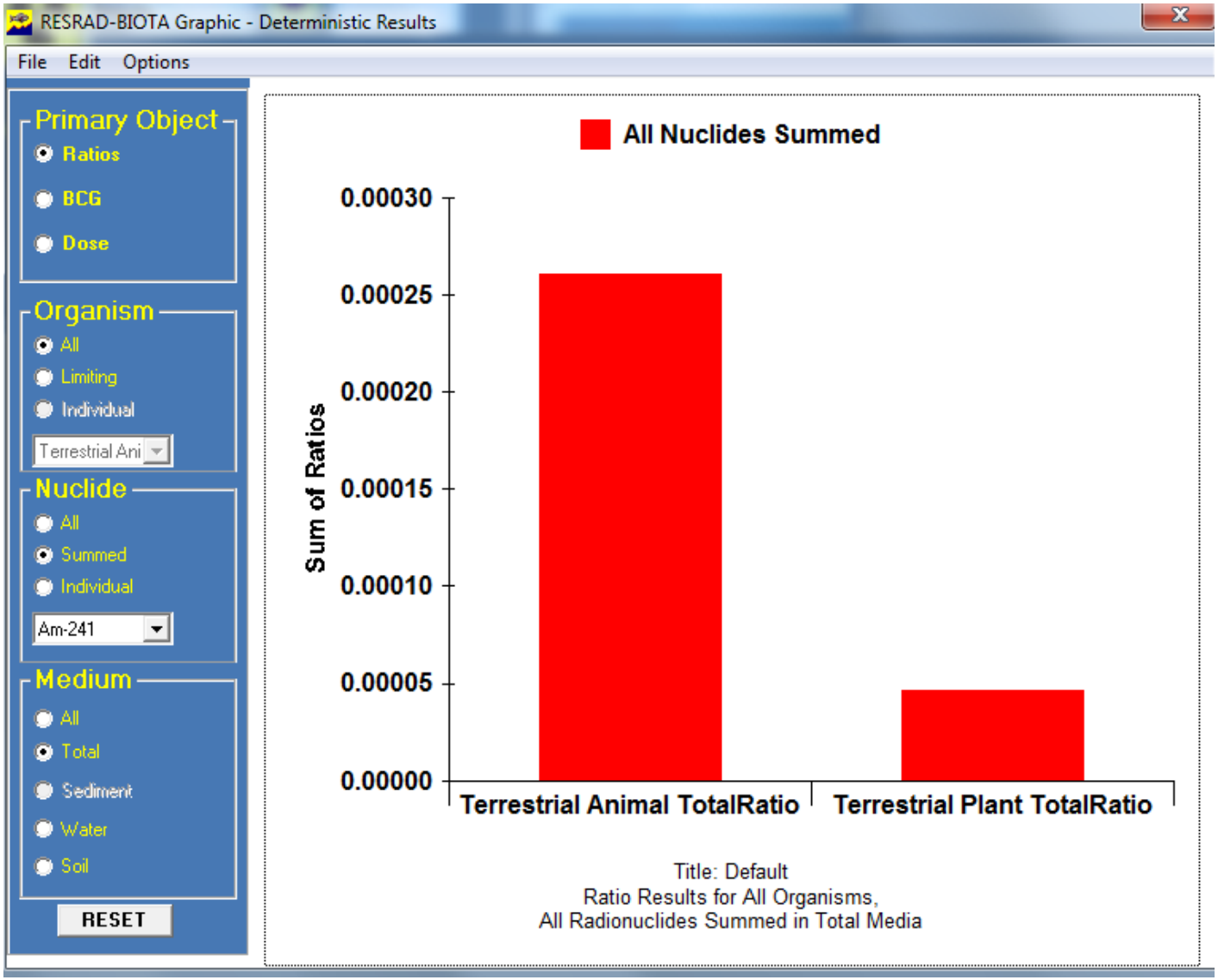
Interactive Report



Interactive Report



Graphs


RESRAD-BIOTA Graphic - Deterministic Results
File
Edit
Options
Primary Object
Ratios
BCG
Dose
Organism
All
Limiting
Individual
Terrestrial Ani
Nuclide
All
Summed
Individual
Am-241
Medium
All
Total
Sediment
Water
Soil
RESET
All Nuclides Summed
Sum of Ratios
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
Terrestrial Animal TotalRatio
Terrestrial Plant TotalRatio
Title: Default
Ratio Results for All Organisms,
All Radionuclides Summed in Total Media

HTML Report

Terrestrial Dose Report for Level 2 in Gy/d

Title: Default

Terrestrial Animal												
Nuclide	External				Internal				Total			
	ext_Wtr	ext_Soil	ext_Sed	ext_Sum	int_Wtr	int_Soil	int_Sed	int_Sum	tot_Wtr	tot_Soil	tot_Sed	tot_Sum
Co-60	1.96E-10	3.56E-08	0.00E+00	3.58E-08	5.30E-11	3.47E-09	0.00E+00	3.53E-09	2.49E-10	3.91E-08	0.00E+00	3.93E-08
Cs-137	5.48E-12	1.10E-08	0.00E+00	1.10E-08	3.96E-11	1.29E-06	0.00E+00	1.29E-06	4.51E-11	1.30E-06	0.00E+00	1.30E-06
Summed	2.01E-10	4.66E-08	0.00E+00	4.68E-08	9.26E-11	1.29E-06	0.00E+00	1.29E-06	2.94E-10	1.34E-06	0.00E+00	1.34E-06

Terrestrial Plant												
Nuclide	External				Internal				Total			
	ext_Wtr	ext_Soil	ext_Sed	ext_Sum	int_Wtr	int_Soil	int_Sed	int_Sum	tot_Wtr	tot_Soil	tot_Sed	tot_Sum
Co-60	1.96E-10	3.56E-08	0.00E+00	3.58E-08	3.32E-12	8.50E-09	0.00E+00	8.50E-09	1.99E-10	4.41E-08	0.00E+00	4.43E-08
Cs-137	5.48E-12	1.10E-08	0.00E+00	1.10E-08	0.00E+00	1.11E-07	0.00E+00	1.11E-07	5.48E-12	1.22E-07	0.00E+00	1.22E-07
Summed	2.01E-10	4.66E-08	0.00E+00	4.68E-08	3.32E-12	1.20E-07	0.00E+00	1.20E-07	2.05E-10	1.66E-07	0.00E+00	1.67E-07

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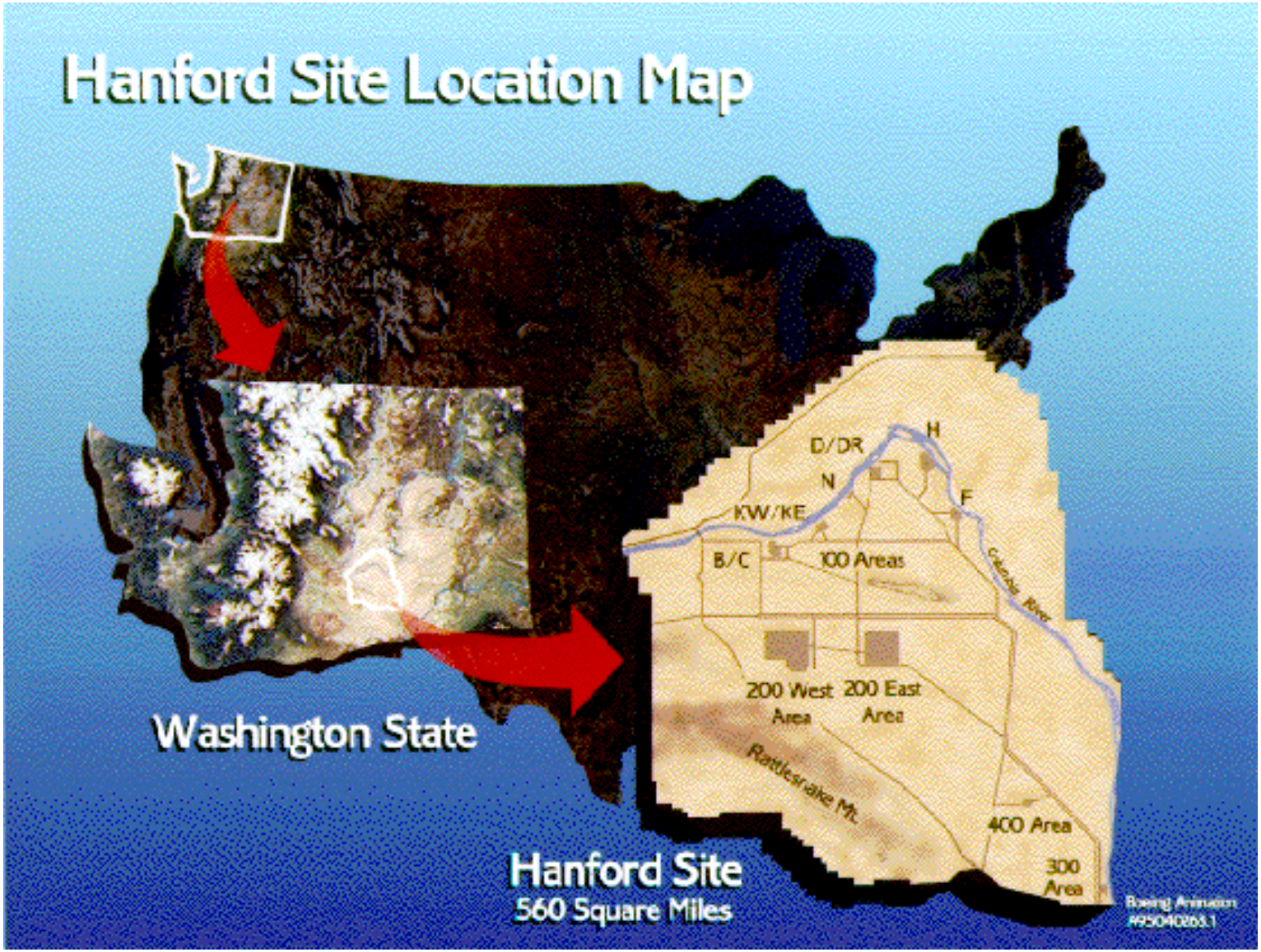
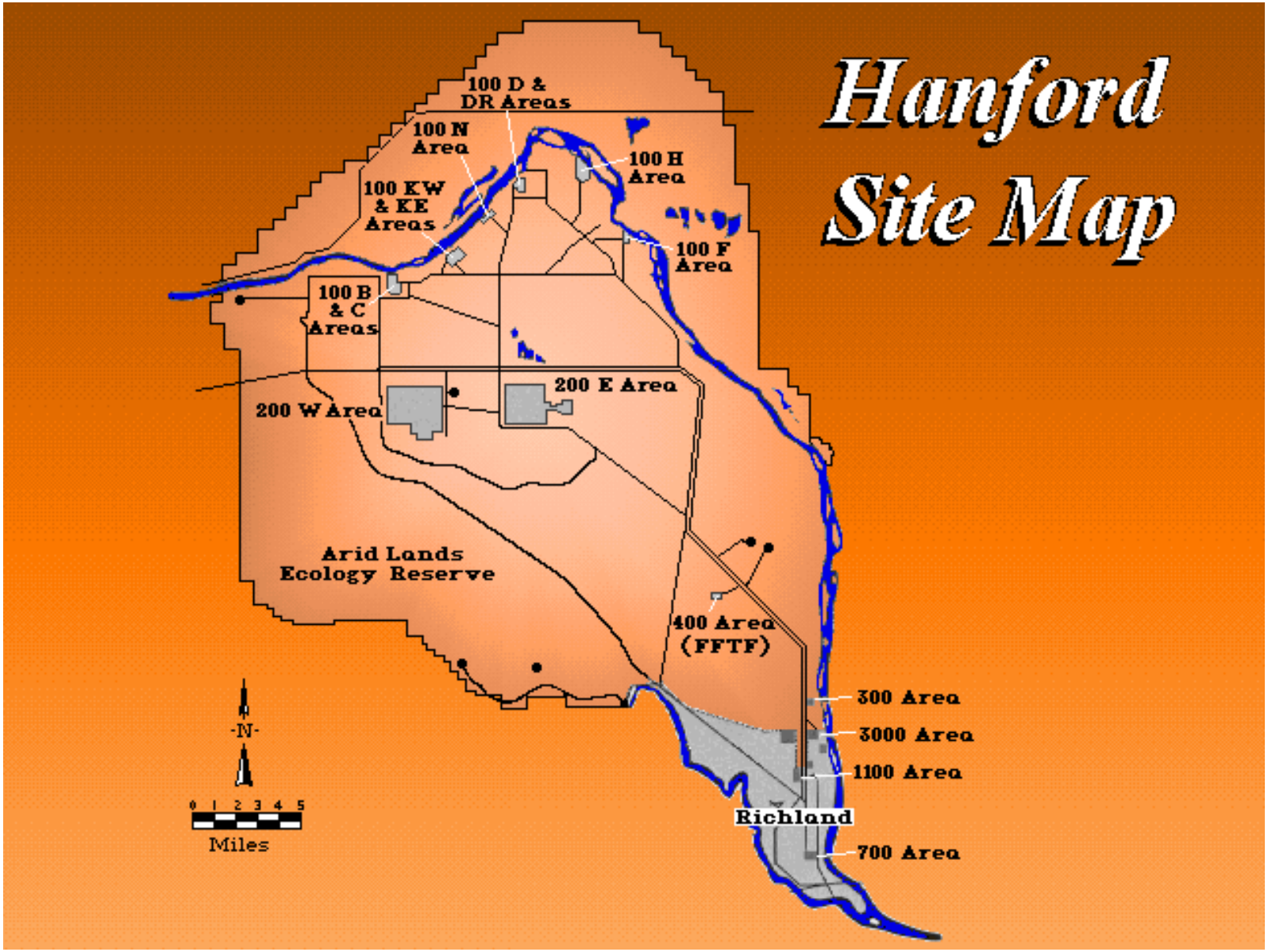
Case Study I & Hands-on Problem 5 Review —

Biota Dose Evaluation of the Hanford 300 Area

Case Study I

- Assess Hanford's 300 Area Shoreline
- Utilize
  - Screening options
  - Site Biv data
  - Create new organism with site-specific parameters
- Discuss
  - Decisions made concerning site data
  - Types of calculations that may be encountered

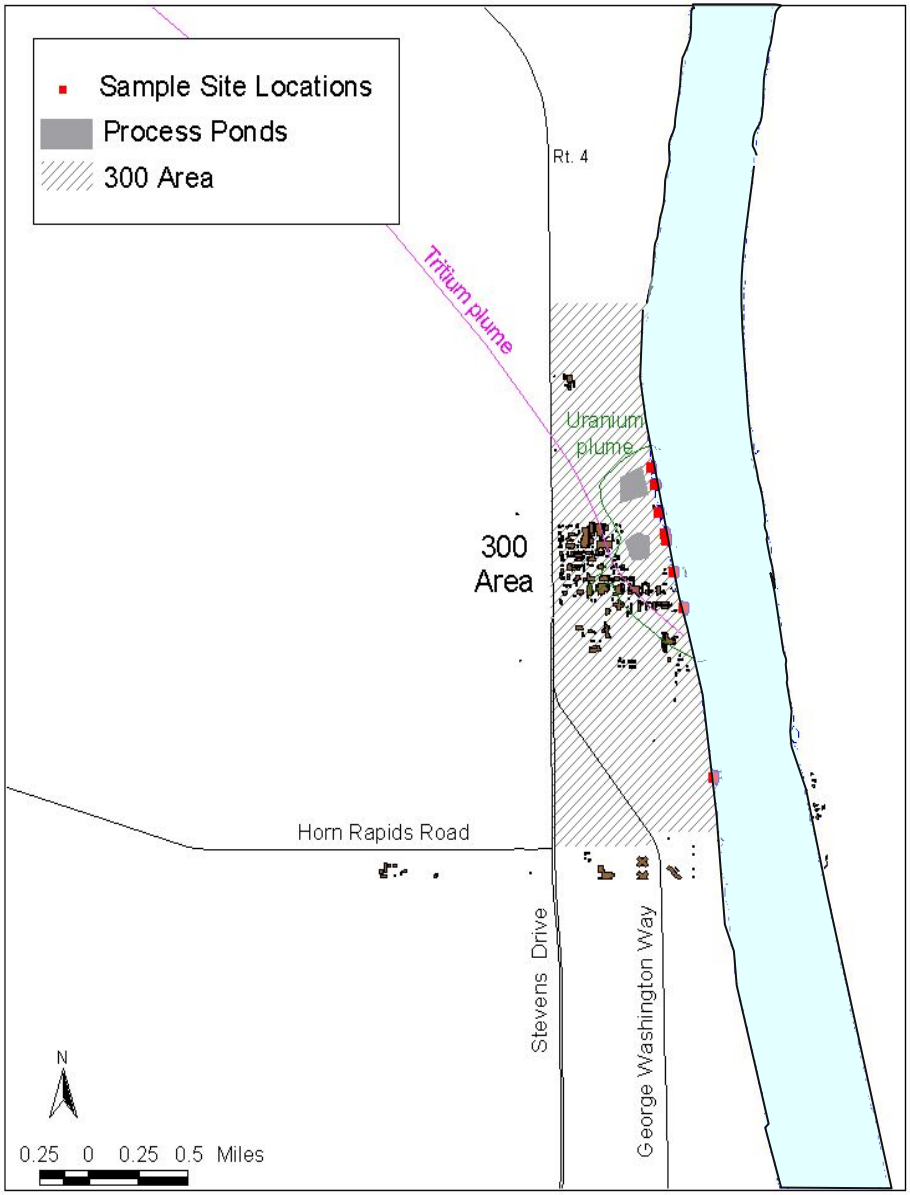

Hanford Site Location Map
Washington State
D/DR
H
N
F
KW/KE
B/C
100 Areas
Columbia River
200 West Area
200 East Area
Rattlesnake Mt.
400 Area
300 Area
Hanford Site
560 Square Miles
Boeing Animation


Hanford
Site Map
100 D &
DR Areas
100 N
Area
100 H
Area
100 KW
& KE
Areas
100 F
Area
100 B
& C
Areas
200 E Area
200 W Area
Arid Lands
Ecology Reserve
400 Area
(FFTF)
300 Area
3000 Area
1100 Area
Richland
700 Area
-N-
0 1 2 3 4 5
Miles

Hanford's 300 Area

- Small portion of larger Hanford Reservation (Washington State, USA)
  - Area of concern: 1.5 km^2
  - Produced fuel elements for defense applications
  - Process waste ponds situated near Columbia River
  - Principal contaminants of concern: U-series

Sampling locations



Water & Sediment Sampling

- Collected at river bank spring locations
- Unfiltered water
- Sediments collected when available

Biota Sampling

- Riparian vegetation
  - Mulberry
  - Sweet clover
- Riparian animals
  - House mice
  - Beetles
- Aquatic vegetation
  - Milfoil
  - Elodea
- Aquatic animals
  - Clams
  - Crayfish
  - Sculpin

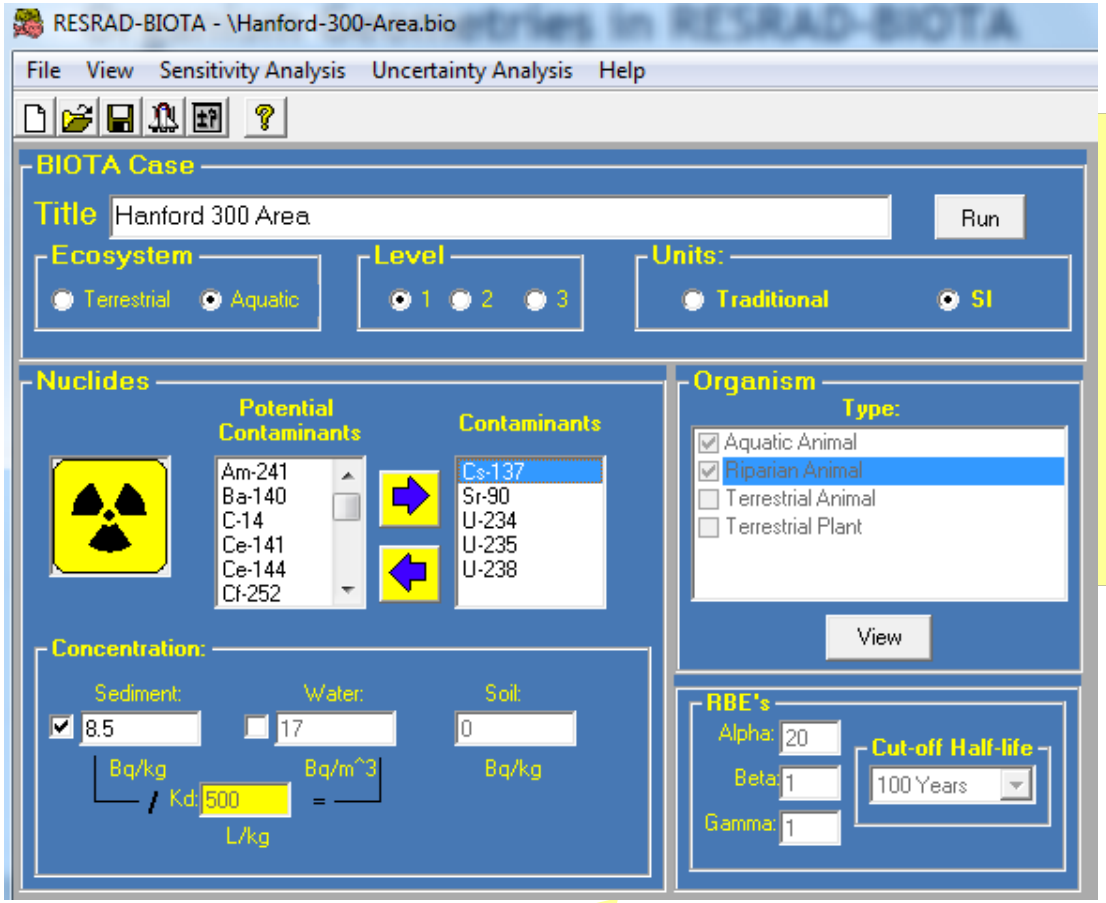
RESRAD-BIOTA Application

- Level 1
  - General Screening
  - Maximum concentrations in water & sediment
- Level 2
  - Site-specific screening
  - Site-specific bioaccumulation coefficients
- Level 3
  - Site-specific analysis phase
  - Configure site-specific organisms
  - Examine results

Data Entry – Level 1

Radio - nuclide	Water Minimum Detection Limit (Bq/m^3)	Water (Bq/m^3)	Sediment Minimum Detection Limit (Bq/kg)	Sediment (Bq/kg)
Sr-90	2.22	7.5E+00	1.9	9.6E-01
Cs-137	370		1.1	8.5E+00
U-234	2.22	2.0E+03	0.75	1.0E+02
U-235	2.22	8.3E+01	0.75	3.8E+00
U-238	2.22	1.8E+03	0.75	9.1E+01

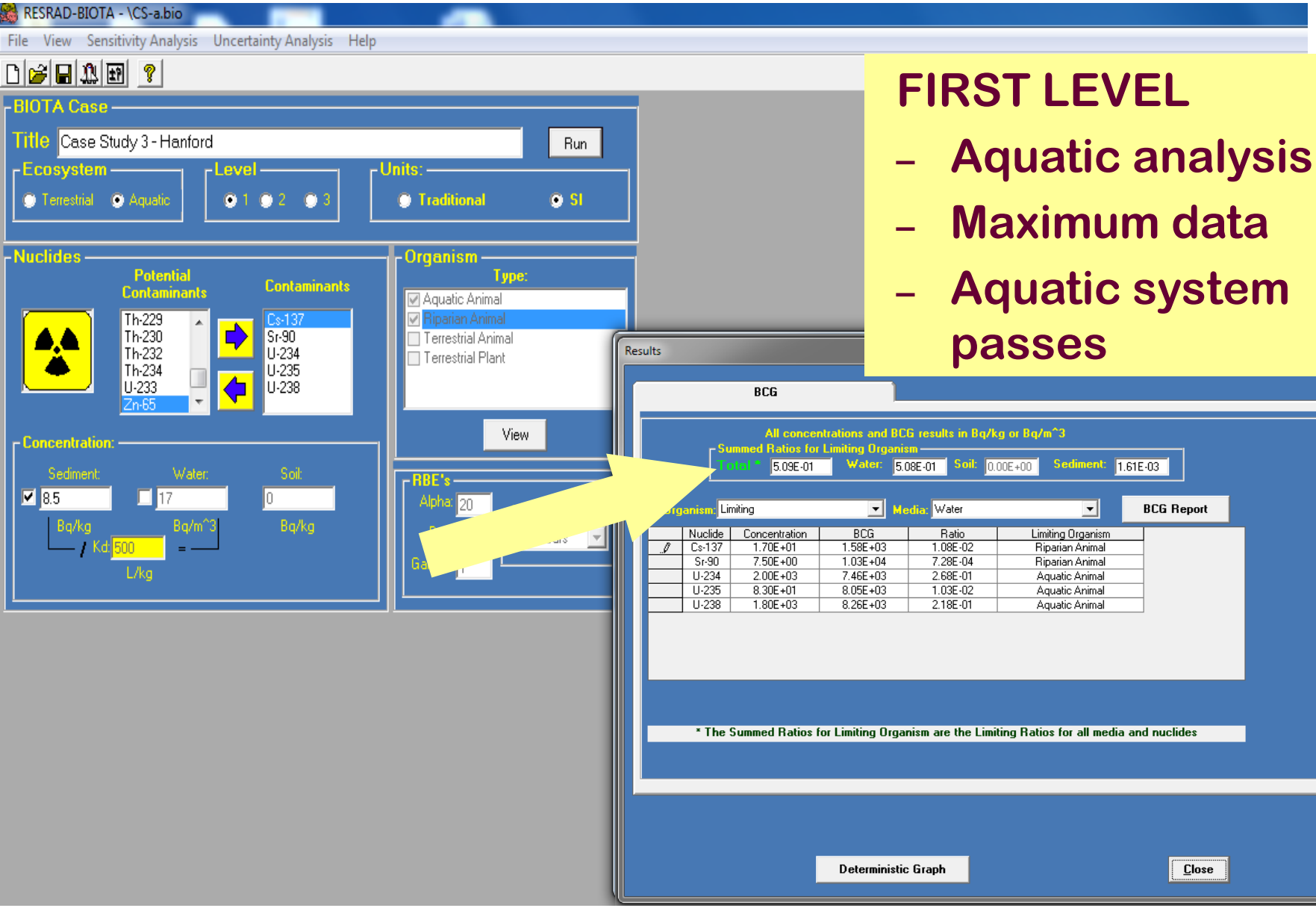
[a]This list represents a selection of nuclides detected in water and sediment, and is used to illustrate the application of the RESRAD-BIOTA code.



FIRST LEVEL

- Aquatic analysis
- Maximum data
- Use Kd to evaluate missing concentration

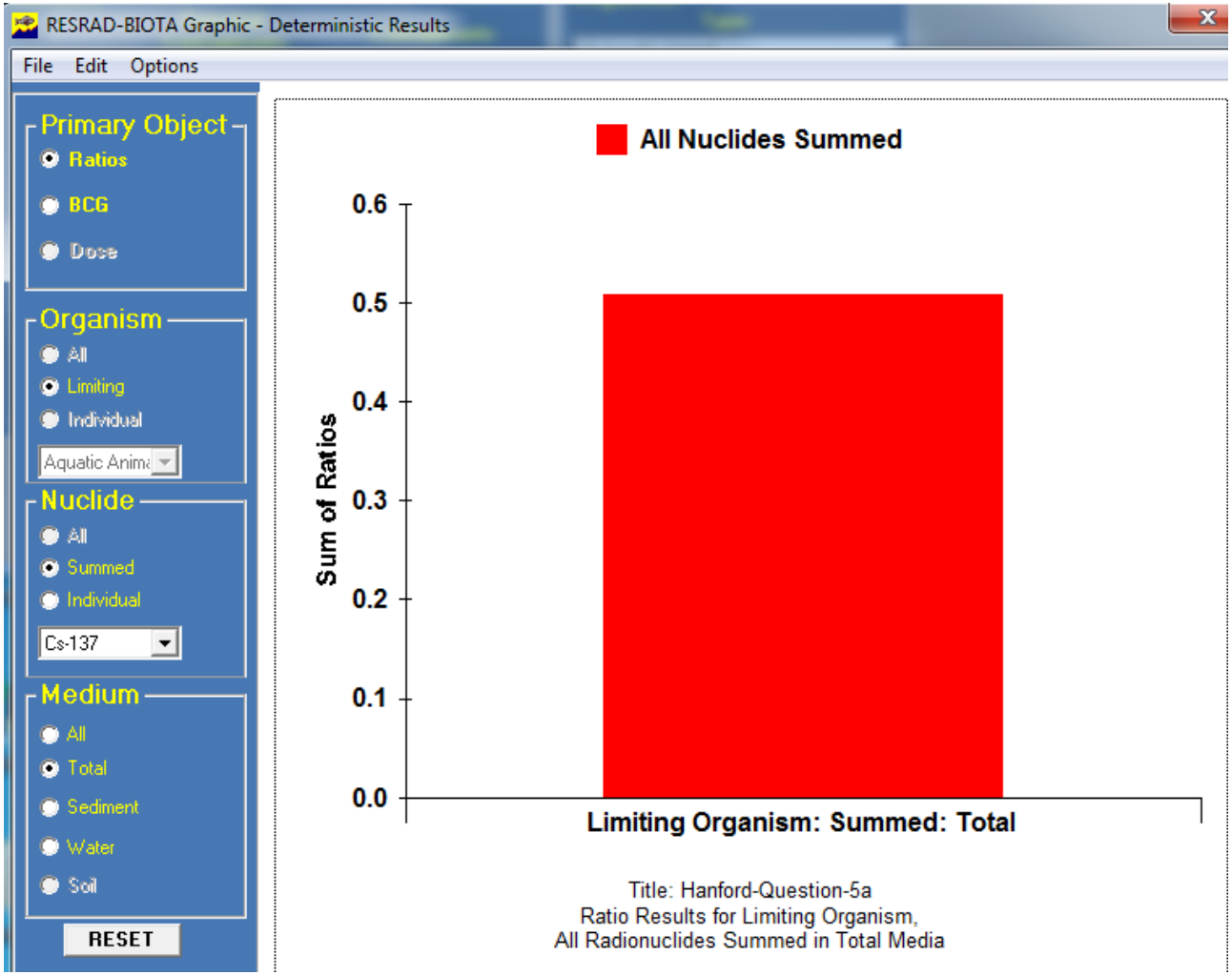
Water concentration estimated



FIRST LEVEL

- Aquatic analysis
- Maximum data
- Aquatic system passes

Level 1 Graphical output



Site-Specific Screen Phase

- Level 2
  - To examine method flexibility and insight gained by additional analyses
- Additional data required
- Selected parameters can be modified:
  - Average values can be used (not demonstrated)
  - Distribution coefficients (where co-located water/sediment samples are lacking) can be modified
  - Organism specific parameters can be adjusted
    - *Site-specific Bivs*

Site-Specific Screen Phase: Biv Modification

Biota Media[a]	Sr-90 Bq/kg	Cs-137 Bq/kg	Uranium µg/g
Detection Limits	1.5	1.5	0.01
Aquatic Community			
Milfoil	3.3	4.4	9.29
Clam			6.77
Sculpin	0.7	-0.4	0.06

[a] **This data represent activity per kg of dry weight. To convert to a wet weight activity, multiply concentration values by 0.2**

Site-Specific Screen Phase: Bivs

Isotope	Wt % of isotope in U (nat)	U (nat) µg per g of clam	µg of isotope per g of clam	Kg of isotope per kg of (dry) clam	Kg of isotope per kg of (wet) clam
U-234	0.0074	6.77	5.0098×10^{-4}	5.0098×10^{-10}	1.0020×10^{-10}
U-235	0.648	6.77	4.387×10^{-2}	4.387×10^{-8}	8.774×10^{-9}
U-238	99.340	6.77	6.7253	6.7253×10^{-6}	1.3451×10^{-6}

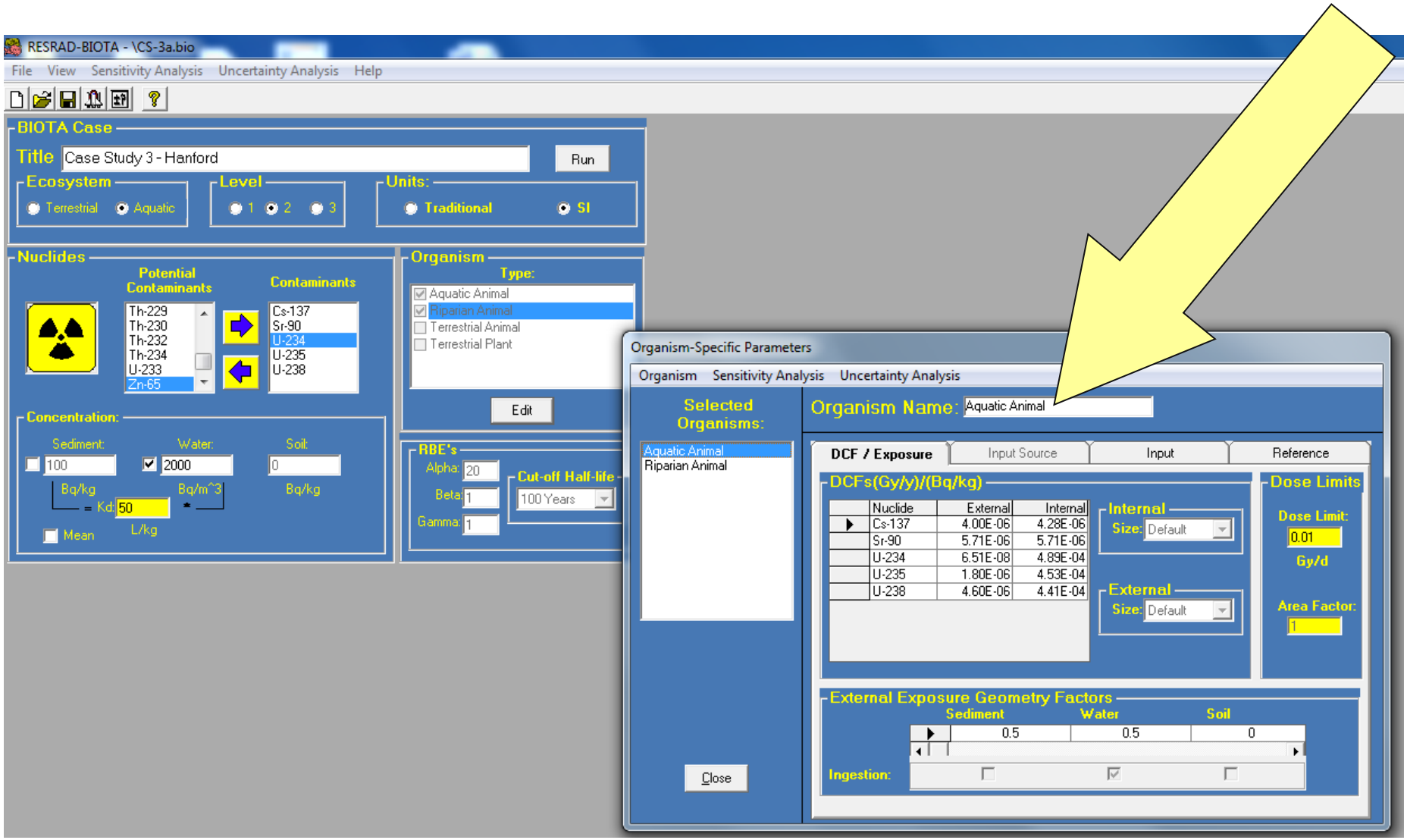
Site-Specific Screen Phase: Bivs

Isotope	Specific Activity, Bq/kg of isotope	Activity concentration, Bq/kg of Clam (wet weight)
U-234	2.279×10^{11}	*22.84*
U-235	7.881×10^{7}	*0.691*
U-238	1.234×10^{7}	*16.6*

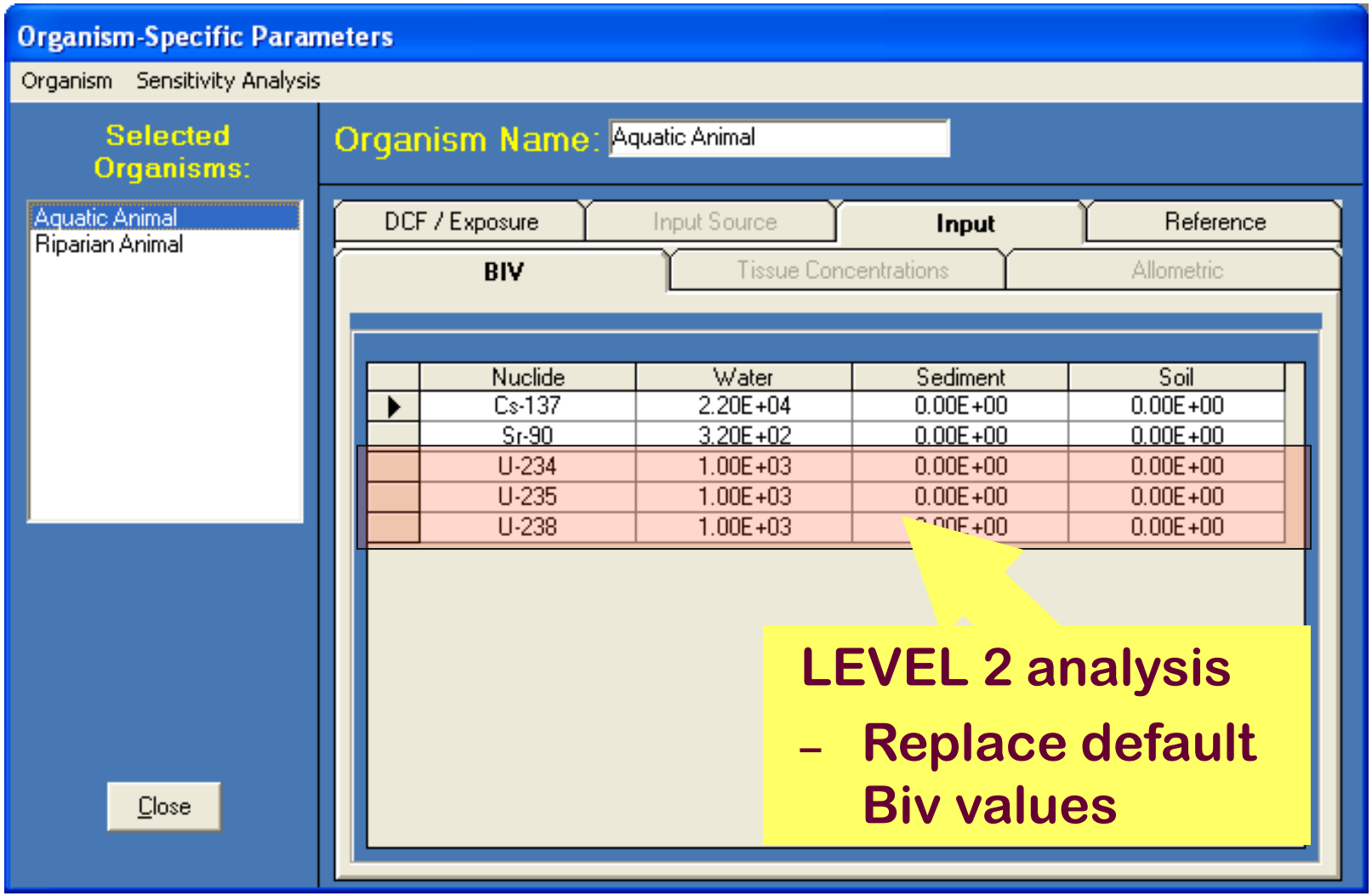
Site-Specific Screen Phase: Bivs

Radio-nuclide	Calculated Biv values for Aquatic Biota				
	Water (Bq/m^3)	Sediment (Bq/kg)	Clam Conc. (Bq/kg)	Clam (water) Biv (L/kg)	Clam (sed.) Biv
U-234	2.0E+03	1.0E+02	22.84	11	0.228
U-235	8.3E+01	3.8E+00	0.691	8.3	0.18
U-238	1.8E+03	9.1E+01	16.6	9.2	0.18

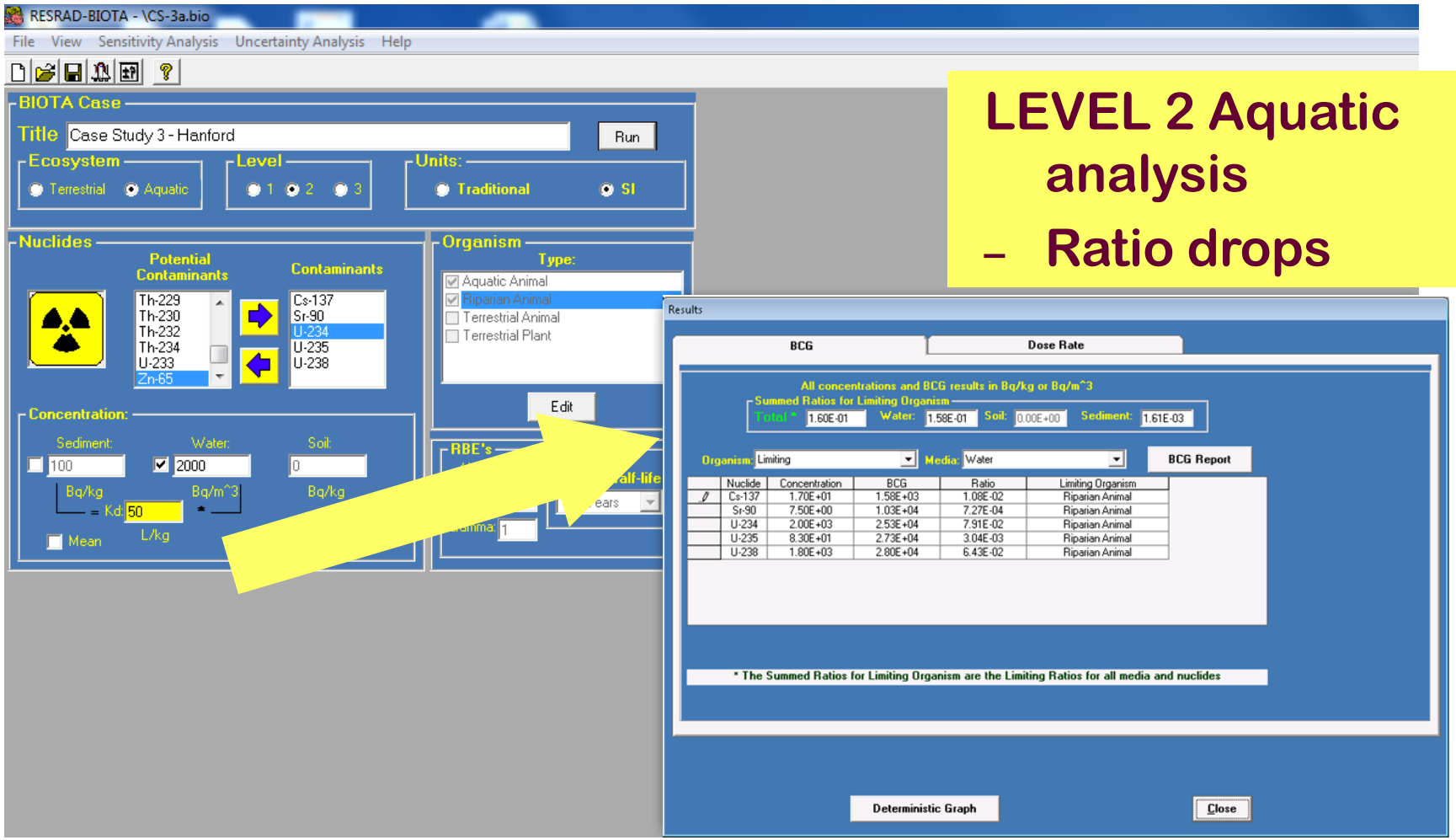
Level 2 Analysis



Level 2 Analysis



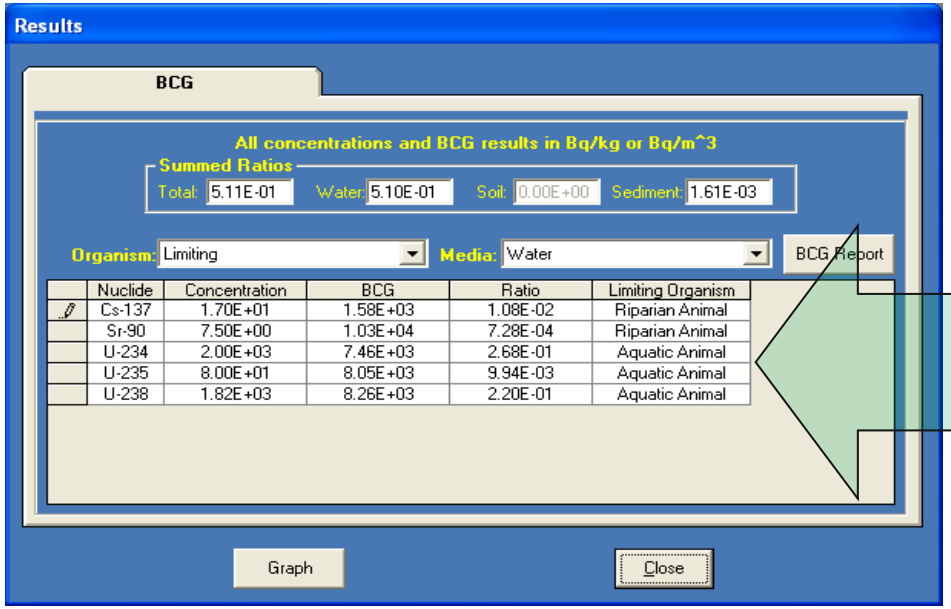
Level 2 Analysis



LEVEL 2 Aquatic analysis

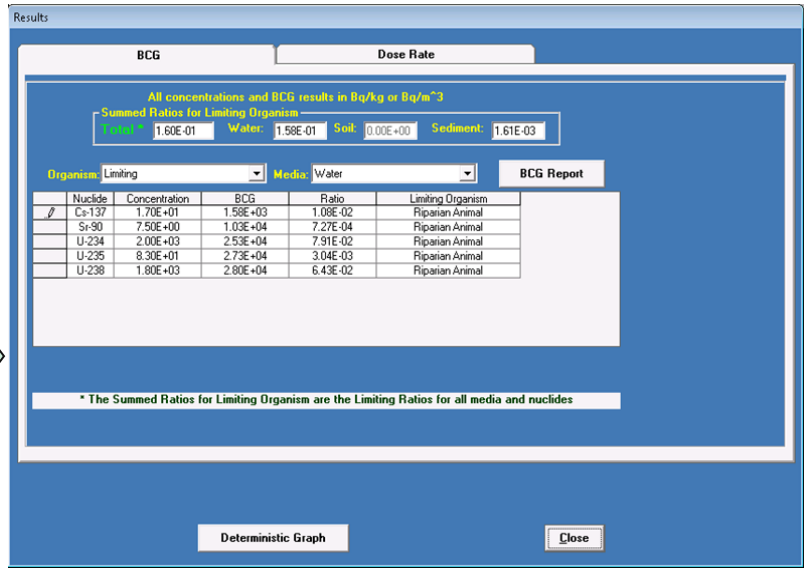
- **Ratio drops**

Observations



- Level 1 – Uranium dominates Sum of Fraction
- Aquatic animal presumed to receive greatest fraction of its limit

- Level 2 – *aquatic animal* Bivs recalculated
- Uranium still dominates, but riparian animal now is presumed to get highest fraction of its limit



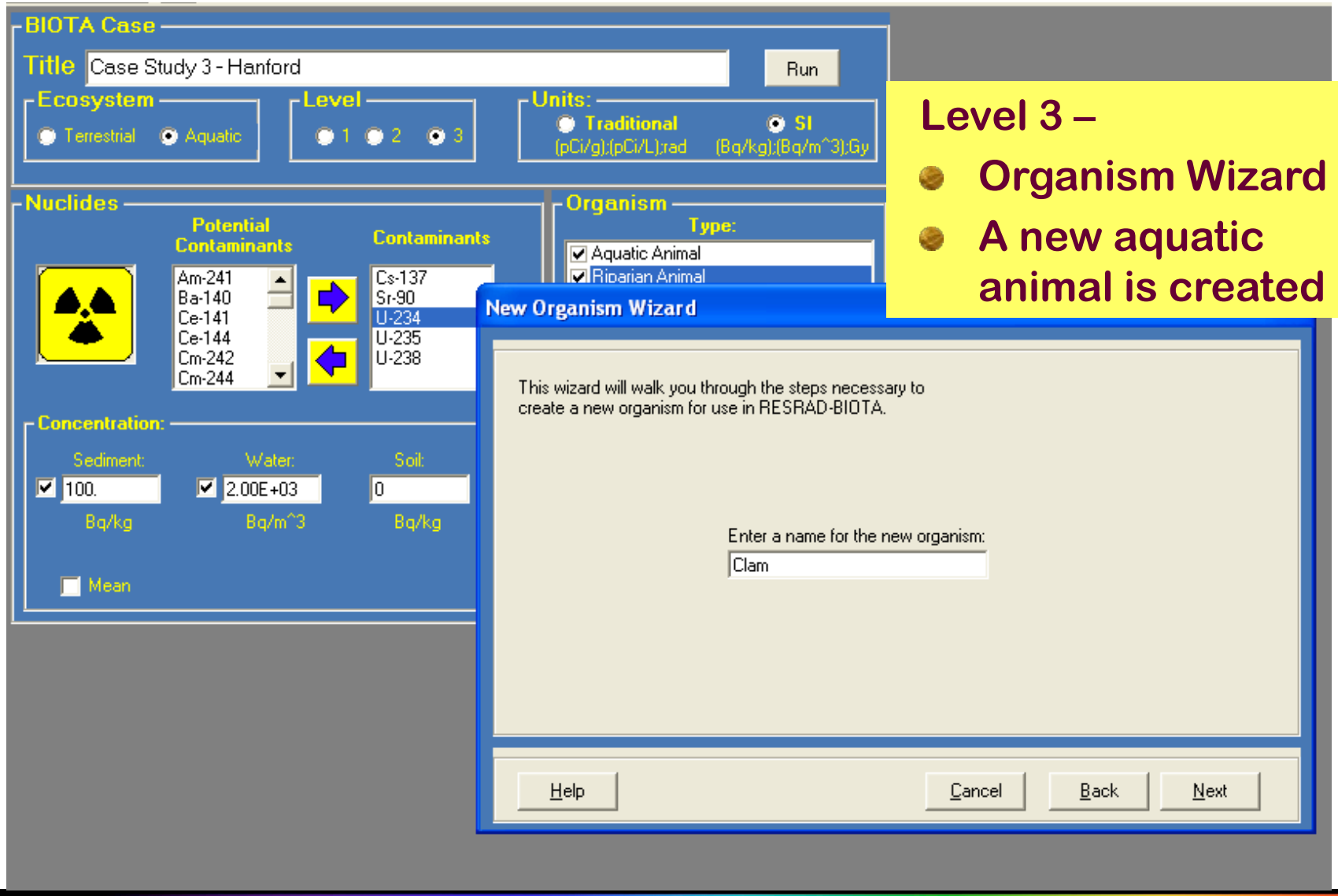
Site-Specific Analysis Phase

- Level 3
- Organism-specific geometries can be created
- Dose factors can be created
- Alpha-RBEs can be modified

Making the Clam

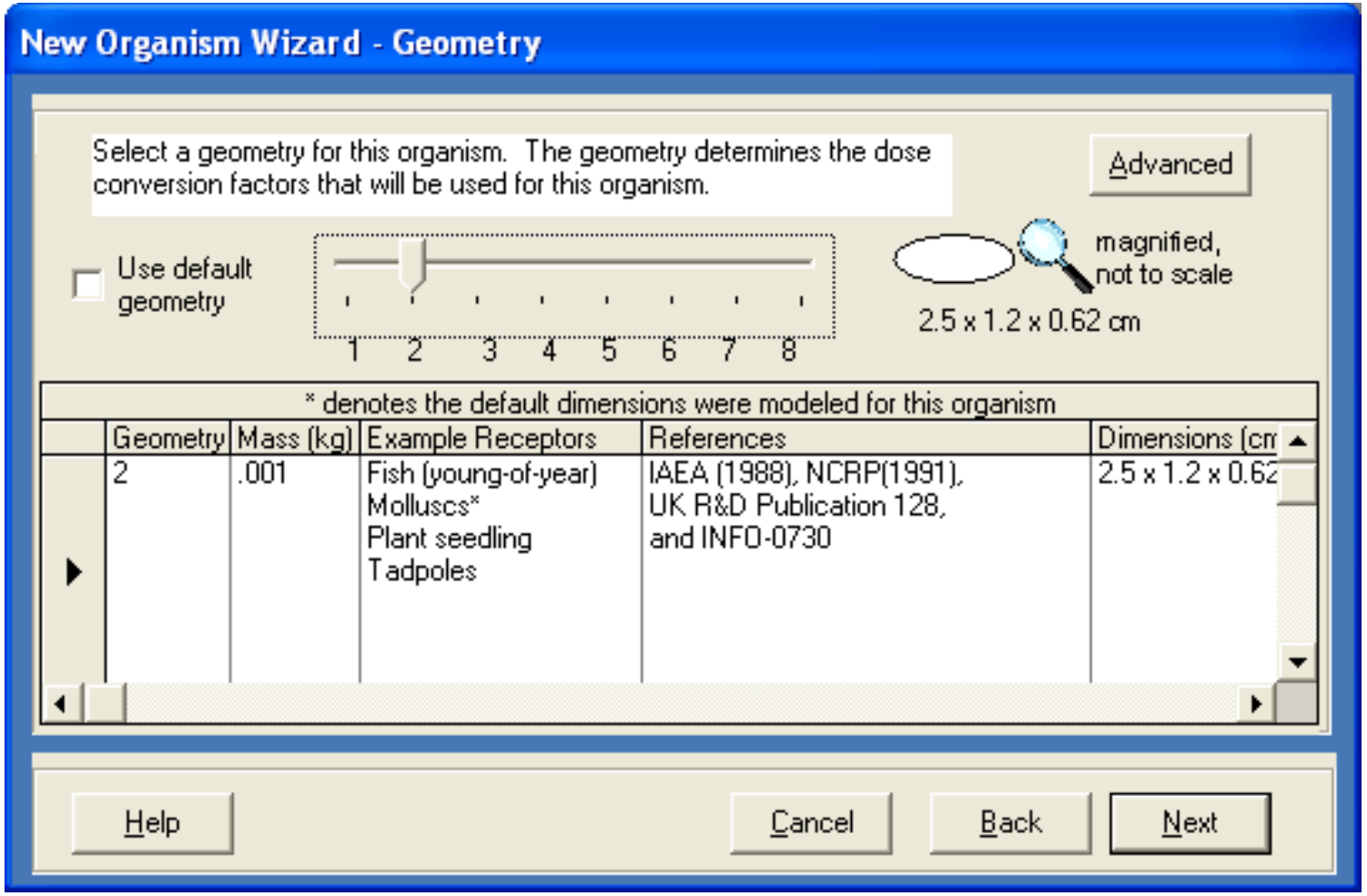
- RESRAD-BIOTA allows site-specific organisms to be created
- Code generates size & geometry specific dose conversion factors
- Other parameters can be modified as needed, using primary reference organisms as a starting point
  - Ingestion / allometrics
  - Bivs
  - Exposure profile
  - Organism residence times

Level 3 Analysis

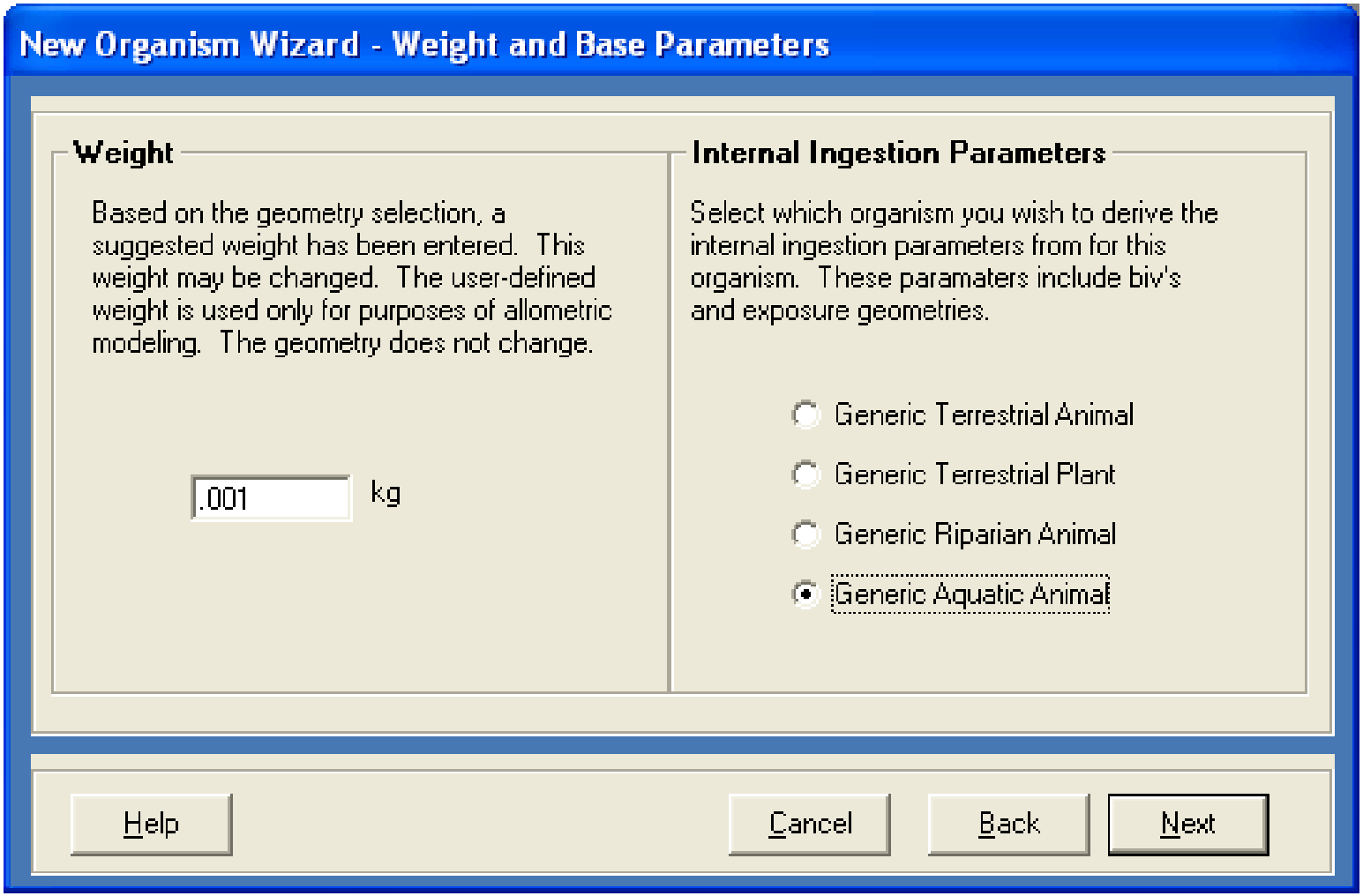


Level 3 –

- **Organism Wizard**
- **A new aquatic animal is created**

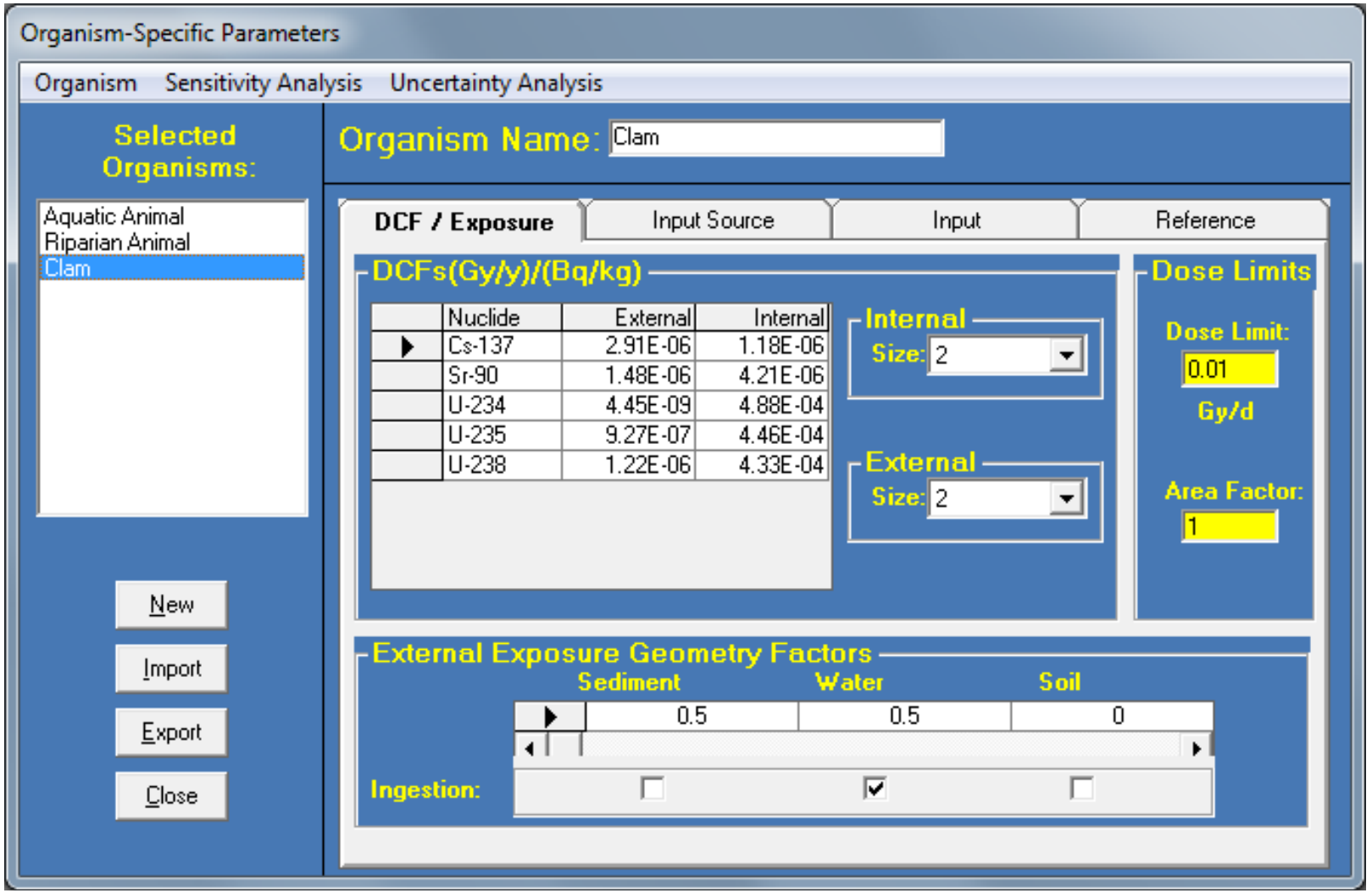


- The geometry of the clam is selected
- Size-specific DCFs will be used



- Mass is selected
- Default organism template is selected

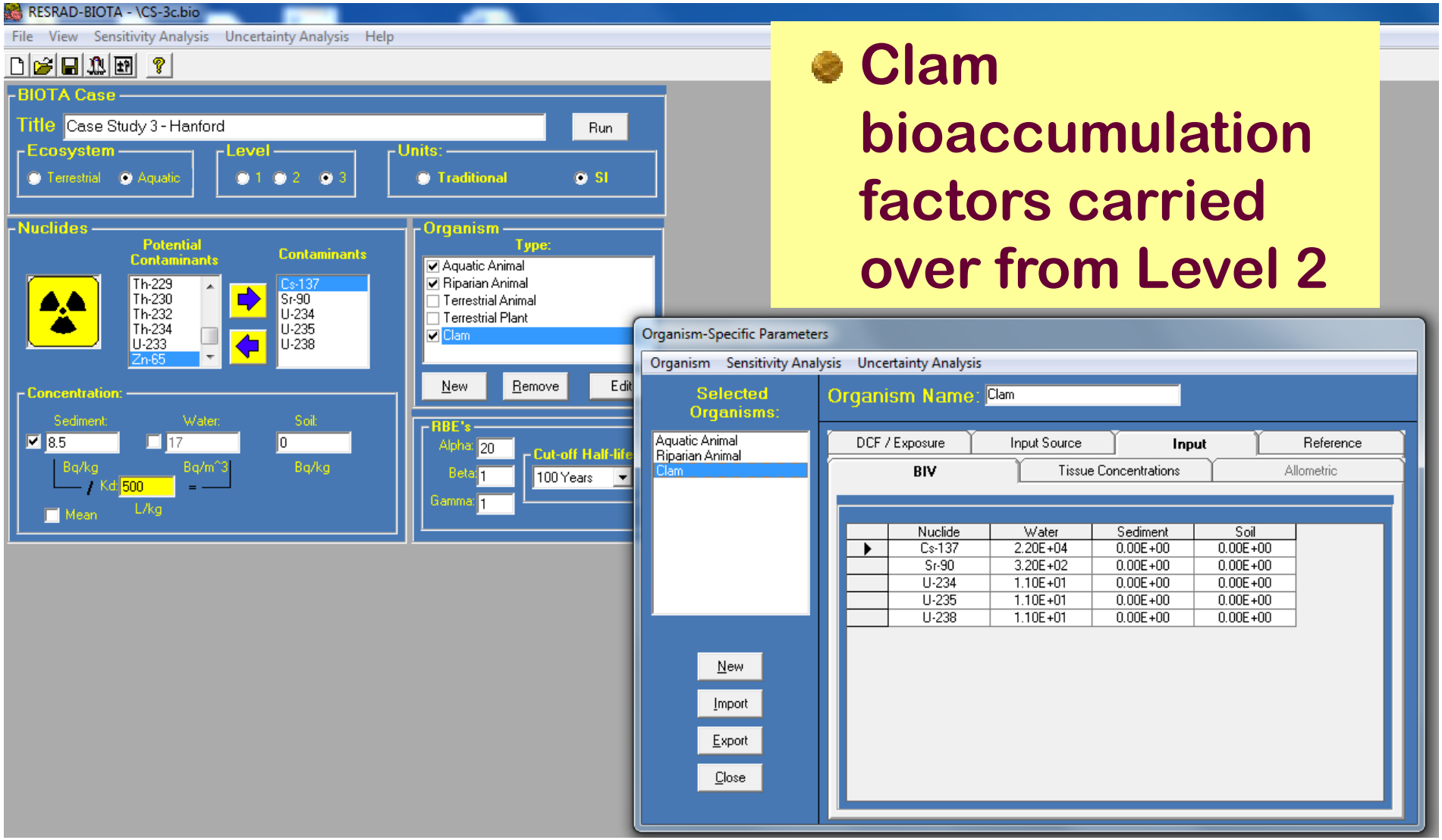
Customized Dose Factors



Example Dose Factors- Gy/y per Bq/kg

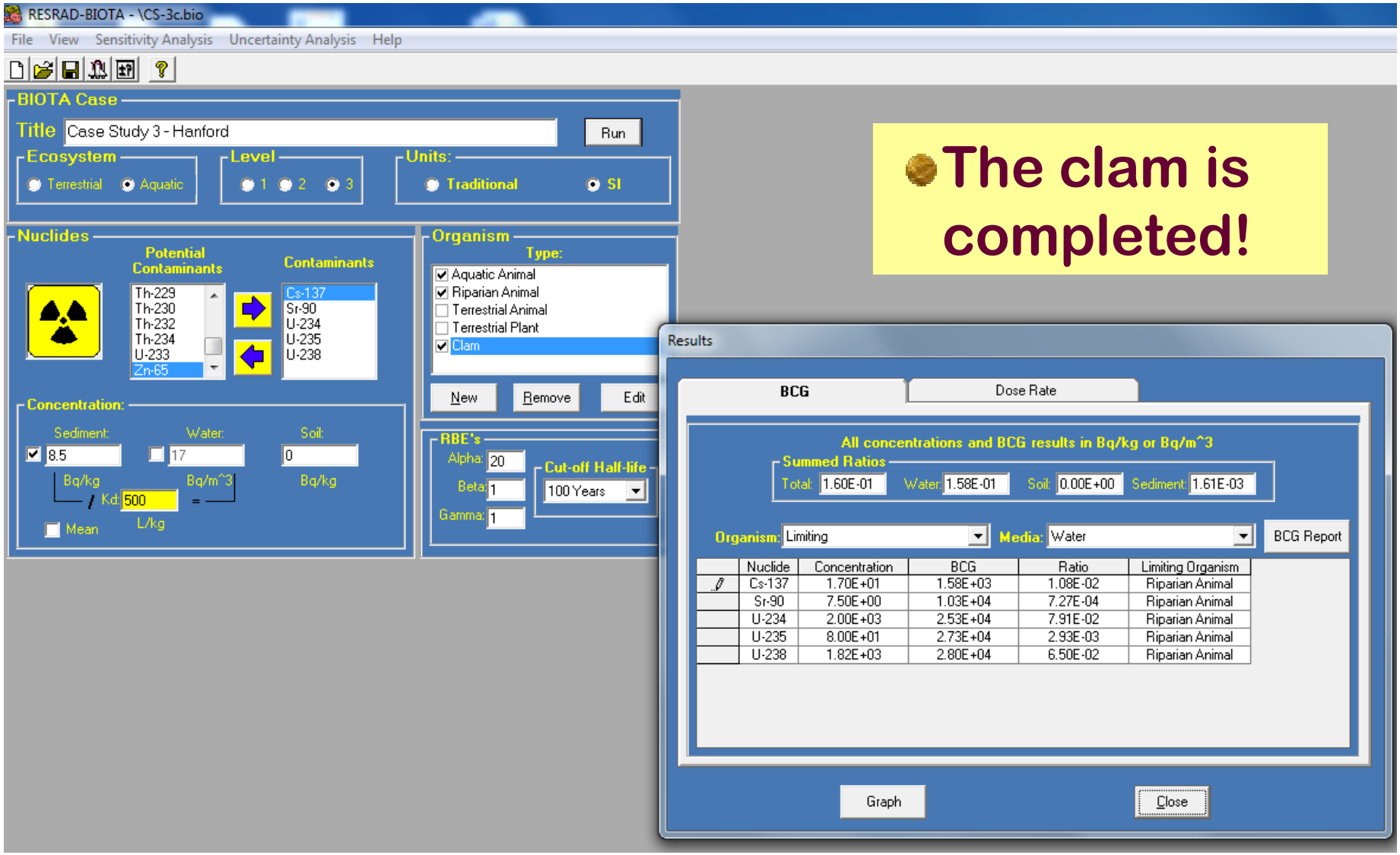
Isotope	External (Default)	External (Clam)	Internal (Default)	Internal (Clam)
Cs-137	4.00×10^{-6}	2.91×10^{-6}	4.28×10^{-6}	1.18×10^{-6}
Sr-90	5.71×10^{-6}	1.48×10^{-6}	5.71×10^{-6}	4.21×10^{-6}
U-238	4.60×10^{-6}	1.22×10^{-6}	4.41×10^{-4}	4.33×10^{-4}

Level 3 Analysis



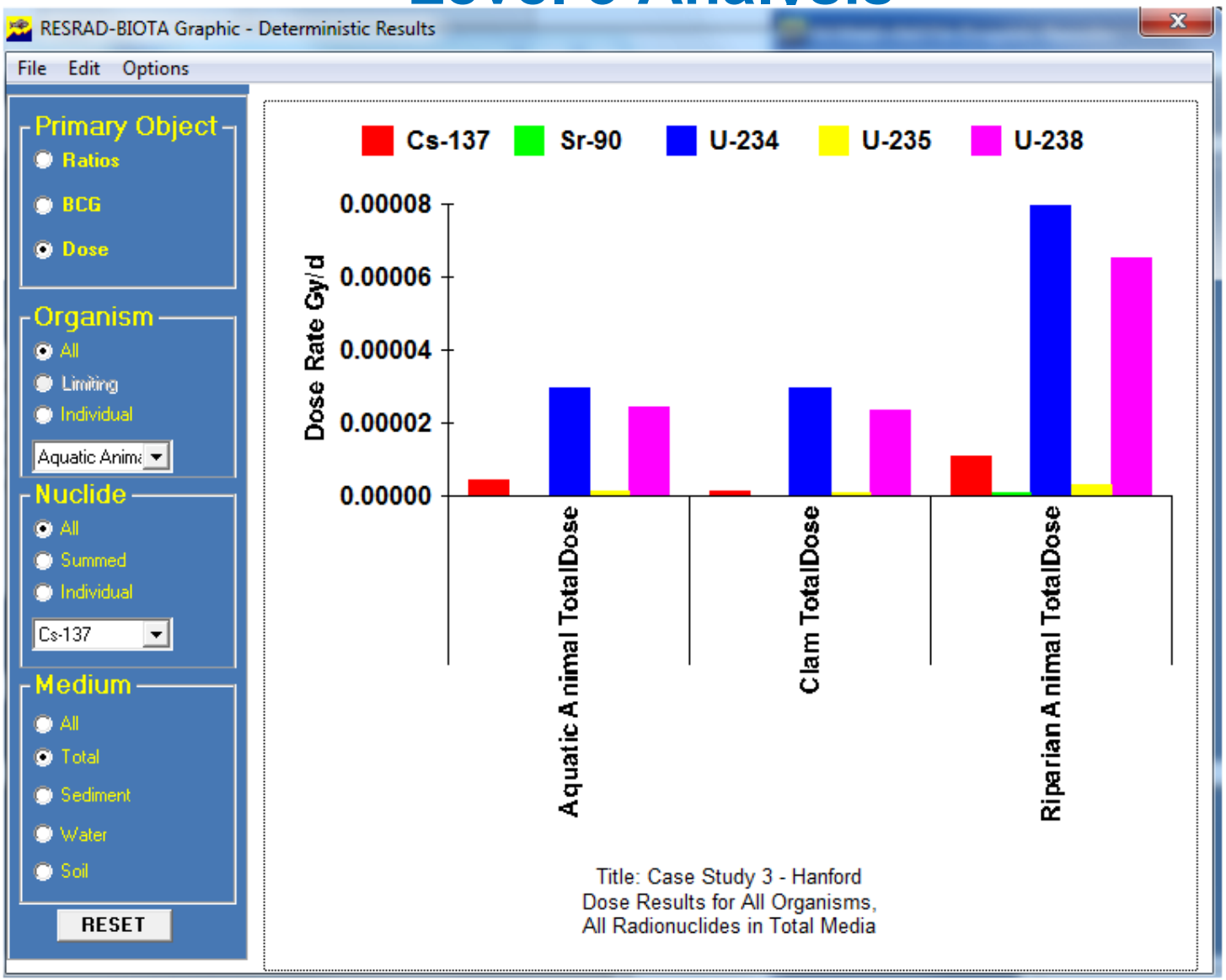
- Clam bioaccumulation factors carried over from Level 2

Level 3 Analysis

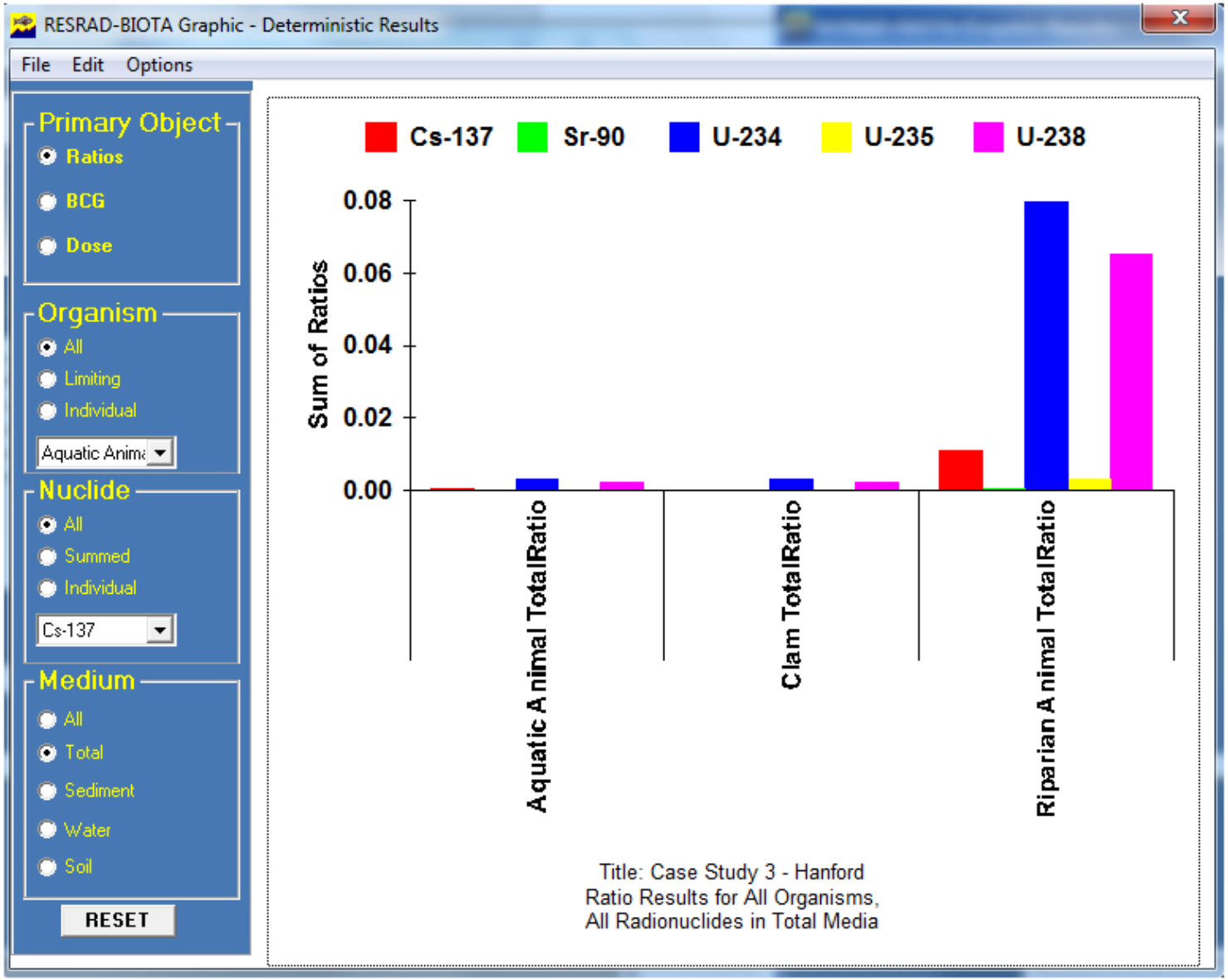


Nuclide	Concentration	BCG	Ratio	Limiting Organism
Cs-137	1.70E+01	1.58E+03	1.08E-02	Riparian Animal
Sr-90	7.50E+00	1.03E+04	7.27E-04	Riparian Animal
U-234	2.00E+03	2.53E+04	7.91E-02	Riparian Animal
U-235	8.00E+01	2.73E+04	2.93E-03	Riparian Animal
U-238	1.82E+03	2.80E+04	6.50E-02	Riparian Animal

Level 3 Analysis

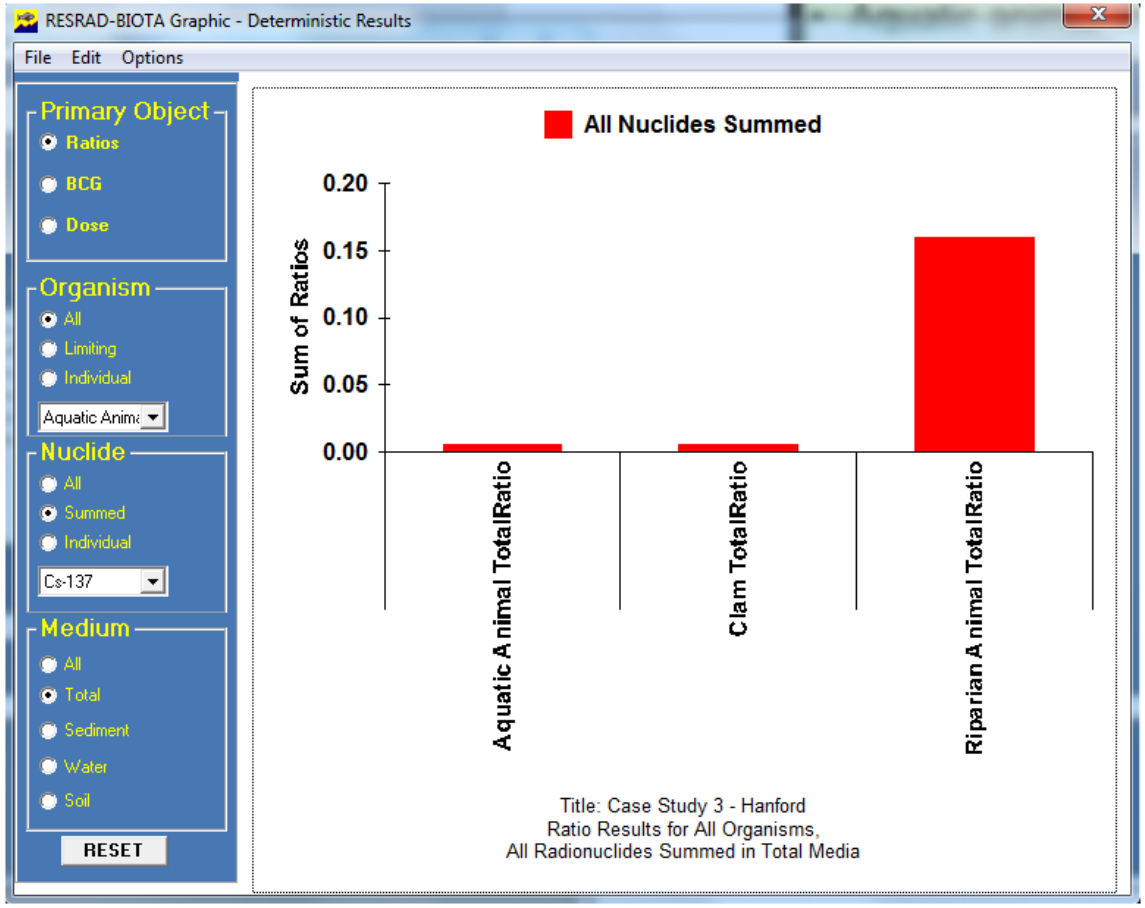


Level 3 Analysis



Summary so far –

- Aquatic animal dominated (level1)
- Bivs recalculated (level 2)
- Clam created (level 3)
- Aquatic organism no longer dominates assessment



Next Step

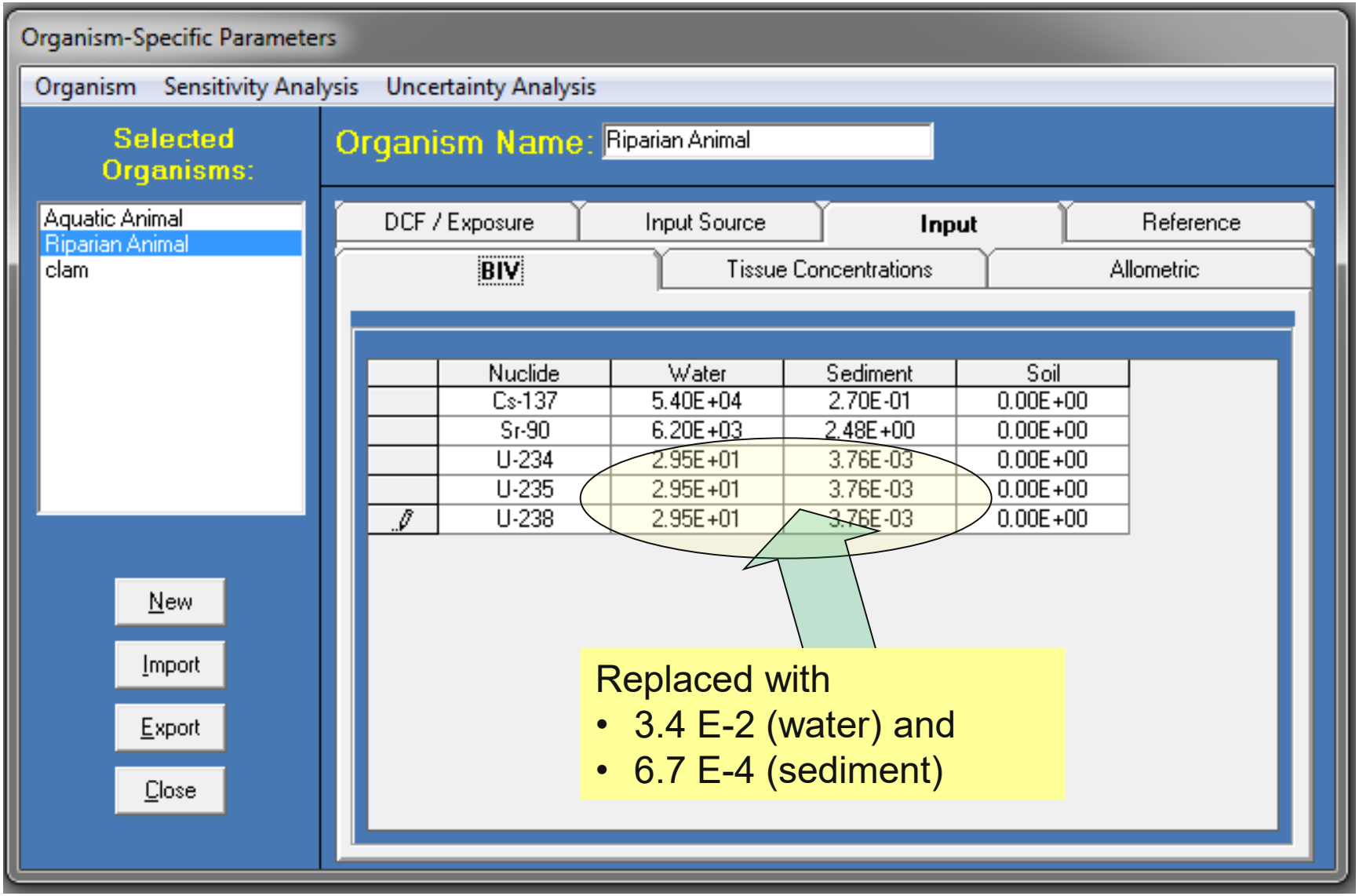
- Revisit data on riparian organisms
  - Sufficient to recalculate Bivs?
  - Can a riparian animal be created?

Environmental Data Revisited

Biota Media	Sr-90 Bq/kg	Cs-137 Bq/kg	Uranium µg/g
Detection Limits	1.5	1.5	0.01
Riparian Community			
Sweet Clover	6.7	10.0	0.12
Mulberry Leaves	6.3	1.1	0.12
Small Mammal		1.5	0.02
Aquatic Community			
Milfoil	3.3	4.4	9.29
Clam			6.77
Sculpin	0.7	-0.4	0.06

Site-Specific Screen Phase: Bivs

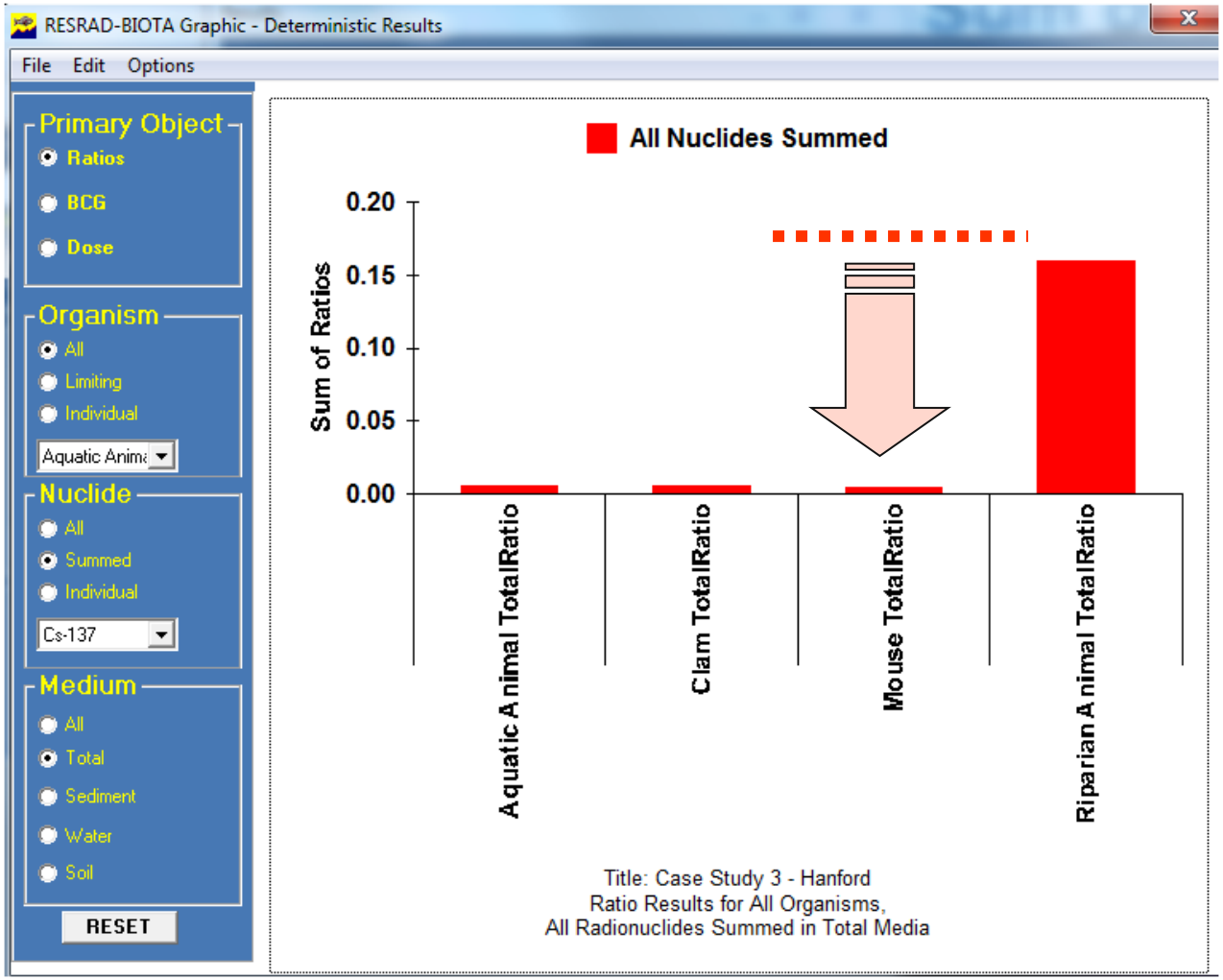
Radio-nuclide	Calculated Biv values for Riparian Biota				
	Water (Bq/m^3)	Sediment (Bq/kg)	Mouse Conc. Bq/kg	Mouse (water) Biv (L/kg)	Mouse (sed.) Biv
U-234	2.0E+03	1.0E+02	*0.067*	*3.4 E-02*	*6.7 E-04*
U-235	8.3E+01	3.8E+00	*0.0020*	*2.5 E-02*	*5.3 E-04*
U-238	1.8E+03	9.1E+01	*0.049*	*2.7 E-02*	*5.4 E-04*


Organism-Specific Parameters
Organism
Sensitivity Analysis
Uncertainty Analysis
Selected Organisms:
Aquatic Animal
Riparian Animal
clam
Organism Name: Riparian Animal
DCF / Exposure
Input Source
Input
Reference
BIV
Tissue Concentrations
Allometric
Nuclide
Water
Sediment
Soil
Cs-137
5.40E+04
2.70E-01
0.00E+00
Sr-90
6.20E+03
2.48E+00
0.00E+00
U-234
2.95E+01
3.76E-03
0.00E+00
U-235
2.95E+01
3.76E-03
0.00E+00
U-238
2.95E+01
3.76E-03
0.00E+00
New
Import
Export
Close
Replaced with
• 3.4 E-2 (water) and
• 6.7 E-4 (sediment)

Customizing Riparian Animal

- House mouse created with organism wizard
- Same approach as used for clam
- Code rerun

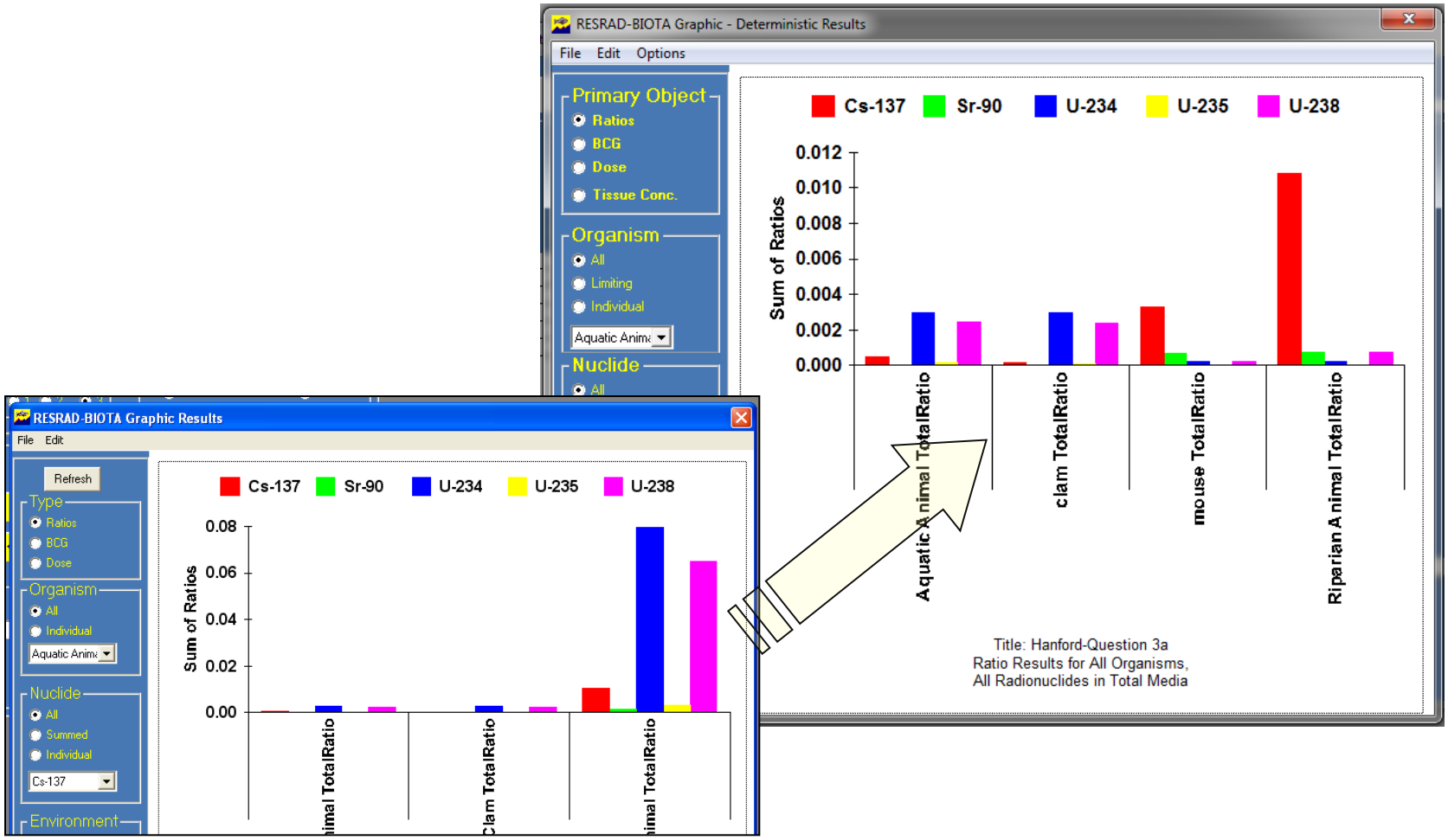
Site-specific Risk Assessment Lowers Sum of Fraction



Adjust Other Parameters

- Continued revisions can be made, based on data, scientific judgment, etc.
  - Adjust area factor
  - Modify RBE for alphas, adjusted to 10 from 20
- Modifications may lower overall dose projection, but also result in “new” nuclide coming to the forefront
- (see example)

Comparison of Results



Conclusions:

- The tiered approach process can provide insight into factors driving dose estimates
- Can guide need for data collection

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Case Study II

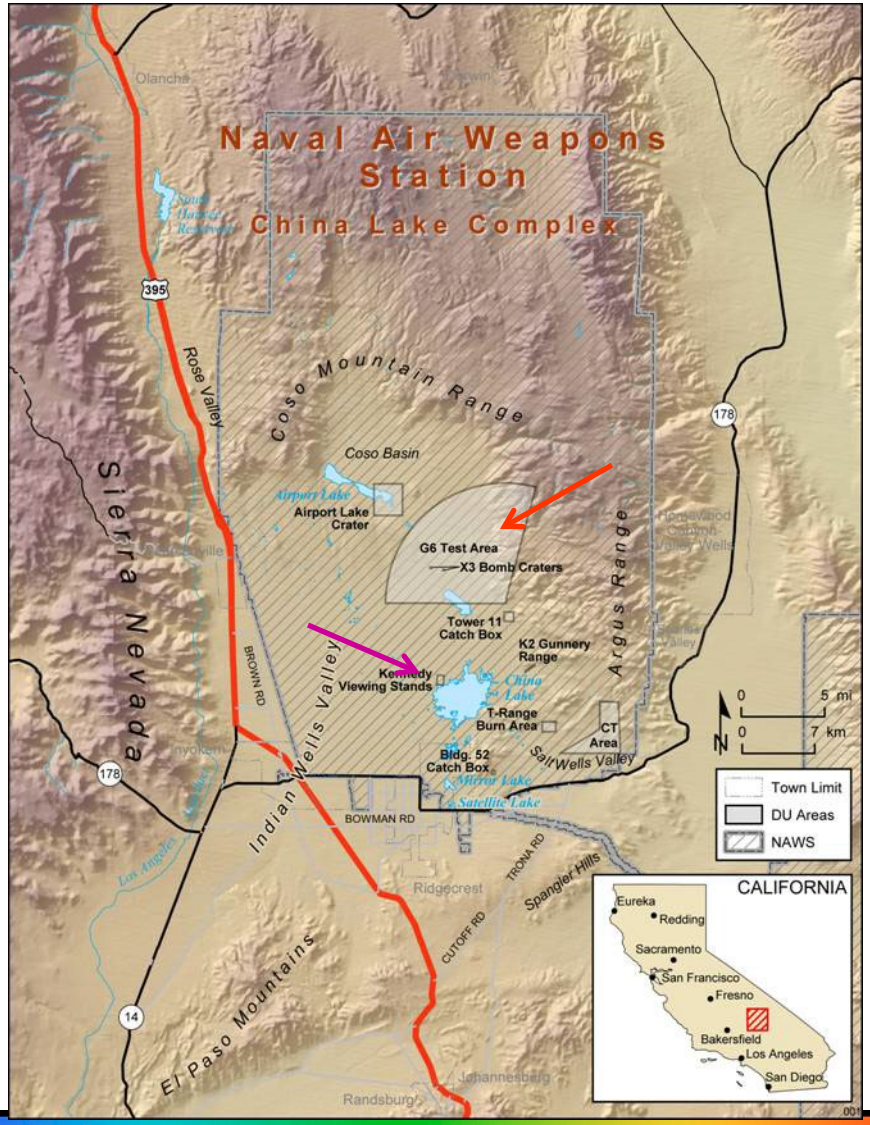
Ecological Risk Assessment for the China Lake Weapon Testing Grounds

Case Study II

- Assess China Lake weapon testing grounds
- Involve
  - Screening and site-specific analyses
  - Developing a food web conceptual model
  - Selecting surrogate organisms
  - Creating new organisms with the Organism Wizard

NAWS China Lake

- NAWS China Lake
  - >1,000,000 acres of high desert on western edge of Mojave Desert in California.
  - Used for variety of military training and testing
- Risk assessments evaluated two areas
  - Kennedy Stands
  - G-6 Test Area
- Weapons testing using depleted uranium (DU) conducted under permit.
- Land reuse requires permit termination
  - Exposure criteria.



Site Activities and Use Assumptions

- Current use is for military training and testing
  - Military use expected to continue.
  - Current activities include general maintenance and repair of utilities.
  - Possible future archeological investigations.
- Land setting largely natural
  - No residential use.
- No future activities expected that could disturb large quantities of soil.

Habitats and Receptors

- No aquatic habitats.
- Terrestrial desert.
- Scattered vegetation.

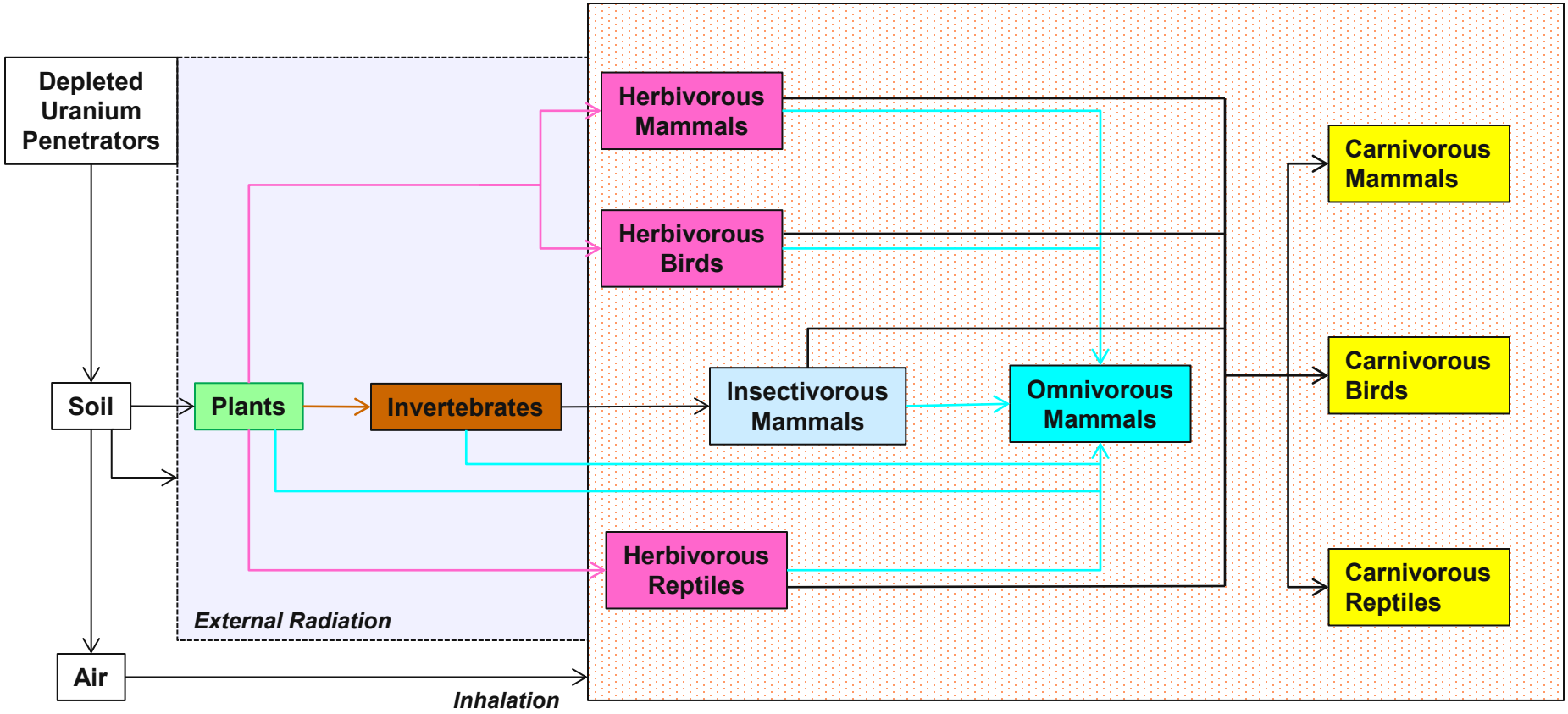
- Receptors include:
  - Insects and other invertebrates; and
  - Reptiles, birds, and mammals.
- Range of diets
  - Plants, insects, vertebrates.

Ecological Risk Conceptual Site Model

- Multiple plant and animal species may occur at the test areas.
- Internal exposure:
  - Plants - root uptake
  - Wildlife - inhalation and ingestion
    - *Food and incidental soil ingestion*

- External Exposure:
  - All ecological receptors may be exposed to external radiation emitted by uranium in the soil.

Conceptual Site Model



Ecological Receptors

Receptor Category	Surrogate Species
Herbivorous Mammal	Kangaroo Rat
Herbivorous Bird	Mourning Dove
Herbivorous Reptile	Desert Iguana, Desert Tortoise*
Insectivorous Mammal	Pallid Bat
Omnivorous Mammal	Coyote
Carnivorous Mammal	Kit Fox
Carnivorous Bird	American Kestrel, Peregrine Falcon*
Carnivorous Reptile	Gopher Snake

Characteristics of Soil Contamination

- Approximately 3,400 DU rounds at Kennedy Stands, 100,000 rounds at G-6
- Soil contamination is very heterogeneously distributed
  - limited to the top 30 cm
  - high DU concentrations located immediately around individual penetrators and decrease exponentially to very low level over short distances
  - DU concentrations for most of the area at background levels

Exposure Point Concentrations

- Radionuclides considered:
  - U-234, U-235, and U-238
- Short-lived decay products assumed at same concentration as parents (secular equilibrium).
- The 90th percentile concentration was used to estimate a reasonable maximum exposure (RME).
- The 50th percentile concentration was used to estimate a central tendency exposure (CTE).

Exposure Parameters and Assumptions

- **Exposure factors:**
  - Body weight; diet composition; food and soil ingestion rates; inhalation rate; exposure time, duration, and frequency; and home range.
- **Exposure factor data sources:**
  - USEPA Federal Guidance Reports and Wildlife Exposure Factor Handbook, RAGS, available literature.
- **For ecological dose food chain modeling:**
  - All ingested food (except insects) and media, and inhaled air.
    - *Considered contaminated at CTE and RME concentrations.*
  - Insect tissue uranium concentrations assumed to equal soil concentrations.

Exposure Point Concentrations

Area	Total Uranium (µg/g)	U-238 (Bq/g)	U-235 (Bq/g)	U-234 (Bq/g)
Kennedy Stands 90% concentration (RME)	3500	43	0.7	50
Kennedy Stands 50% concentration (CTE)	57	0.71	0.01	0.81
G-6 90% concentration (RME)	440	5.5	0.2	6.0
G-6 50% concentration (CTE)	15.3	0.20	0.01	0.20

Ecological Assessment Approach

- Screening Level Analysis:
  - Compared soil concentrations with screening soil BCGs.
- Site-Specific Analysis:
  - Conducted only if screening analysis indicated potential risks;
  - Modeled absorbed radiation dose for each receptor; and compared doses with ecological dose criteria.
- Internal dose estimates based on modeled tissue concentrations and internal dose conversion factors.
- External dose estimates adjusted for time fractions spent above and below ground.

Ecological Risk Characterization

- Based on Hazard Quotient (HQ) Approach
  - In the screening analysis:
    - *HQ calculated as ratio of soil concentration to the soil BCG.*
  - In the site-specific analysis::
    - *HQ calculated as ratio of the modeled dose to the dose criteria*
      - 10 mGy/day (1 rad/day) for terrestrial plants.
      - 1 mGy/day (0.1 rad/day) for terrestrial wildlife.
- Hazard Index (HI) – sum of HQs of all U isotopes.
  - *HI < 1, no unacceptable risks.*
  - *HI > 1, potential for unacceptable risks.*

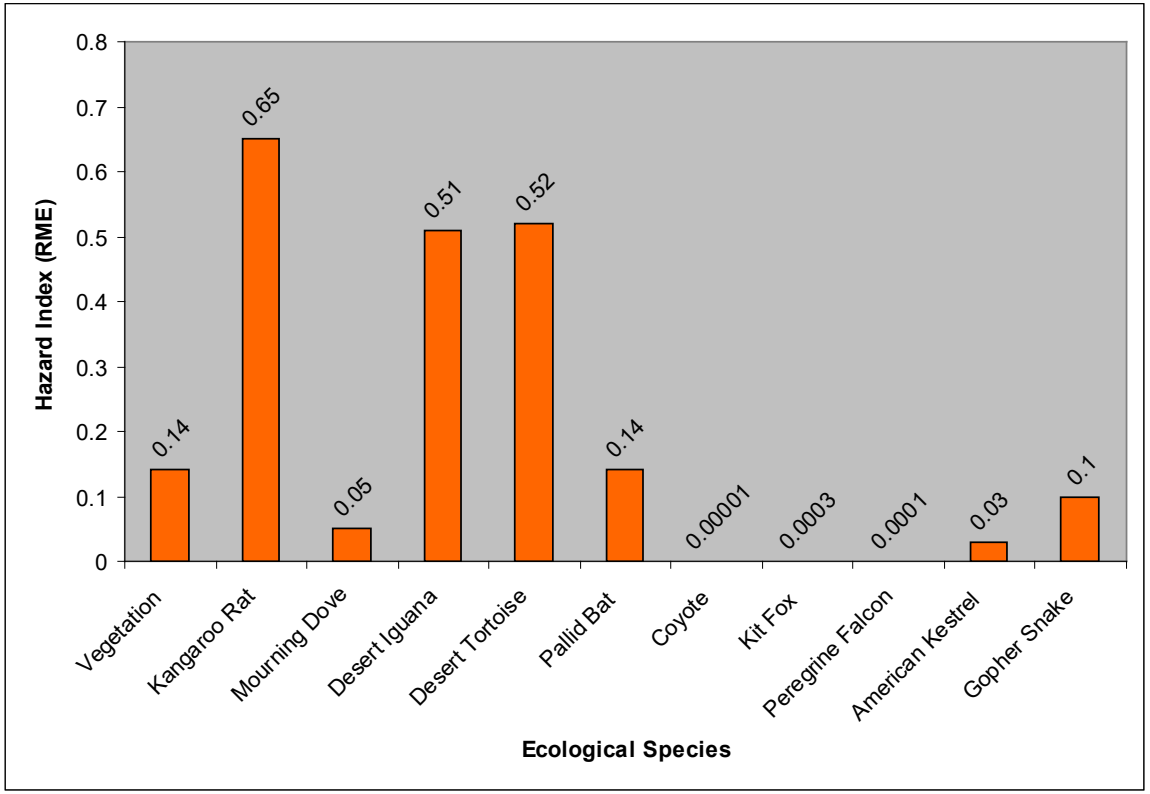
Ecological Risk Screening Level Analysis

- No unacceptable risks indicated from the G-6 Test Area.
- At 90% (RME) concentrations, HI >1 only at Kennedy Stands.
  - **No unacceptable risks identified for 50% (CTE) concentrations.**

Area and Concentration	HQ U-238	HQ U-235	HQ U-234	Hazard Index
Kennedy Stands – 90%	0.70	0.006	0.26	*1.01*
Kennedy Stands – 50%	0.01	0.0001	0.004	0.02
G6 – 90%	0.09	0.002	0.03	0.13

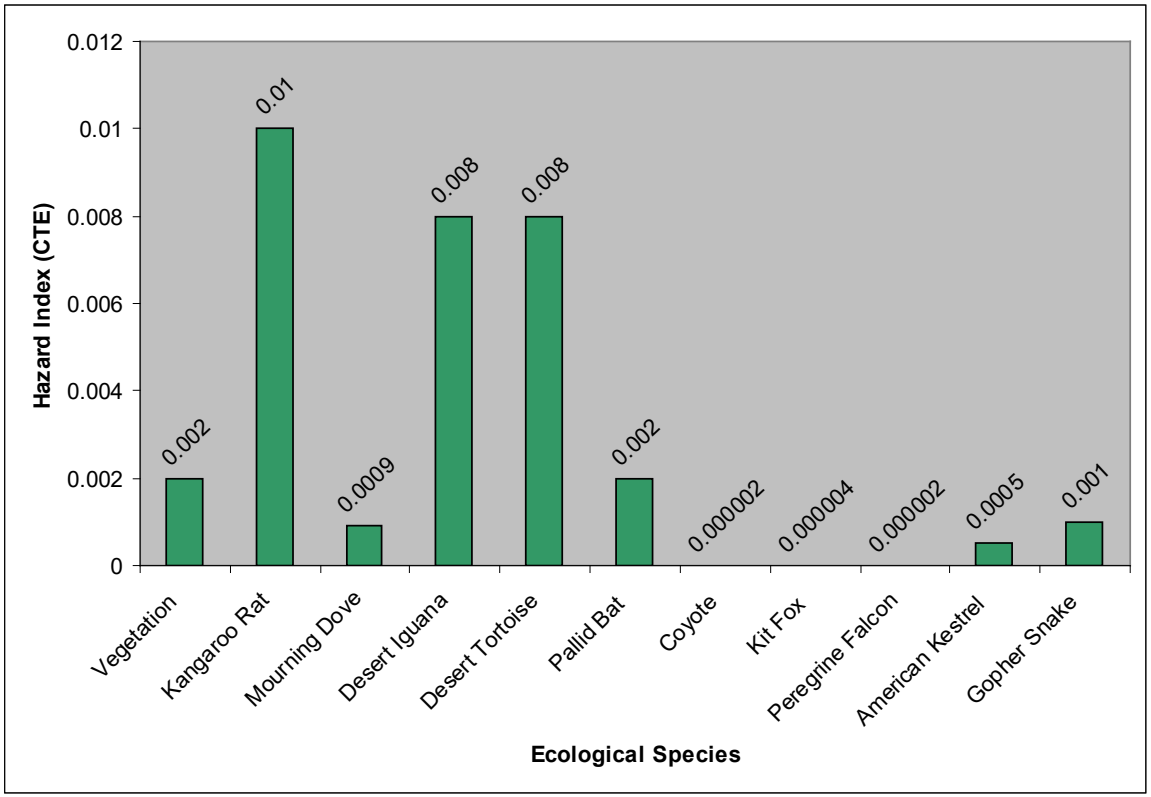
Site-specific Analysis - RME

- Only conducted for the Kennedy Stands Impact Area
  - Using 90% soil concentration
- The maximum HI was 0.65
  - Calculated for the kangaroo rat



Site-specific Analysis - CTE

- Only conducted for the Kennedy Stands Impact Area
  - Using 50% soil concentration
- The maximum HI was 0.01
  - Calculated for the kangaroo rat



Ecological Risk Summary

- Screening level and site-specific assessments conducted.
- Internal and external dose estimates conducted for terrestrial vegetation and 10 wildlife species.
  - Dose modeling included food chain uptake of DU-associated radionuclides.
  - Dose limits were 10 mGy/day (1.0 rad/day) for terrestrial plants and 1 mGy/day (0.1 rad/day) for wildlife.
- Screening level analysis identified a very slight potential for unacceptable ecological risks (HI = 1.01).
- Site-specific analysis indicated all receptor-specific CTE and RME dose estimates to be below the ecological dose limits.

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Food Chain/Web Model In RESRAD-BIOTA

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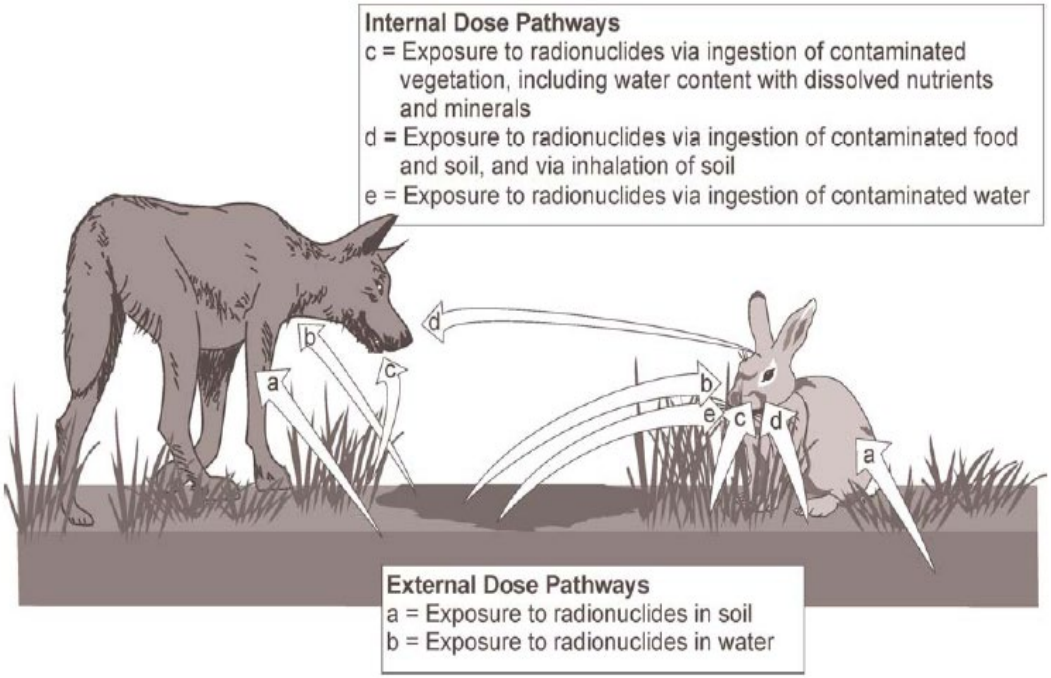
What is Food Chain/Web Model?

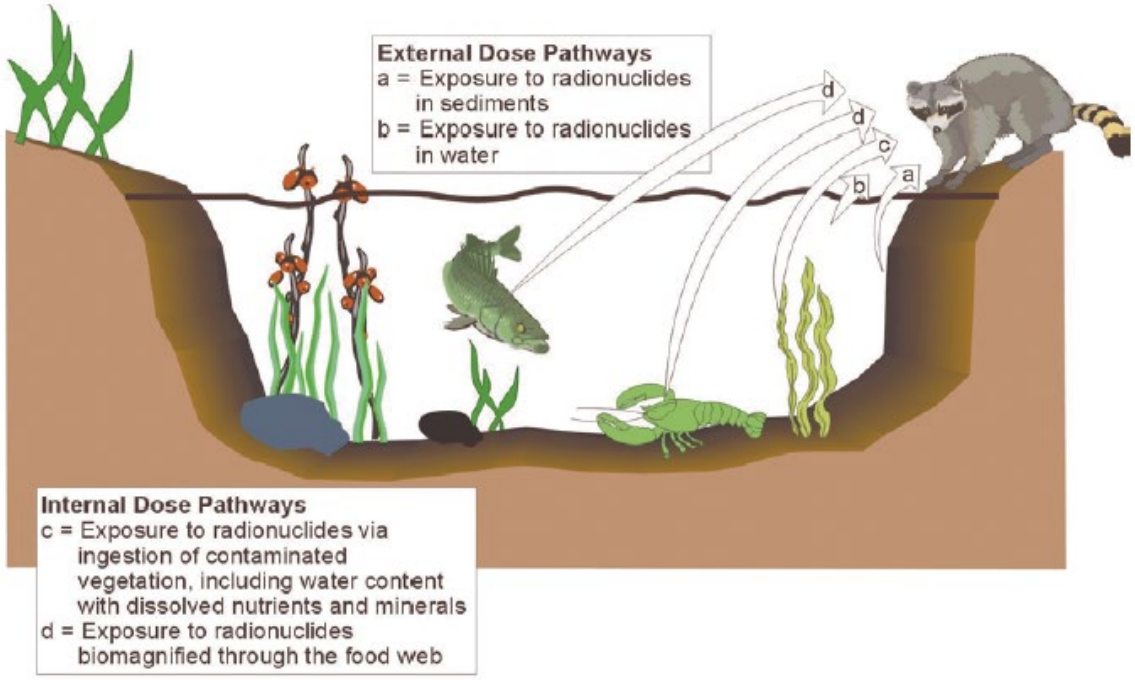
- At a level 3 analysis, the user has an option of using food chain/web model
- A food chain shows how energy is passed in the form of food from one organism to another organism



Exposure Pathways for Terrestrial Animals (Source: DOE 2002)

What is Food Chain/Web Model? (cont.)

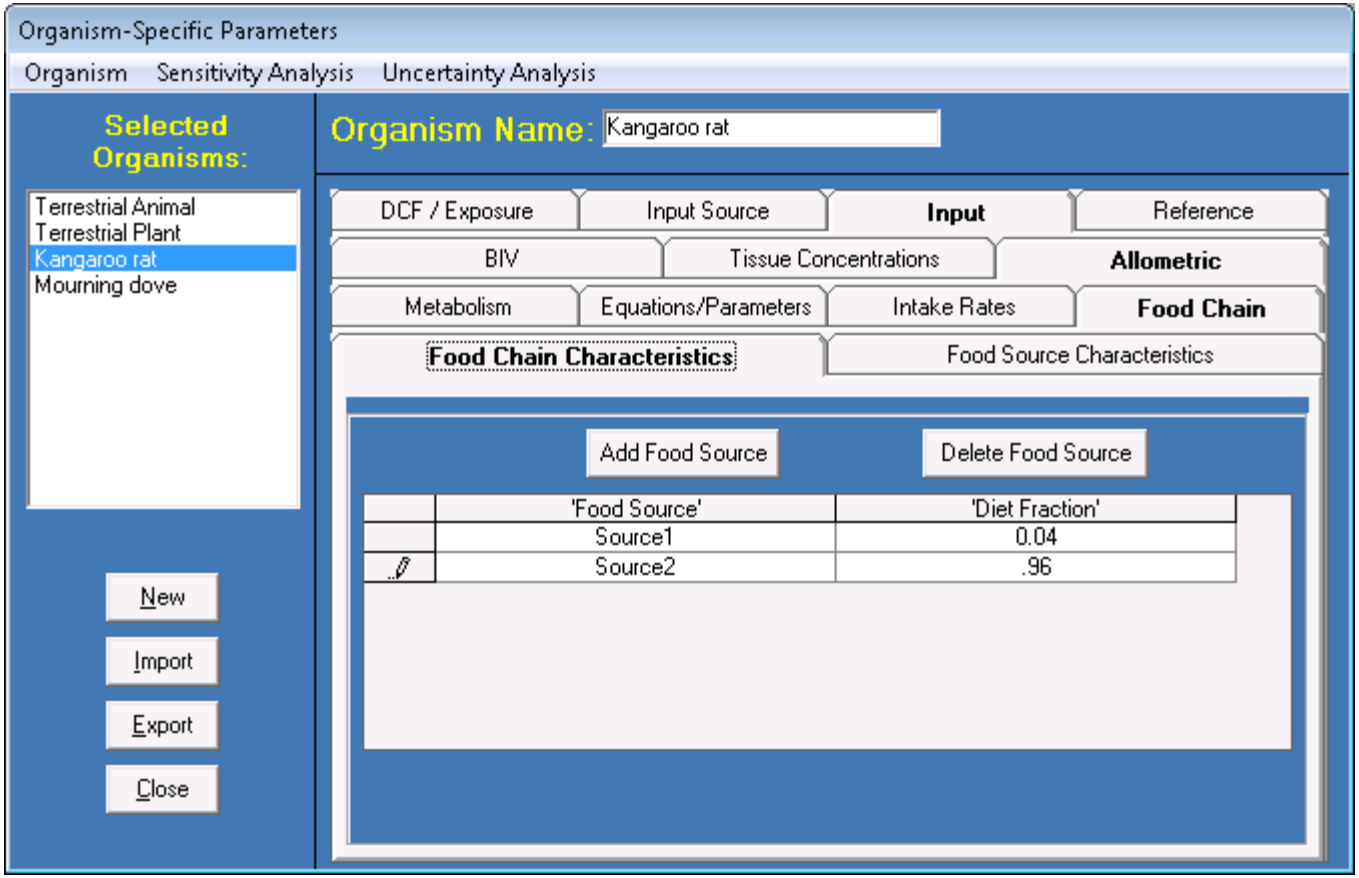
- Green plants are capable of making their own energy from sun through photosynthesis.
- Herbivorous animals get their energy just from plants
- Carnivores also depend on animals for their energies



Exposure Pathways for Riparian Animals (Source: DOE 2002)

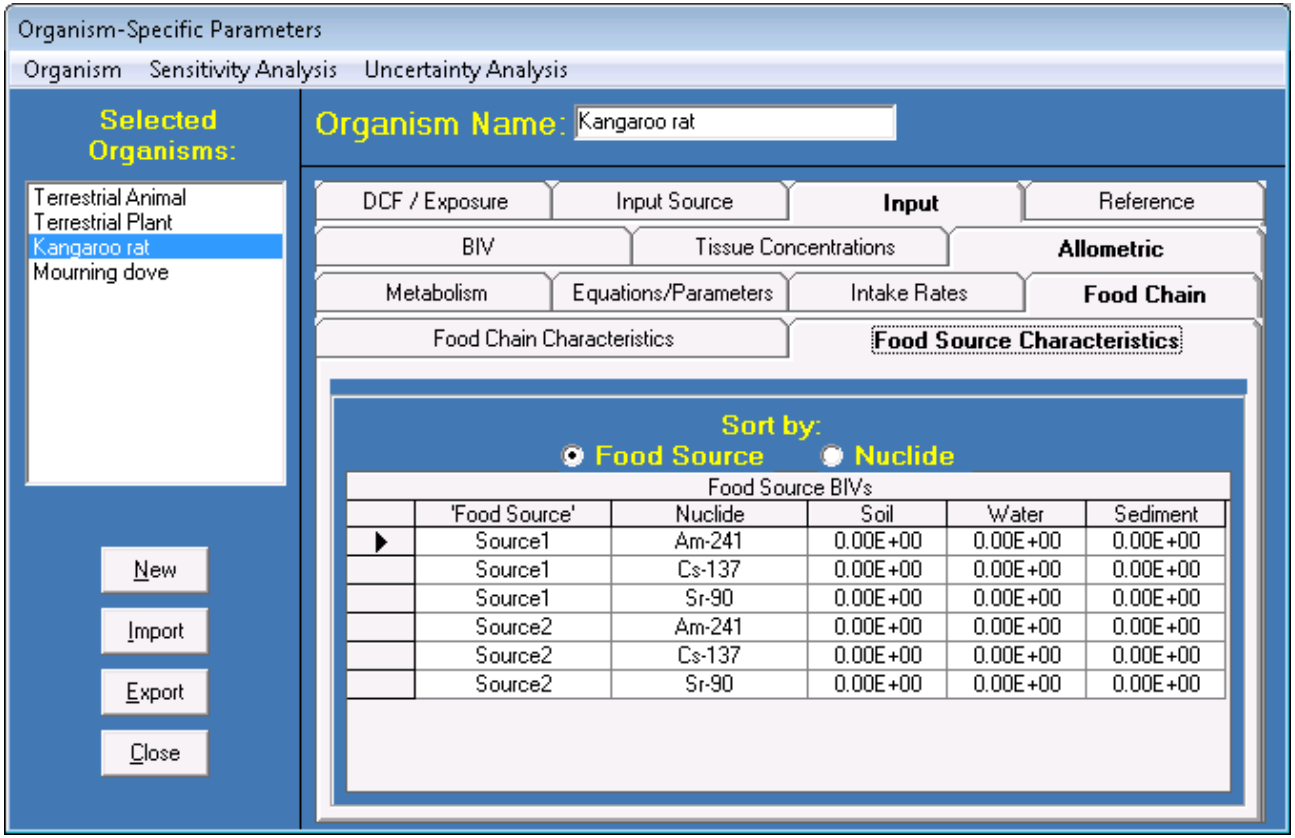
Food Chain Model in RESRAD-BIOTA

- The user has the option of adding multiple food sources
- The user provides the diet fraction of the food source



Food Chain Model in RESRAD-BIOTA (Cont.)

- The user provides the bioaccumulation factors (Bivs) for all food sources
- If Biv of a food source is not known, use RESRAD-BIOTA in a separate run to calculate Biv values



Food Chain Model in RESRAD-BIOTA (Cont.)

- Terrestrial and Riparian animals also have other exposure pathways:
  - Ingestion of water
  - Ingestion of soil or sediment
  - Inhalation of air
- Calculate total contamination intake

$$I_{total} = I_{air-inhalation} + I_{soil-intake} + I_{water-intake} + I_{food-intake}$$

Where,

I_{total} = total contamination intake by the organism (Bq/d);

$I_{air\text{-}inhalation}$ = contamination intake from air (Bq/d);

$I_{soil\text{-}intake}$ = contamination intake from soil (Bq/d);

$I_{water\text{-}intake}$ = contamination intake from water (Bq/d);

$I_{food\text{-}intake}$ = contamination intake from food (Bq/d).

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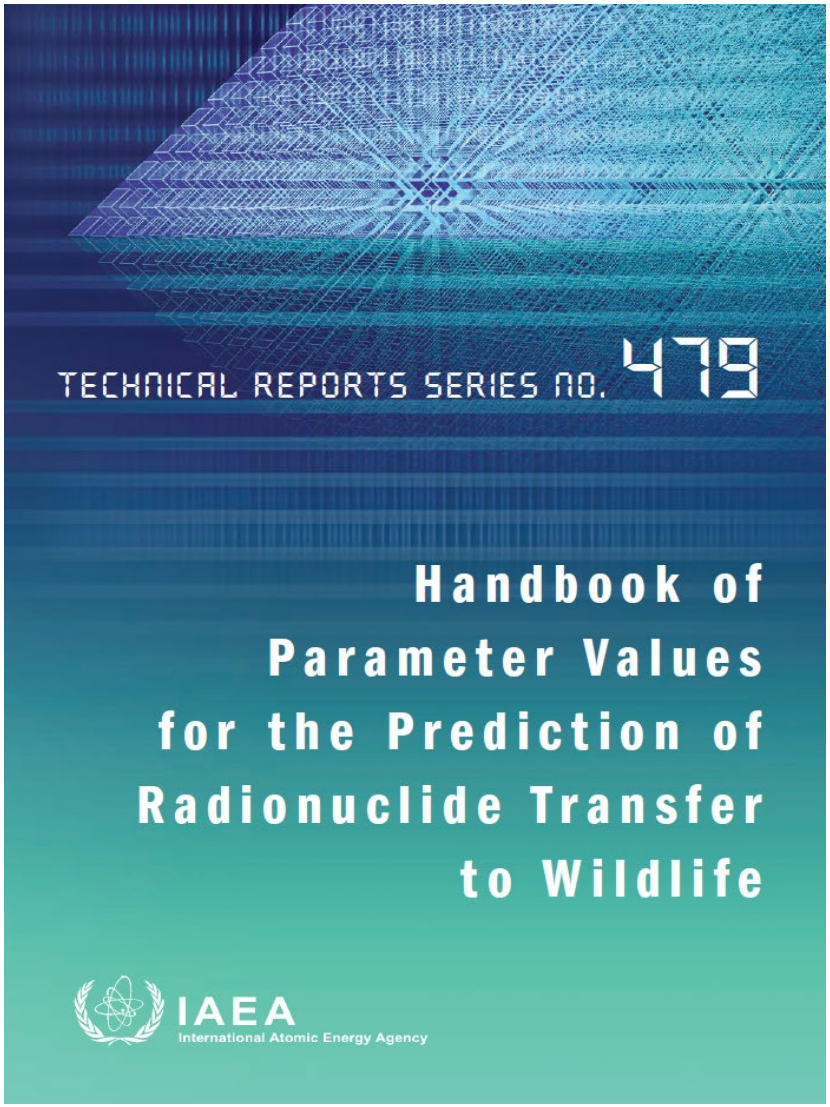
Wildlife Transfer Factors Database

Source of Concentration Ratios

This publication focuses on "concentration ratios" – one of the key parameter for evaluating the transfer of radionuclides from environmental media (soil, air, water, and sediments) to wildlife groups.

Prepared by the members of Working Group 5 of the EMRAS II program



Handbook of Parameter Values for the Prediction of Radionuclide Transfer to Wildlife

- Provides equilibrium concentration ratios from environmental media to wildlife groups
  - Includes mean/median transfer factors and associated statistical distribution information
  - Includes wildlife groups in terrestrial, freshwater, marine, and brackish (such as estuaries) water environments
- Describes the approach used to derive and collate available data
- Provides conversion from tissue activity concentrations to whole organism concentration
- Provides guidance on using the data
- Approaches for filling data gaps

Example Table of Concentration Ratio Values in the TRS Handbook – Terrestrial Ecosystems

TABLE 4.1 CONCENTRATION RATIO (CR_{WO}) VALUES FOR WILDLIFE GROUPS IN TERRESTRIAL ECOSYSTEMS

Wildlife group	AM	AMSD	GM	GMSD	Min	Max	n	ID number
Cs (Caesium)								
Amphibian	4.40E-01	8.10E-01	2.10E-01	3.40E+00	3.20E-02	2.10E+00	137	188, 205, 256, 486
Annelid	9.00E-02	1.60E-01	4.30E-02	3.40E+00	1.50E-02	6.90E-01	19	171, 207, 264, 488
Arachnid	3.00E-02	3.50E-02	1.90E-02	2.50E+00	2.00E-02	1.60E-01	20	170, 488
Arthropod	1.10E-01	4.70E-01	2.40E-02	5.70E+00	2.00E-03	1.70E+00	192	169, 170, 172, 175, 176, 195, 223, 257, 382, 388, 488
Arthropod – carnivorous	2.50E-01	4.70E-01	1.10E-01	3.50E+00	1.10E-02	1.70E+00	15	170, 195, 488
Arthropod – detritivorous	9.00E-02	2.90E-01	2.70E-02	4.70E+00	3.00E-03	1.40E+00	76	169, 170, 172, 176, 223, 257, 488
Arthropod – herbivorous	9.80E-03	1.80E-02	4.70E-03	3.40E+00	3.00E-03	7.10E-02	25	170, 176
Bird	6.70E-01	1.60E+00	2.70E-01	3.90E+00	1.40E-03	1.60E+01	180	163, 189, 190, 228, 258, 263, 405, 486
Bird – herbivorous	1.00E+00	1.50E+00	5.40E-01	3.00E+00	2.30E-02	5.80E+00	57	163, 190, 228, 258, 263, 405, 486
Bird – omnivorous	5.70E-01	1.80E+00	1.70E-01	4.80E+00	9.40E-03	1.60E+01	79	189, 190, 405, 486
Mammal	3.50E+00	8.30E+00	1.30E+00	4.00E+00	2.80E-03	1.40E+02	2463	163, 168, 172, 184, 190, 208, 209, 228, 230, 242, 268, 275, 289, 294, 405, 406, 486, 488
Mammal – carnivorous	5.40E-01	1.90E+00	1.40E-01	5.10E+00	2.80E-03	2.30E+01	231	190, 275, 405, 406, 486, 488
Mammal – herbivorous	3.90E+00	9.10E+00	1.50E+00	3.90E+00	1.00E-02	1.40E+02	1879	163, 184, 190, 208, 209, 228, 230, 242, 268, 294, 405, 486, 488
Mammal – omnivorous	3.20E+00	5.20E+00	1.70E+00	3.10E+00	1.70E-02	3.60E+01	335	168, 190, 268, 289, 405, 486, 488
Mammal – Rangifer spp.[b]	1.70E+01	1.60E+01	1.30E+01	2.20E+00	1.20E-01	8.10E+01	916	160, 163, 164, 218, 228, 241
Gastropod	4.00E-02	3.10E-02	3.20E-02	2.00E+00	2.10E-02	6.50E-02	23	191, 486, 488
Reptile	5.80E-01	1.00E+00	2.80E-01	3.30E+00	6.00E-04	3.00E+00	137	169, 267, 407, 486, 487
Reptile – carnivorous	5.20E-01	9.40E-01	2.50E-01	3.30E+00	6.00E-04	3.00E+00	125	169, 267, 407, 486, 487
Grasses and herbs	1.20E+00	2.60E+00	5.10E-01	3.70E+00	1.90E-03	3.70E+01	2028	166, 193, 210, 236, 253, 257, 259, 272, 395, 400, 403, 404, 409, 413, 414, 432, 433, 434, 435, 437, 442, 443, 444, 448, 452, 453, 467, 486, 498, 500, 501, 510, 516, 519
Grasses	1.80E+00	3.20E+00	8.50E-01	3.40E+00	3.60E-03	3.70E+01	1081	210, 236, 253, 272, 395, 409, 413, 414, 448, 453, 486, 501, 510, 519
Herbs	1.10E+00	2.20E+00	5.00E-01	3.50E+00	3.00E-03	2.20E+01	155	253, 272, 400, 403, 409, 432, 452, 467, 500, 519
Lichens and bryophytes	4.10E+00	3.90E+00	3.00E+00	2.20E+00	3.00E-02	1.40E+01	142	163, 253, 272, 382, 435, 440, 467, 486, 519
Shrub	2.30E+00	4.00E+00	1.10E+00	3.30E+00	9.80E-03	1.60E+01	354	164, 167, 210, 272, 468, 472, 486, 519
Tree	1.40E-01	2.40E-01	7.50E-02	3.10E+00	1.20E-03	1.80E+00	487	183, 190, 210, 265, 470, 471, 472, 473, 474, 475, 476, 477, 478, 484, 485, 519
Tree – broadleaf	1.40E-01	2.20E-01	7.50E-02	3.10E+00	1.20E-03	1.30E+00	252	190, 210, 265, 470, 471, 472, 473, 474, 475, 477, 478, 484, 485, 519
Tree – coniferous	1.50E-01	2.50E-01	7.50E-02	3.20E+00	1.20E-03	1.80E+00	235	183, 472, 474, 475, 476, 484

Example Table of Concentration Ratio Values in the TRS Handbook – Freshwater Ecosystems

TABLE 4.2 CONCENTRATION RATIO (CR_{WO}) VALUES FOR WILDLIFE GROUPS IN FRESHWATER ECOSYSTEMS

Wildlife Group	AM	AMSD	GM	GMSD	Min	Max	N	ID number
Am (Americium)								
Fish – forage[a]	7.60E+02	6.70E+02	5.70E+02	2.10E+00	2.40E+00	1.50E+03	17	309, 411
Mollusc	1.00E+04	1.30E+04	6.60E+03	2.60E+00	1.20E+02	3.60E+04	60	309, 411
Mollusc – gastropod	6.30E+03	9.40E+03	3.50E+03	3.00E+00	1.20E+02	2.80E+04	50	309, 411
Insect	1.30E+02						7	309
Insect larvae	1.80E+03						15	309
Reptile	3.20E+03						1	487
Algae	5.30E+02						8	309
Vascular plant	1.30E+03	2.60E+03	6.20E+02	3.50E+00	6.70E+00	7.50E+03	66	309, 410, 411
As (Arsenic)								
Fish	3.60E+02	4.20E+02	2.30E+02	2.50E+00	1.40E+01	2.00E+03	148	339, 340, 355, 356, 357, 358, 359, 361, 363, 364, 376, 377, 378
Fish – benthic feeding	3.90E+02	4.40E+02	2.50E+02	2.50E+00	1.40E+01	2.00E+03	75	339, 355, 356, 357, 358, 361, 363, 364, 376, 377, 378
Fish – piscivorous	3.20E+02	3.90E+02	2.00E+02	2.60E+00	4.40E+01	1.50E+03	72	339, 340, 355, 358, 359, 361, 363, 376, 377, 378
Reptile	2.60E+02	9.50E+01	2.50E+02	1.40E+00	7.20E+01	3.30E+02	9	487
Vascular plant	8.80E+01				5.20E+01	1.20E+02	2	333
B (Boron)								
Reptile	1.10E+01				1.10E+00	2.00E+01	2	487
Ba (Barium)								
Fish	8.10E+01	1.30E+02	4.30E+01	3.10E+00	3.00E-01	8.80E+02	497	304, 333, 336, 339, 340, 343, 350, 355, 356, 357, 358, 359, 361, 363, 371, 376, 378, 517
Fish – benthic feeding	9.50E+01	1.30E+02	5.70E+01	2.80E+00	1.40E+00	6.60E+02	148	333, 336, 339, 343, 355, 356, 357, 358, 361, 363, 371, 376, 378
Fish – piscivorous	7.60E+01	1.30E+02	3.90E+01	3.20E+00	3.00E-01	8.80E+02	340	333, 336, 340, 350, 355, 356, 358, 359, 363, 376, 378, 517
Reptile	1.40E+02						1	487
Vascular plant	1.40E+03	1.20E+03	1.10E+03	2.10E+00	3.20E+02	4.40E+03	18	343, 517

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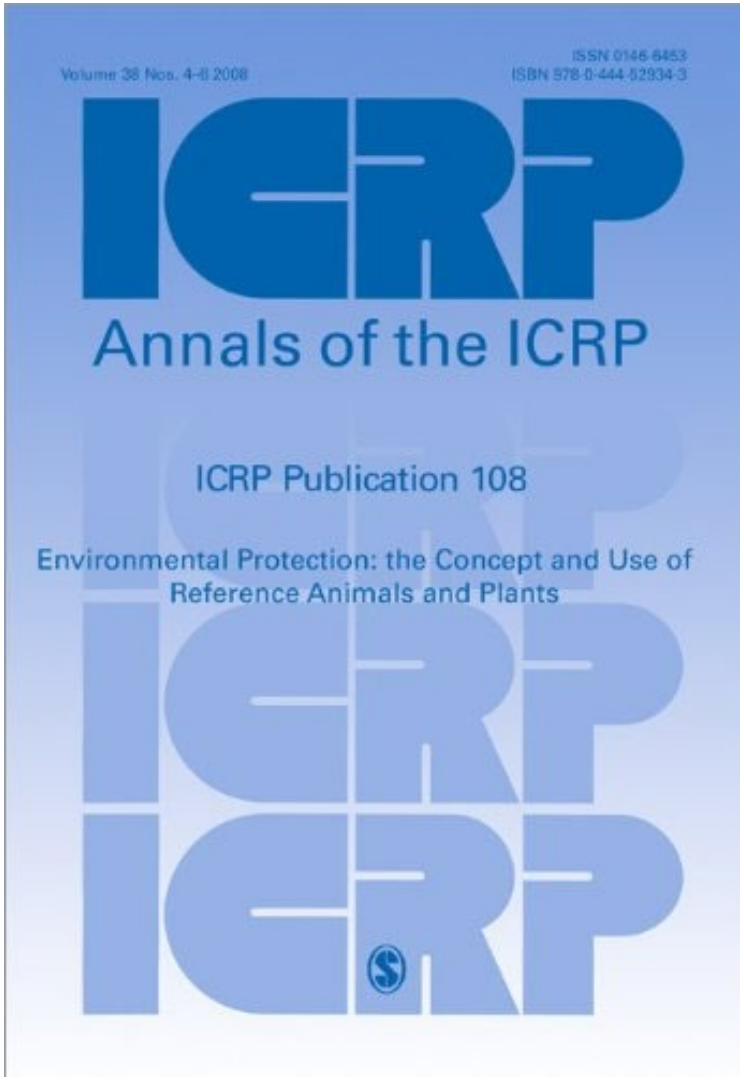
ICRP RAPs and Dose Coefficients

ICRP Publication 108

- Considered the subject of protection of the environment
- Environmental protection should be commensurate with the overall level of risk and should be optimized
- Set of Reference Animals and Plants (RAP)
- Set of dose conversion factors for 75 radionuclides
- Set of reference dose/risk level for each biotic type



What is a Reference Animal or Plant?

A hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.

External Exposure Geometry Assumptions for Reference Animals and Plants				
		Terrestrial		
		On soil		
RAP	Aquatic	Planar	Volume	In soil
Deer adult		x	x	
Rat adult		x	x	x
Duck egg		x	x	
Duck	x	x	x	
Frog egg	x			
Frog egg mass	x			
Frog tadpole	x			
Frog adult	x	x	x	
Trout egg	x			
Trout	x			
Flatfish egg	x			
Flatfish	x			
Crab egg mass	x			
Crab larve	x			
Crab	x			
Bee		x	x	
Bee colony		x	x	
Earthworm egg				x
Earthworm				x
Pine tree		x	x	
Grass		x	x	
Brown seaweed	x			

12 RAPs, some have multiple life stages

22 RAP Geometries, 11 aquatic, 9 terrestrial, and 2 both

Three exposure geometries for terrestrial

Dimensions, Habitats, and Life span for the RAP						
Reference animals and plants (RAP)	Major axis cm	First minor axis cm	Second minor axis cm	Body mass Kg	Habitat	Life span
Deer adult	130	60	60	245	Terrestrial	15 years
Rat	20	6	5	0.314	Terrestrial	2 years
Duck egg	6	4	4	0.0503	Terrestrial	30 days
Duck	30	10	8	1.26	Aquatic/T	11 years
Frog egg	1	1	1	5.24E-04	Aquatic	10 days
Frog mass of spawn	20	6	5	0.314	Aquatic	10 days
Tadpole	1.5	0.75	0.75	4.42E-04	Aquatic	100 days
Frog	8	3	2.5	0.0314	Aquatic/T	10 years
Trout egg/crab larvae	0.4	0.4	0.4	3.35E-05	Aquatic	100 days
Trout	50	8	6	1.26	Aquatic	6 years
Flatfish egg	0.2	0.2	0.2	4.19E-06	Aquatic	15 days
Flatfish	40	25	2.5	1.31	Aquatic	10 years
Crab egg mass	6	4	1	0.0126	Aquatic	0.5 years
Crab	20	12	6	0.754	Aquatic	15 years
Bee	2	0.75	0.75	5.89E-05	Terrestrial	100 days
Bee colony (natural)	60	30	30	28.3	Terrestrial	3 years
Earthworm egg	0.5	0.5	0.5	6.54E-05	Terrestrial	50 days
Earthworm (elongated)	10	1	1	5.24E-03	Terrestrial	5 years
Pine tree trunk	1000	30	30	471	Terrestrial	200 years
Grass (spike)*	5	1	1	2.62E-03	Terrestrial	1 year
Brown seaweed	50	50	0.5	0.652	Aquatic	5 years

* Grass meristem modeled only as a homogenous layer

Comparison of External Absorbed Dose Coefficients for In-soil Organisms

Table B.1 Comparison of external absorbed doses for in-soil organisms per unit photon, 50-cm-depth volume source (Gy/photon/kg).

Organism	Model	Photon energy (keV)			
		60	122	662	1250
Earthworm	EDEN	2.7×10^{-15}	9.0×10^{-15}	6.5×10^{-14}	1.3×10^{-13}
	EPIC	3.5×10^{-15}	1.3×10^{-14}	1.7×10^{-13}	3.3×10^{-13}
	EA R&D 128	9.4×10^{-15}	1.9×10^{-14}	1.0×10^{-13}	2.0×10^{-13}
	ERICA/FASSET	3.9×10^{-15}	1.1×10^{-14}	9.4×10^{-14}	1.8×10^{-13}
	RESRAD-Biota	2.6×10^{-15}	1.0×10^{-14}	9.9×10^{-14}	1.9×10^{-13}
Rat	EDEN	3.2×10^{-15}	1.0×10^{-14}	6.2×10^{-14}	1.3×10^{-13}
	EPIC	3.3×10^{-15}	1.2×10^{-14}	1.6×10^{-13}	3.1×10^{-13}
	EA R&D 128	8.4×10^{-15}	1.8×10^{-14}	9.8×10^{-14}	1.9×10^{-13}
	ERICA/FASSET	3.6×10^{-15}	1.1×10^{-14}	8.8×10^{-14}	1.7×10^{-13}
	RESRAD-Biota	2.6×10^{-15}	9.5×10^{-15}	8.7×10^{-14}	1.7×10^{-13}

Source: ICRP Publication 108

Comparison of External Absorbed Dose Coefficients for On-soil Organisms

Table B.2 Comparison of absorbed doses for on-soil organisms per unit photon, plane source (Gy/photon/m^2).

Organism	Model	Photon energy (keV)			
		60	122	662	1250
Earthworm	EDEN	1.0×10^{-15}	3.2×10^{-15}	3.1×10^{-14}	6.4×10^{-14}
	EPIC	1.4×10^{-15}	5.4×10^{-15}	4.8×10^{-14}	9.3×10^{-14}
	EA R&D 128	4.7×10^{-15}	9.6×10^{-15}	5.2×10^{-14}	9.9×10^{-14}
	ERICA	1.7×10^{-15}	5.4×10^{-15}	3.5×10^{-14}	6.9×10^{-14}
	RESRAD-Biota	1.2×10^{-15}	3.8×10^{-15}	3.0×10^{-14}	6.1×10^{-14}
Rat	EDEN	1.2×10^{-15}	3.6×10^{-15}	2.5×10^{-14}	5.1×10^{-14}
	EPIC	1.3×10^{-15}	5.2×10^{-15}	4.4×10^{-14}	8.7×10^{-14}
	EA R&D 128	4.2×10^{-15}	8.8×10^{-15}	4.9×10^{-14}	9.3×10^{-14}
	ERICA	1.7×10^{-15}	5.3×10^{-15}	3.5×10^{-14}	6.7×10^{-14}
	RESRAD-Biota	1.2×10^{-15}	3.8×10^{-15}	2.7×10^{-14}	6.1×10^{-14}

Source: ICRP Publication 108

Comparison of Photon Absorbed Fractions

Table B.3. Comparison of photon absorbed fractions calculated by different models for selected ellipsoidal organisms.

Target	Model	Photon energy (keV)			
		60	122	662	1250
Flatfish egg	EDEN	2.7×10^{-3}	1.9×10^{-3}	2.4×10^{-3}	2.2×10^{-3}
	EPIC	2.2×10^{-3}	1.9×10^{-3}	2.4×10^{-3}	2.2×10^{-3}
	EA R&D 128	2.5×10^{-3}	2.4×10^{-3}	2.3×10^{-3}	2.1×10^{-3}
	ERICA	2.2×10^{-3}	1.9×10^{-3}	1.3×10^{-3}	4.8×10^{-4}
	RESRAD-Biota	2.2×10^{-3}	1.9×10^{-3}	1.3×10^{-3}	4.6×10^{-4}
Duck	EDEN	0.23	0.15	0.14	0.12
	EPIC	0.14	0.12	0.14	0.12
	EA R&D 128	0.22	0.15	0.14	0.12
	ERICA	0.21	0.15	0.14	0.12
	RESRAD-Biota	0.15	0.12	0.13	0.12
Adult deer	EDEN	0.79	0.71	0.65	0.51
	EPIC	0.65	0.58	0.60	0.56
	EA R&D 128	0.80	0.66	0.55	0.51
	ERICA	0.76	0.68	0.60	0.54
	RESRAD-Biota	0.69	0.60	0.56	0.52

Source: ICRP Publication 108

DCFs [(uGy/day) per (Bq/kg)] for Flat Fish Egg

	Internal				External
Nuclide	DCF	f1	f2	f3	In water
Cl-36	2.10E-03	0	0	100	1.60E-03
Cr-51	6.40E-05	0	82	18	4.40E-04
Co-60	1.20E-03	0	0	100	3.50E-02
Sr-90	3.90E-03	0	0	100	1.20E-02
Cs-134	1.50E-03	0	0	100	2.20E-02
Cs-135	8.70E-04	0	1	99	6.00E-05
Cs-137	2.00E-03	0	0	100	9.20E-03
Eu-152	1.10E-03	0	7	93	1.60E-02
U-238	5.80E-02	100	0	0	1.80E-05
Am-241	7.70E-02	99	0	1	4.40E-04
f1 = fraction of the internal DCFs due to alpha, fission fragments					
f2 = fraction of internal DCFs due to low energy (<10 keV) beta					
f3 = fraction of internal DCFs due to high energy beta and photons					

For aquatic organism, no substantial difference in density in water and organism. The radioactive progeny with a half-life <10 days are included as being in secular equilibrium

Comparison of DCFs [(uGy/day) per (Bq/kg)] for Flat Fish Egg in ICRP 108 and RESRAD-BIOTA

	Flat Fish Egg - ICRP 108		Fish Egg - RESRAD-BIOTA	
Nuclide	Internal	External	Internal	External
Cl-36	2.10E-03	1.60E-03	2.85E-03	5.58E-04
Cr-51	6.40E-05	4.40E-04	5.78E-05	4.38E-04
Co-60	1.20E-03	3.50E-02	1.50E-03	3.44E-02
Sr-90	3.90E-03	1.20E-02	1.56E-02	1.56E-02
Cs-134	1.50E-03	2.20E-02	2.12E-03	2.16E-02
Cs-135	8.70E-04	6.00E-05	1.02E-03	2.55E-05
Cs-137	2.00E-03	9.20E-03	2.75E-03	8.44E-03
Eu-152	1.10E-03	1.60E-02	1.46E-03	1.63E-02
U-238	5.80E-02	1.80E-05	5.92E-02	6.75E-03
Am-241	7.70E-02	4.40E-04	7.66E-02	3.58E-04