Voxel Phantoms for Biota: Challenges and Controversies

Kathryn Higley, PhD, CHP
Professor and Head
Department of Nuclear Engineering & Radiation Health Physics
Vice-Chair, ICRP C5, Protection of the Environment

Outline of Presentation

I. ICRP System for Protection of the Environment
II. Evolution of human radiation protection system
III. Dose modeling for non human biota
IV. Challenges and controversies moving forward

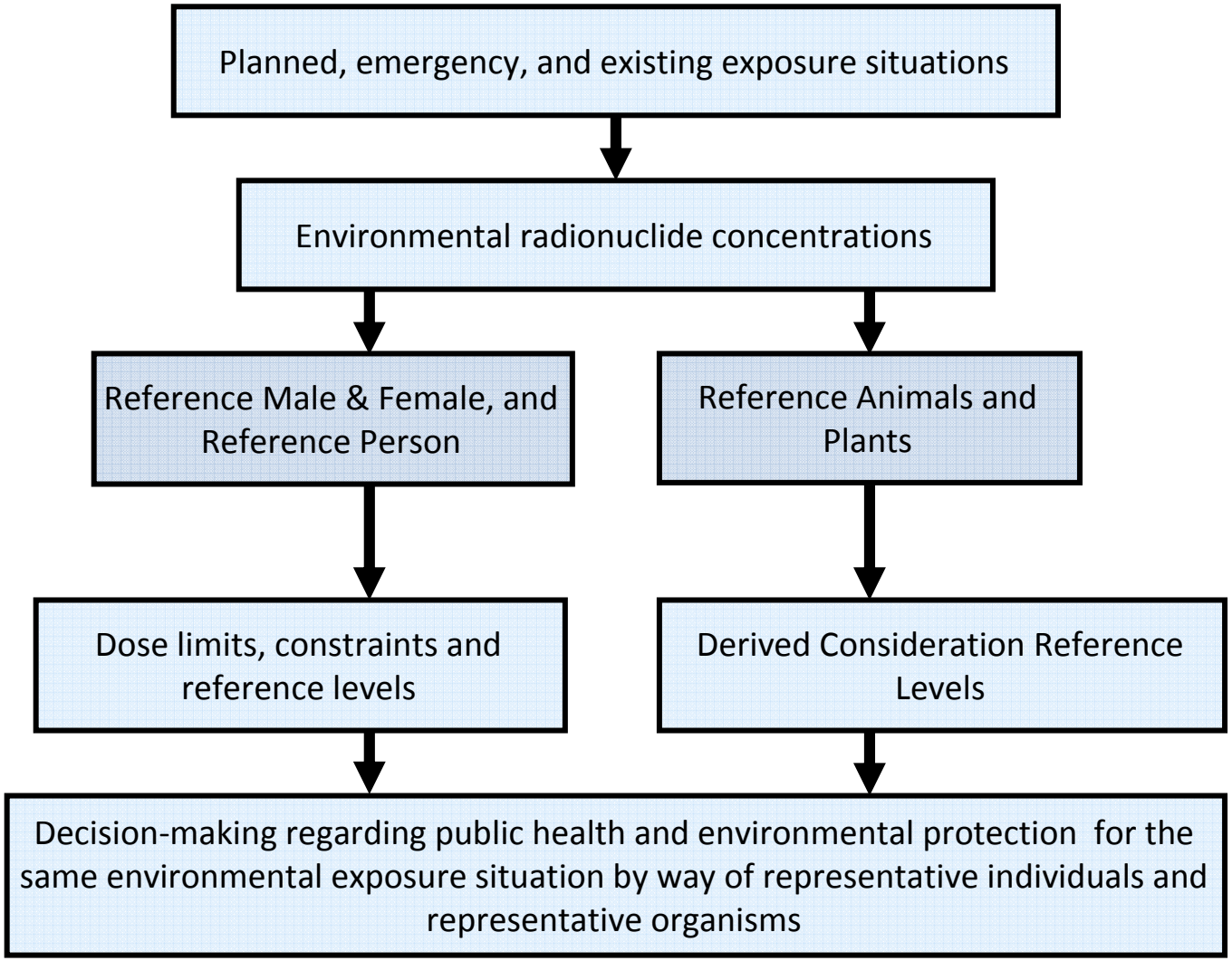
I. ICRP System for Protection of the Environment

ca 1950s — **No explicit environmental protection**

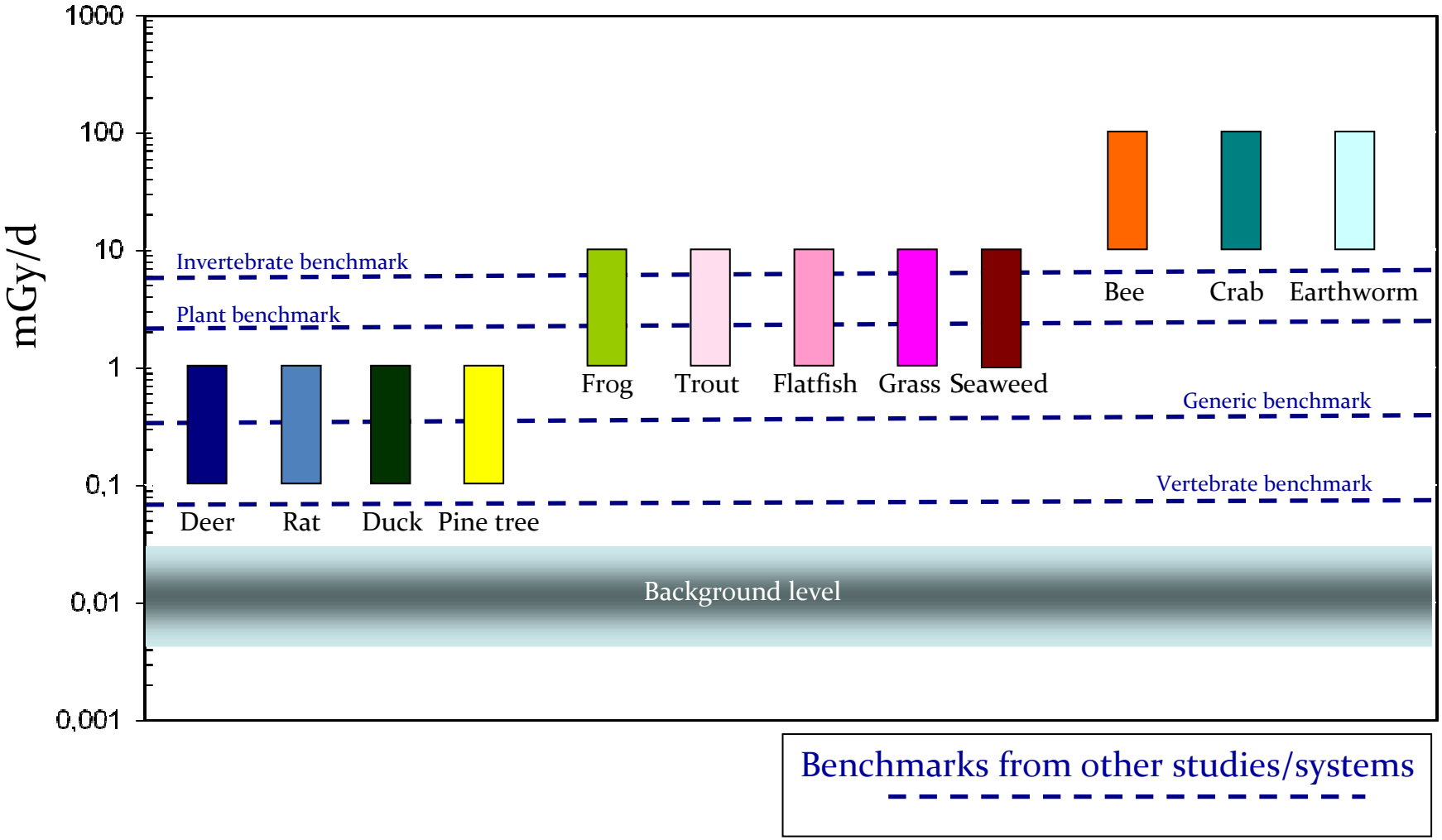
ca 1980s — **'If you protect man, then you protect the environment'**

ca 2000s — **Development of a protection system parallel to that for humans**

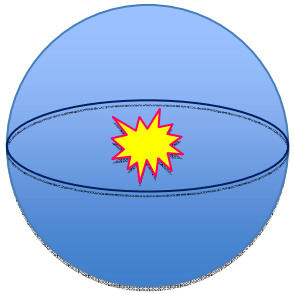
Parallel pathways



ICRP 108:
Derived Consideration Reference Levels, DCRLs

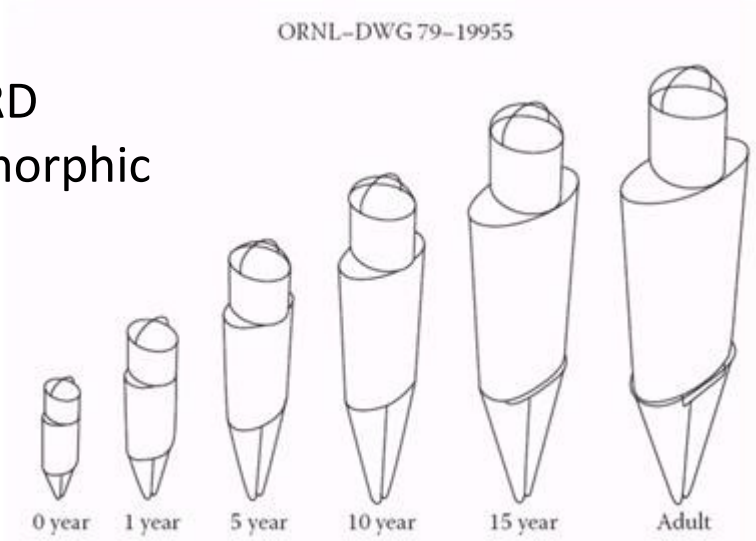


II. Evolution of human radiation protection system

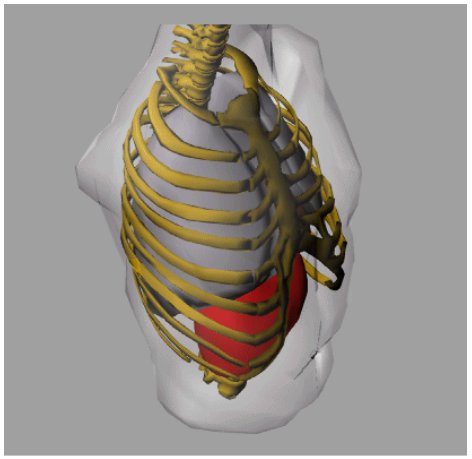


1950s-1960s, ICRU spheres with effective radius and source at center

1960s, MIRD Anthropomorphic Phantoms



1990s -Image-based rigid, 3D modes

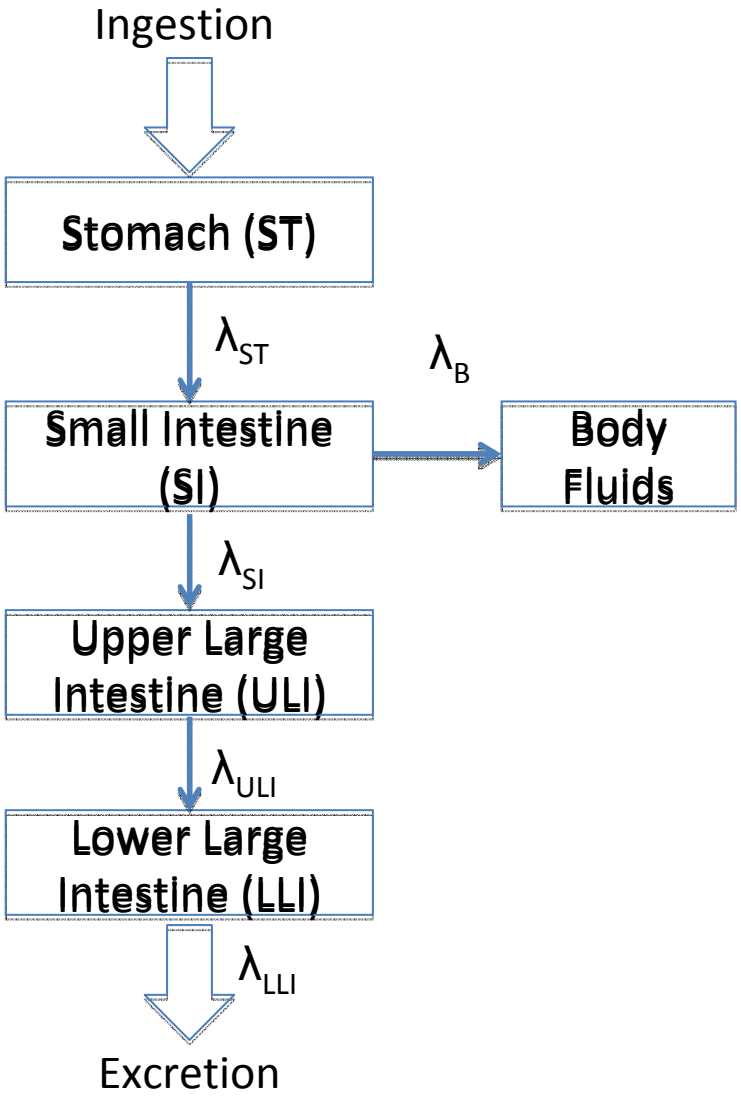


Future: Deformable models

II. Evolution, continued

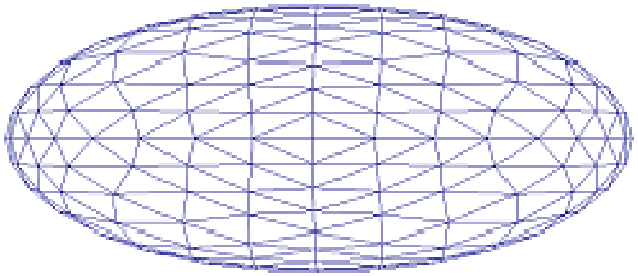
Internally deposited nuclides and biokinetic modeling

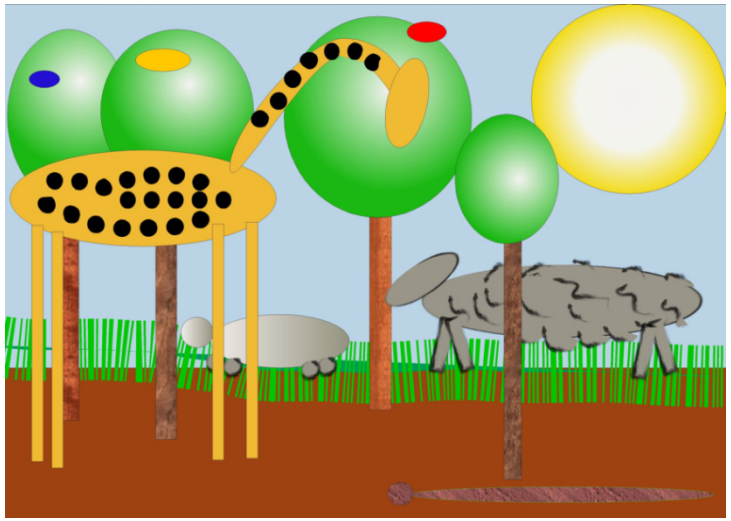
- Organ dose calculation requires
  - Biokinetic modeling
  - Absorbed Fraction (AF) (leakage)
  - Radiation weighting factors
  - Specific Effective Energy (dose)
  - Number of decays (50 year period)
- Cannot measure directly dose
- Inhomogeneous distribution
- Protraction of dose
- Varying elemental residence times
- Whole body dose calculation requires
  - Tissue weighting factors (risk)

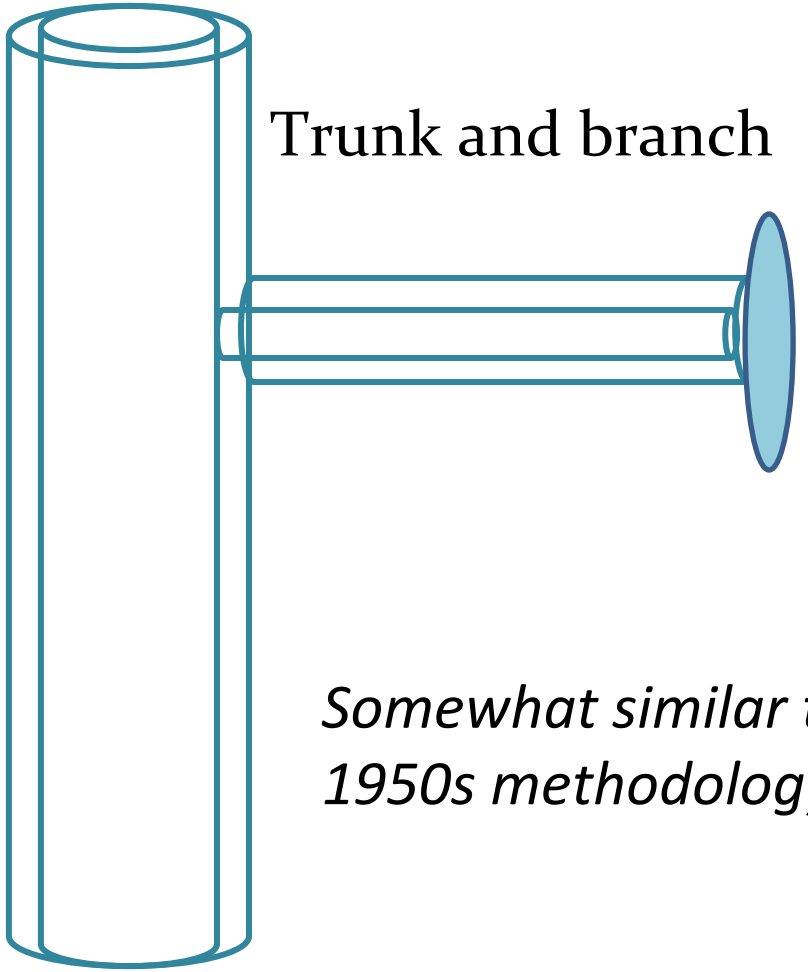


III. Dose Modeling for Non Human Biota: ICRP 108

DCCs for simple geometries







Trunk and branch

Somewhat similar to 1950s methodology

Radiation dose depends on:
Type, energy, organism size, location, density, Z,…

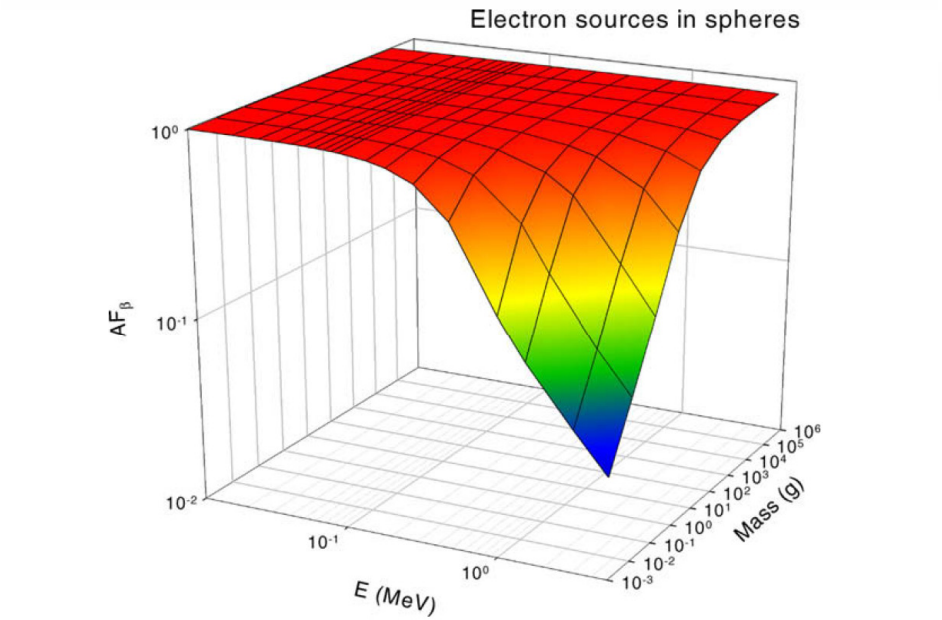


Fig. E.1. Absorbed fractions for electrons in relation to mass and energy for spheres.

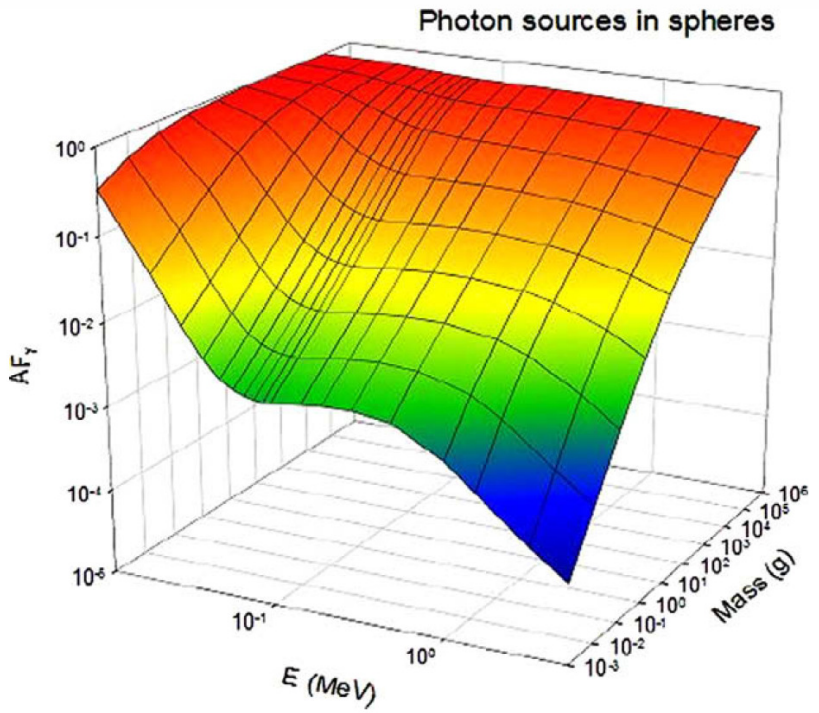
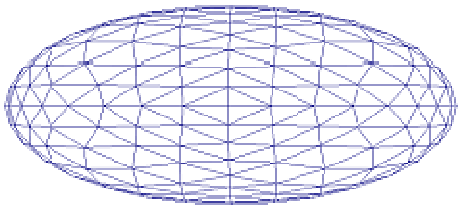


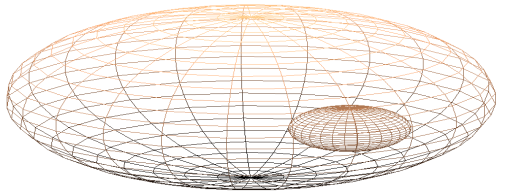
Fig. E.2. Absorbed fractions for photons in relation to mass and energy for spheres.

From: Environmental Protection: the Concept and Use of Reference Animals and Plants
ICRP Publication 108

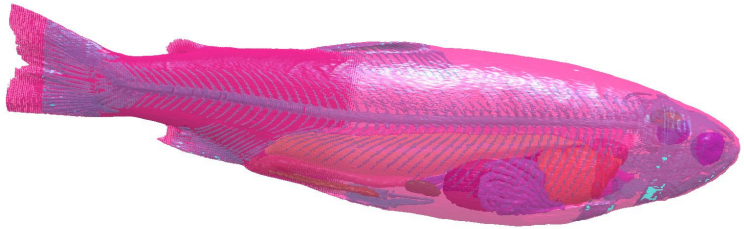
III. Dose Modeling cont'd: Next Step for Biota: Voxels

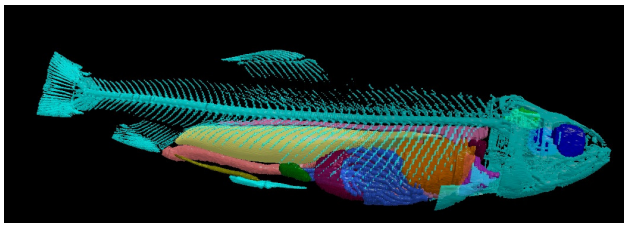
- Current practice
  - Simplified geometry
  - Organism modeled as homogeneous ellipsoid
  - Possibly with rudimentary organs





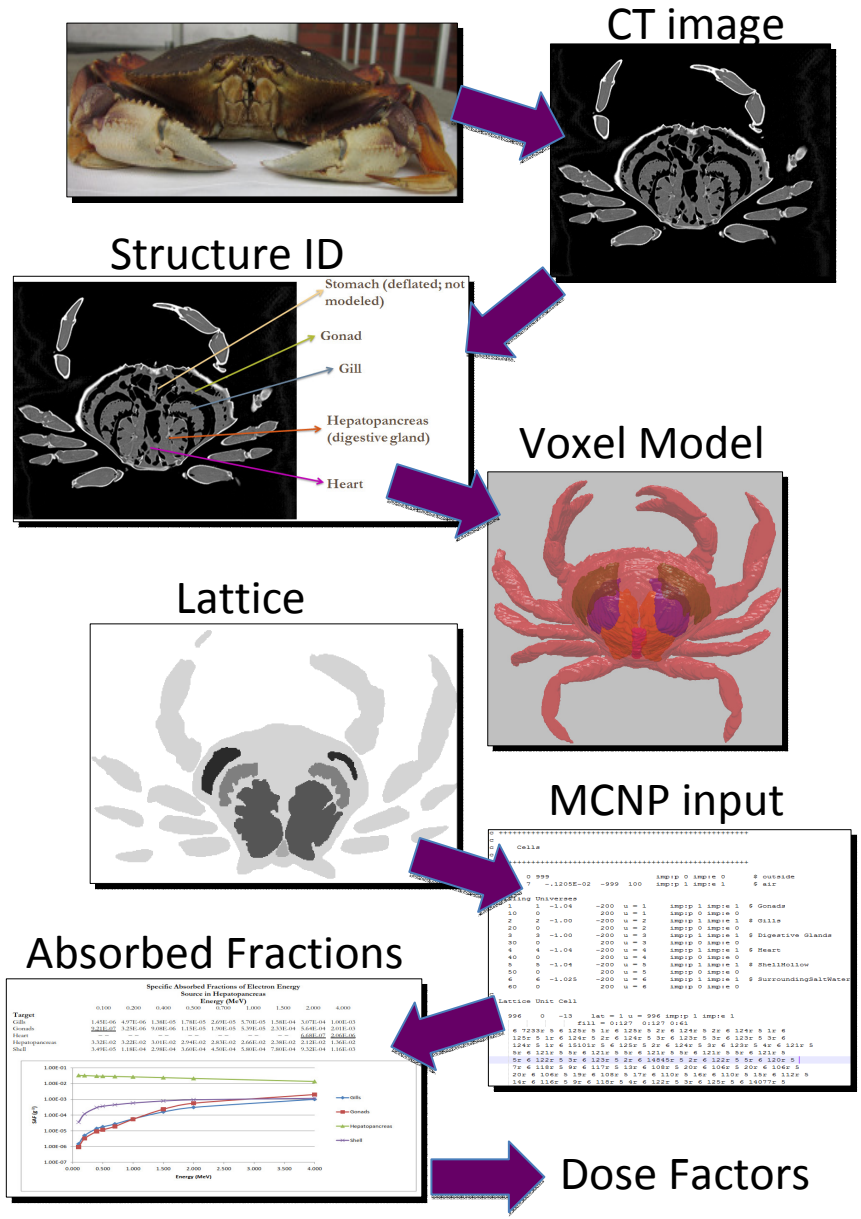
- Voxelized models
  - Complex geometry obtained through medical imaging
  - MCNP or other codes used to derive dosimetric data





Building a Voxel Model from a RAP

- Voxel models require considerable effort:
  - Organism
  - Medical image with CT/MRI
  - Identify tissues /structures
  - Build 3 dimensional representation
  - Determine density
  - Determine tissue elemental composition
  - Use radiation interaction software
  - Calculate absorbed fractions
  - Merge with nuclide data to build dose factors



RAPs Reference Organisms / Stages

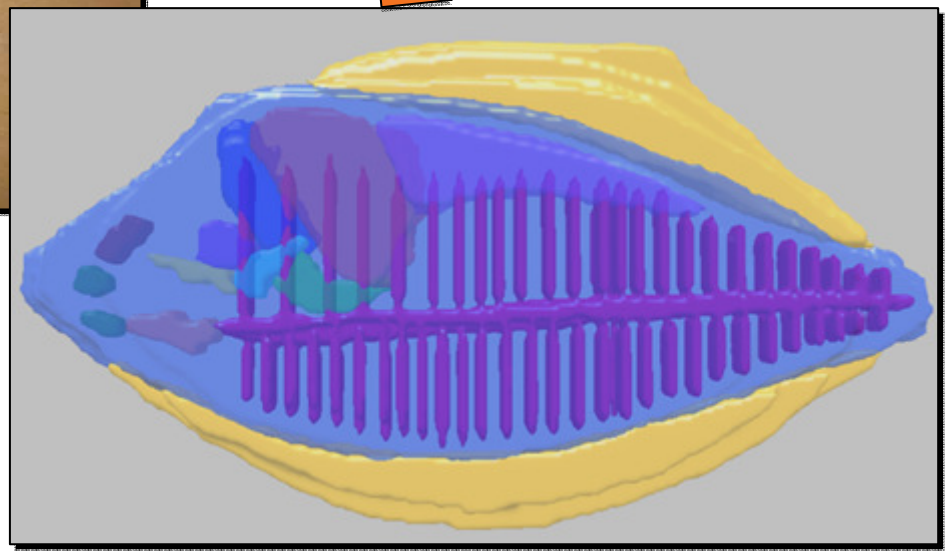
Terrestrial	Freshwater	Marine
Pine tree	Frog (**adult***, egg, egg mass, tadpole)	Flatfish (egg, **adult***+)
Bee (**adult***+, **colony**+)	Trout (**adult***+, egg)	Crab (**adult***+, egg mass, larvae)
Earthworm (egg, **adult***+)	Duck (adult, eggs)	Seaweed
Grass (meristem, grass spike)		
Deer (calf, adult)		
Rat*		
*Indicates voxel model and DCFs done or near completion +OSU developed		

Other organisms where voxel model has been developed – Snail, Rabbit

Ellipsoid vs Voxel

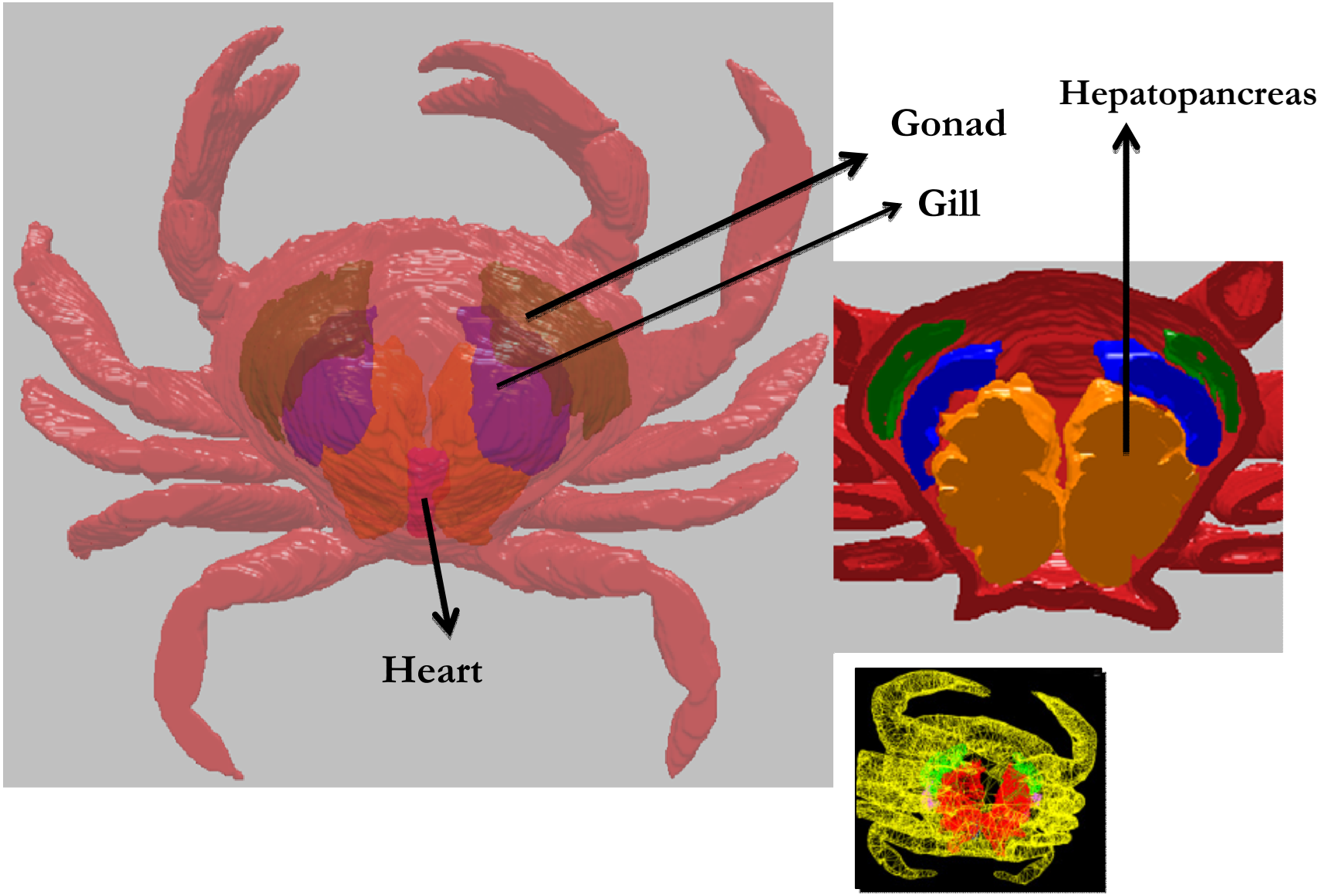
Ellipsoid	Voxel
Easy to construct	Laborious to construct
Simple to calculate conservative AF for alpha, beta, gamma	Can calculate accurate AF that incorporates organ geometry and can model radiation leakage
Doesn't routinely estimate dose to organ with highly partitioned nuclide	Can estimate dose to organ with highly partitioned nuclide (but need partitioning information)
Doesn't allow for crossfire calculations	Crossfire calculations can be addressed when tissue partitioning considered
Assumes homogeneous tissue composition and density	Can incorporate heterogeneous tissue composition, variable density, and highly partitioned radionuclides
Doesn't allow for multi-compartment radionuclide kinetics	Can be combined with multi-compartment models to address radionuclide kinetics and estimate dose rate and integrated dose

Limanda Limanda (Sand Dab)

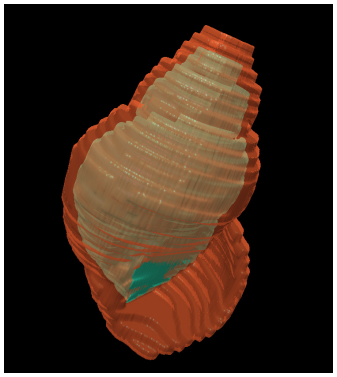


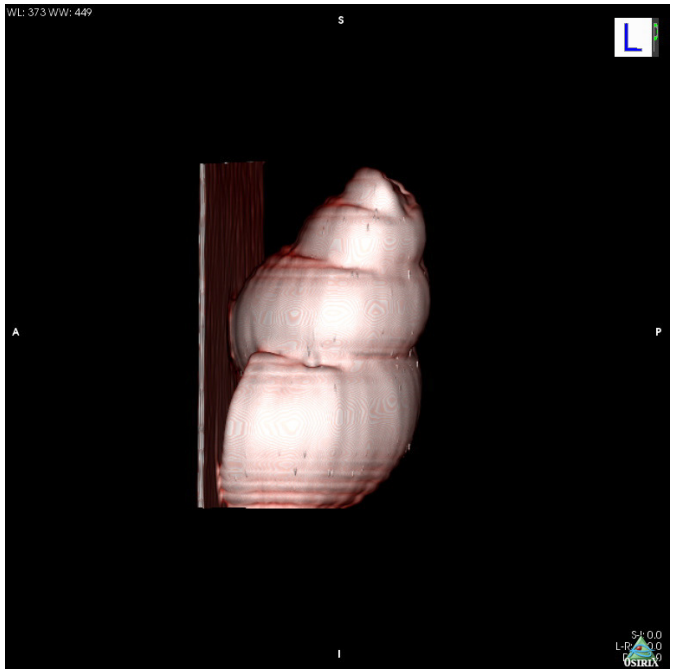
Source: Photo courtesy of Andrew Marriott, published on MLIN website

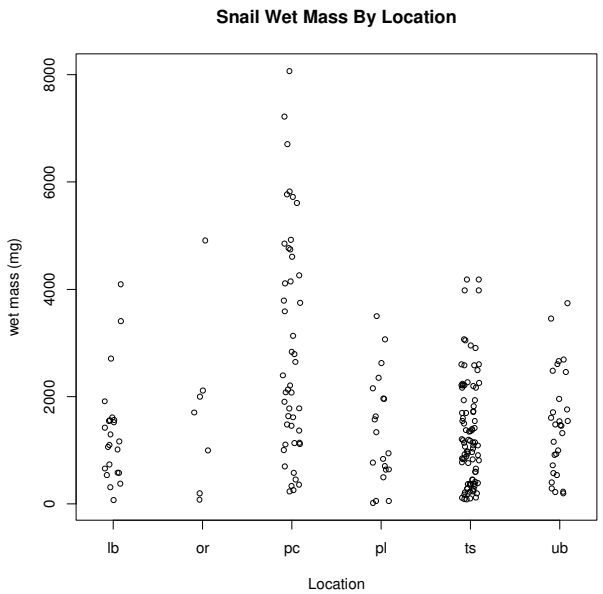
Completed Crab Voxel Phantom



Non RAP: Snail







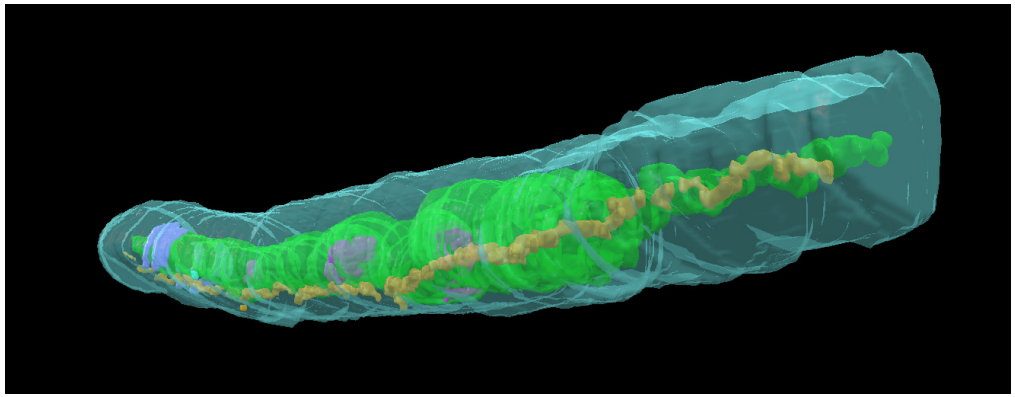
- Utilized in dose calculation from Sr-90
- Highly partitioned into shell
- Preliminary results show up to 80% difference between doses calculated using these new methods and traditional spheroid or ellipsoid approximations.

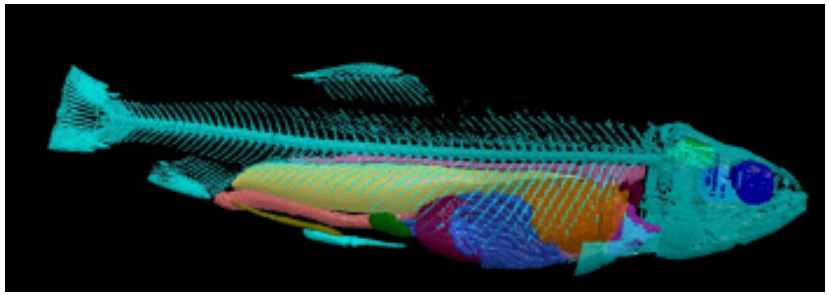
[YouTube Snail Animation]

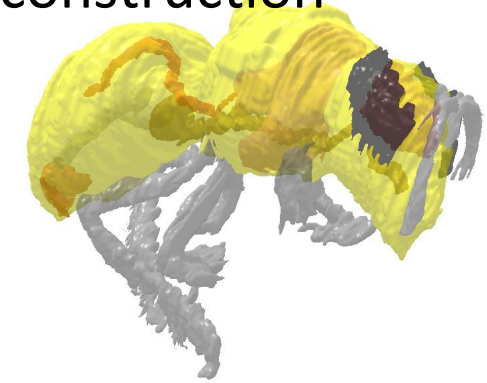
Oregon State University

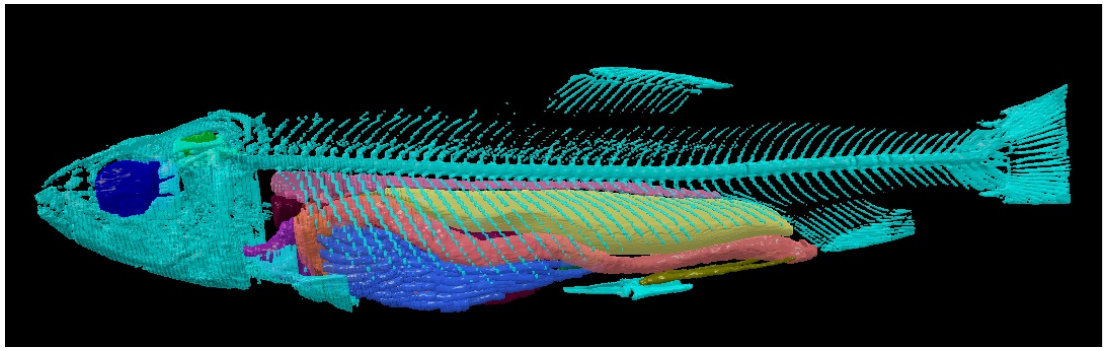
Ongoing Model and DCC development

- Earthworm
- Trout
- Bee
- All have been imaged
- MCNP model constructed and run
- AFs developed
- DCC's under construction



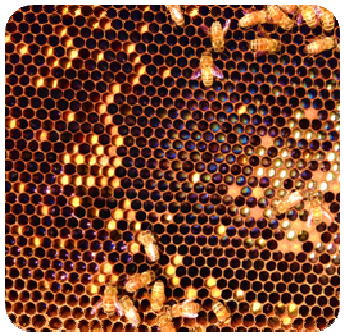


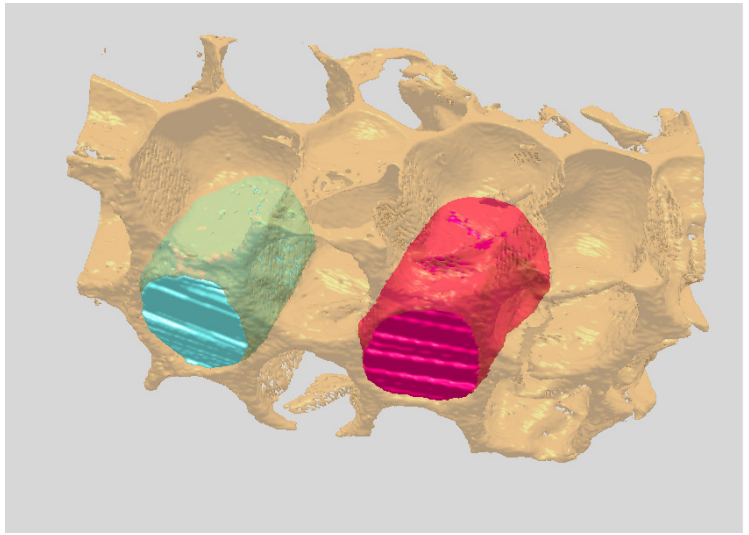


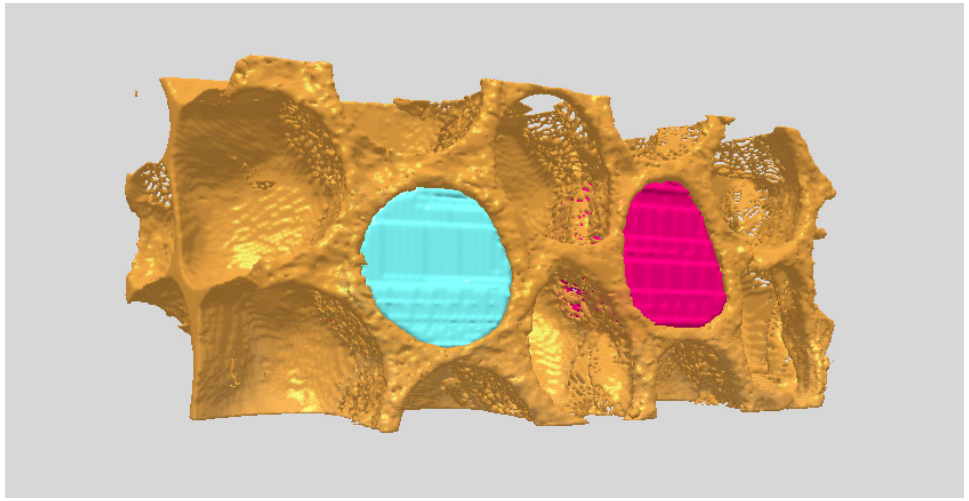


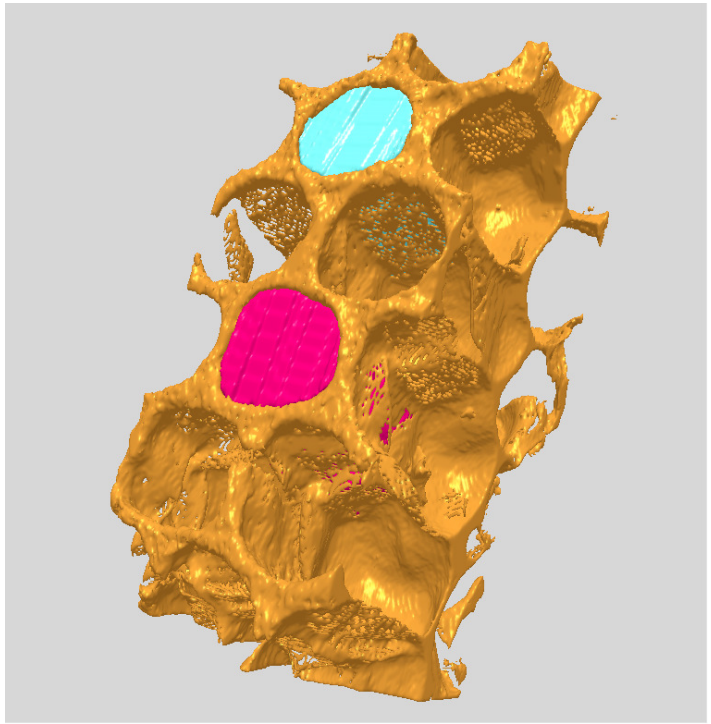
Ongoing Development

Bee Hive -



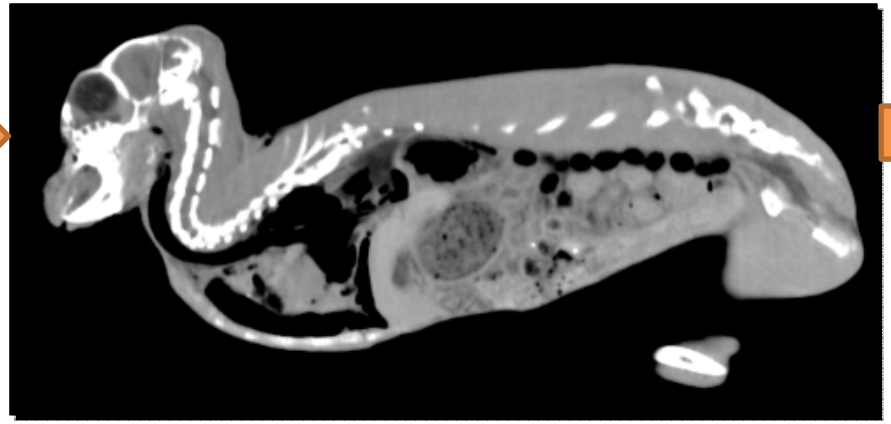


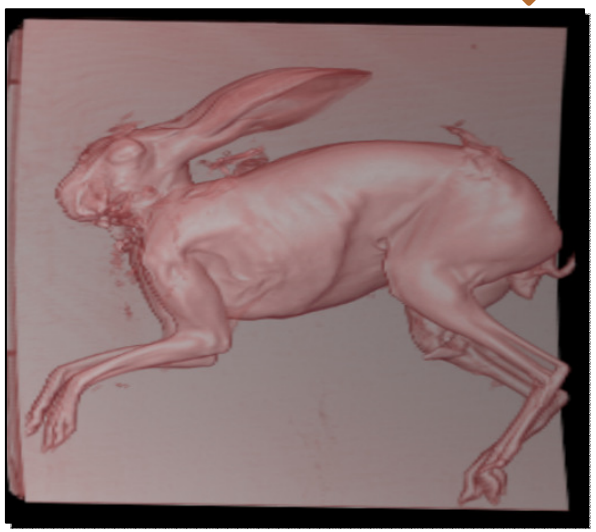




Ongoing Development: Jack Rabbit

http://en.wikipedia.org/wiki/File:Jackrabbit2_crop.JPG





Under Development

Previous Model - Ellipsoidal

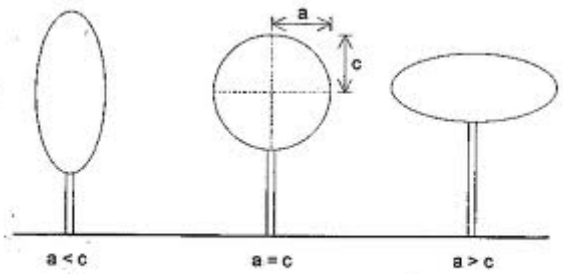
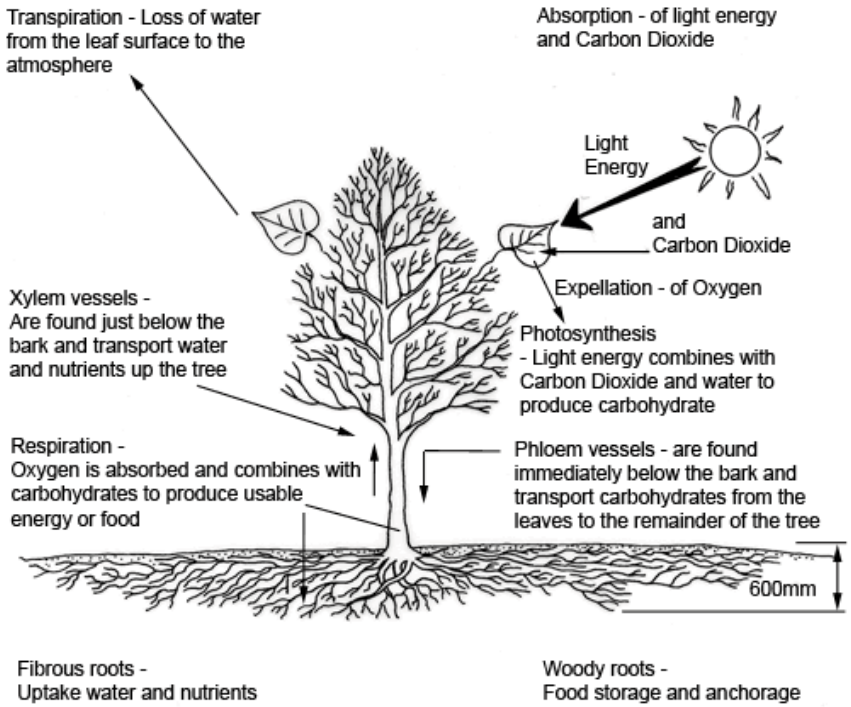
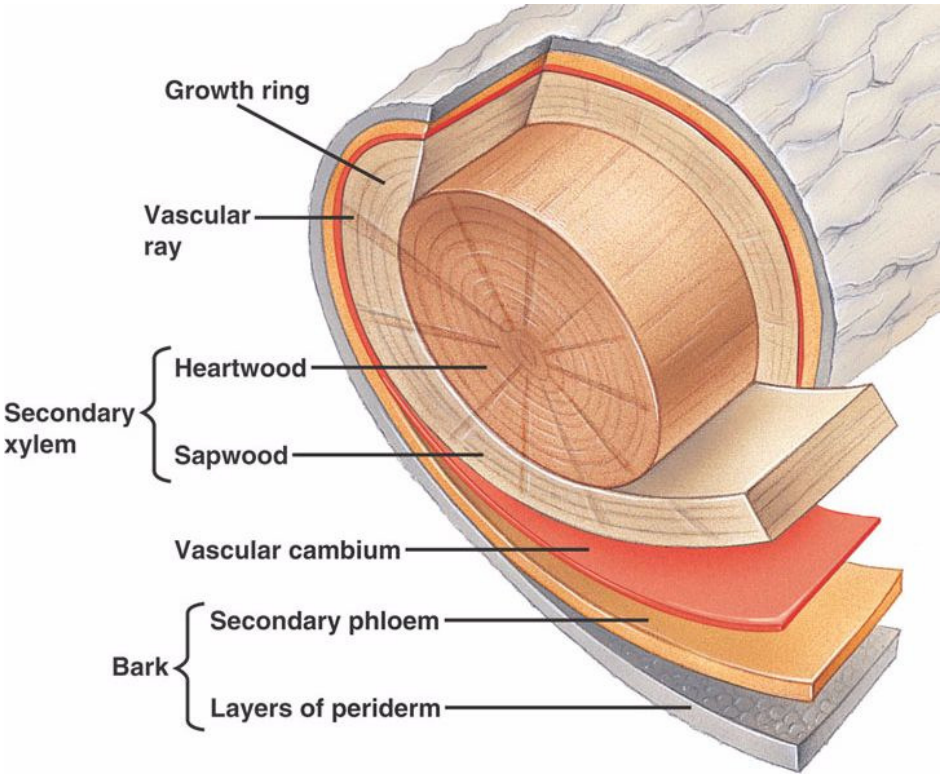


Figure 3.3. Possible tree crown ellipsoids.

More Accurate Tree System



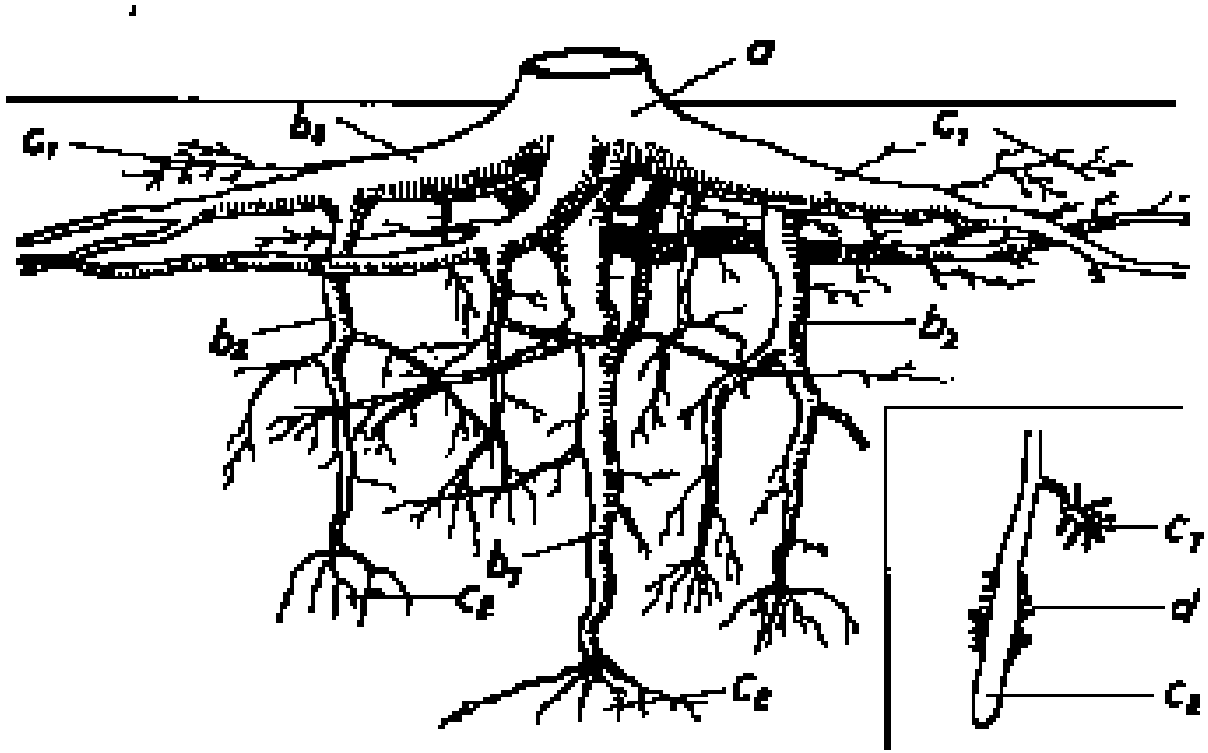
Challenges in Modeling Plants



- Plants organs are less defined than those seen in animals & insects; they cover regions but do not have defined margins
  - Root system (large, branching, large root turnover)
  - Pine needles (pine needles have a much shorter lifetime than the pine trees)
  - Pine cones
  - Xylem/Phloem lateral nutrient movement

http://prezi.com/2monyfphlyau/biology-habitat-project/

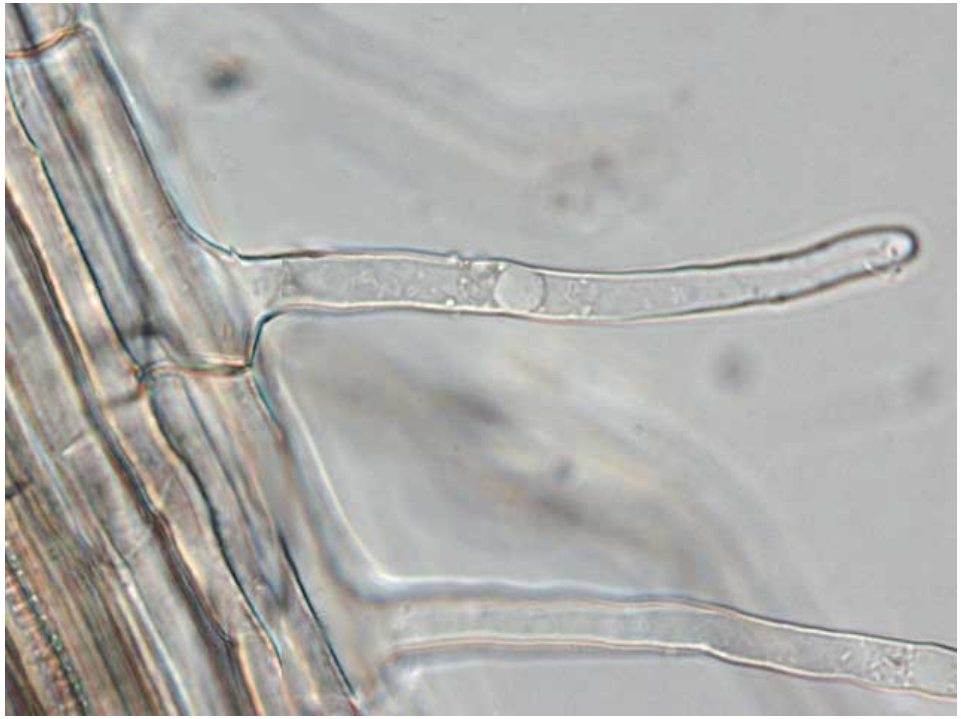
Challenges in Modeling



Roots start with primary roots and break into secondary and tertiary roots; with root hair forming on the primary and secondary roots.

http://www.sefs.washington.edu/classes.esc.401/TreeGrowth.htm

Challenges in Modelling



http://botit.botany.wisc.edu/Anatomy/Glossary/Ep4.html
http://bomi.ou.edu/libault/

IV. Challenges and controversies moving forward

- Knowledge gaps and their significance
- How important are the following in dose calculations:
  - Tissue composition, major and minor components (10-30% difference in dose?)
  - Tissue density (factor of 2? difference in dose)
  - Organ geometry (may be significant)
  - Heterogeneous distribution of constituents (radionuclides and trace elements) (may be significant)
  - Organ-specific partitioning (we should focus on this – if deterministic impacts are the driver)

IV. continued, Challenges and Controversies

- Challenges
  - Voxel modeling is laborious
  - Model is based on a single organism – not a ‘reference’ construct
  - Tissue composition data, density, structure not widely available
  - Extremely small organisms (e.g., crab larvae) and organs (root hairs) move into realm of microdosimetry and stochastic events

- Controversies
  - Why bother with realistic modeling of non human biota?
  - Why bother with dose modeling non human biota?

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Even Tiny Amounts of Radioactive Food Made Caterpillars Become Abnormal Butterflies

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The biological impacts of the Fukushima nuclear accident on the pale grass blue butterfly

SUBJECT AREAS:
ENVIRONMENTAL SCIENCES
ECOLOGY
BIODIVERSITY
PATTERN FORMATION

Atsuki Hiyama[1]*, Chiyo Nohara[1]*, Seira Kinjo[1], Wataru Taira[1], Shinichi Gima[2], Akira Tanahara[2] & Joji M. Otaki[1]

[1]The BCPH Unit of Molecular Physiology, Department of Chemistry, Biology and Marine Science, Faculty of Science, [2]Instrumental Research Center, University of the Ryukyus, Nishihara, Okinawa 903-0213, Japan.

Received
6 June 2012

Hiyama *et al. BMC Evolutionary Biology* 2013, **13**:168
http://www.biomedcentral.com/1471-2148/13/168

BMC Evolutionary Biology

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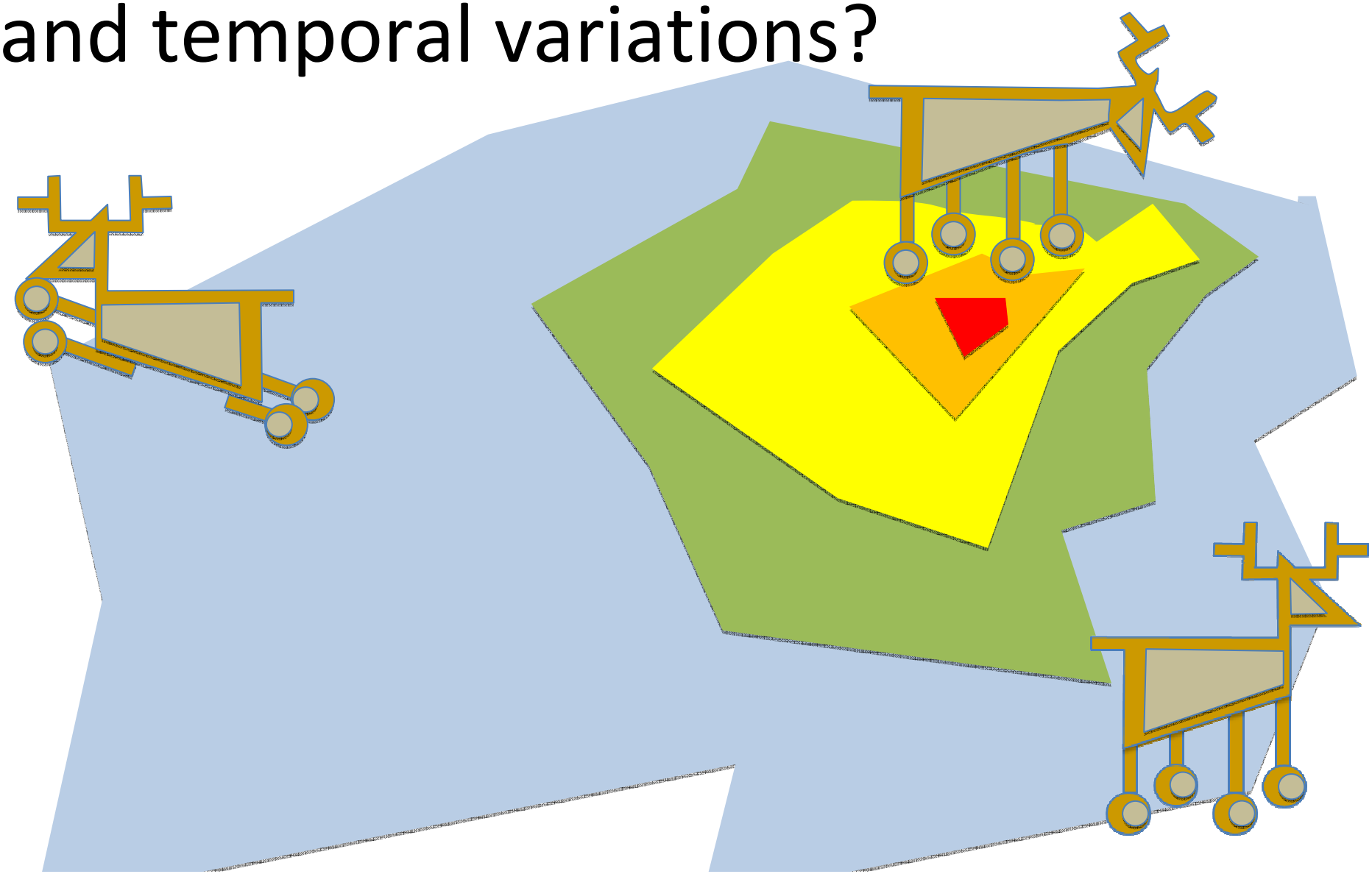
The Fukushima nuclear accident and the pale grass blue butterfly: evaluating biological effects of long-term low-dose exposures

Atsuki Hiyama, Chiyo Nohara, Wataru Taira, Seira Kinjo, Masaki Iwata and Joji M Otaki*

Abstract

And what about spatial and temporal variations?