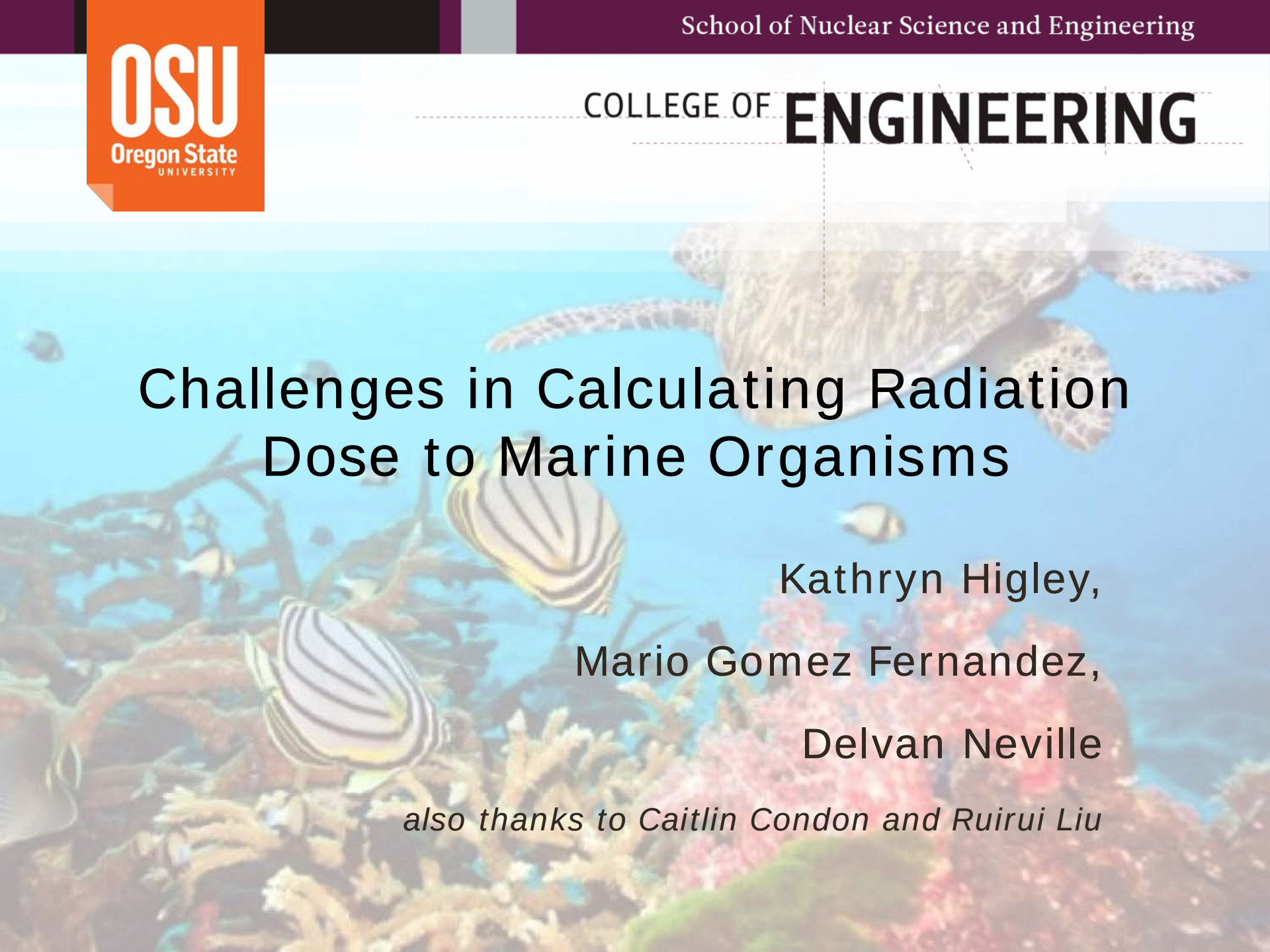


Challenges in Calculating Radiation Dose to Marine Organisms

Kathryn Higley,

Mario Gomez Fernandez,

Delvan Neville

also thanks to Caitlin Condon and Ruirui Liu

Why Do Need to Calculate Dose to Marine (or other non human) Organisms? Answer: 20 years of serious discussion:

ca 1950s — No explicit environmental protection

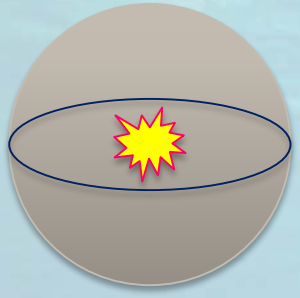
↓

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

↓

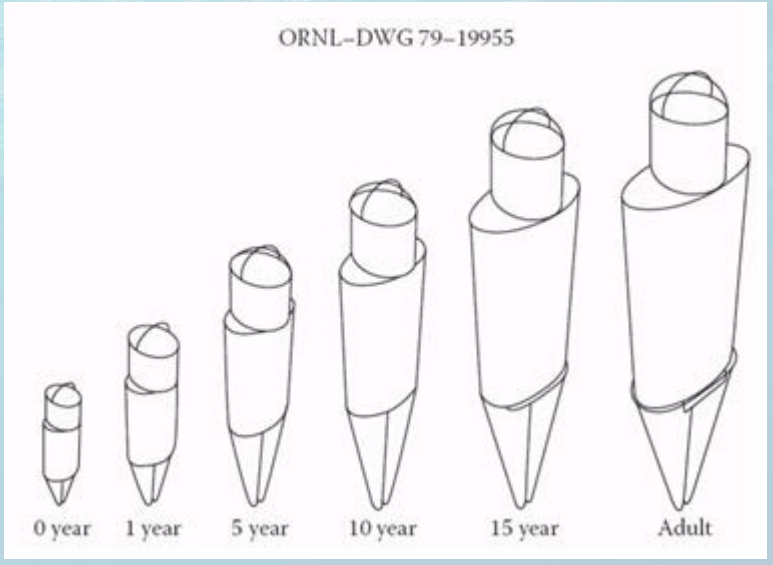
ca 2000s — Development of a protection system parallel to that for humans

Calculating Radiation Dose to Humans – 100+ years of Effort

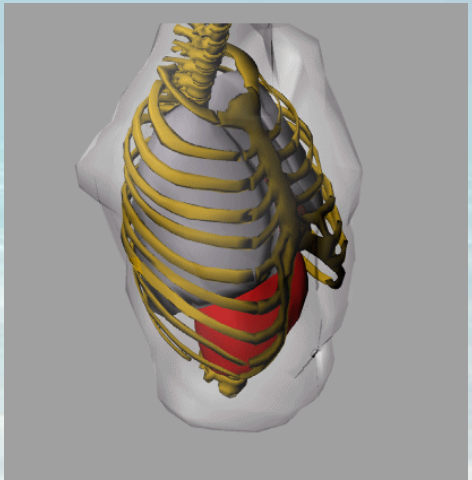


1950s-1960s, ICRU spheres with effective radius and source at center

1960s, MIRD Anthropomorphic Phantoms



1990s - Image-based rigid, 3D modes



Future: Deformable models

OSU Oregon State UNIVERSITY

The ICRP Proposed Parallel Pathways

Planned, emergency, and existing exposure situations

Environmental radionuclide concentrations

Reference Male & Female, and Reference Person

Reference Animals and Plants

Dose limits, constraints and reference levels

Derived Consideration Reference Levels

Decision-making regarding public health and environmental protection for the same environmental exposure situation by way of representative individuals and representative organisms

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

ICRP ESTABLISHED 12 REFERENCE ANIMALS AND PLANTS (RAPS)

Terrestrial

Deer
Rat
Bee
Earthworm
Pine tree
Grass

Marine

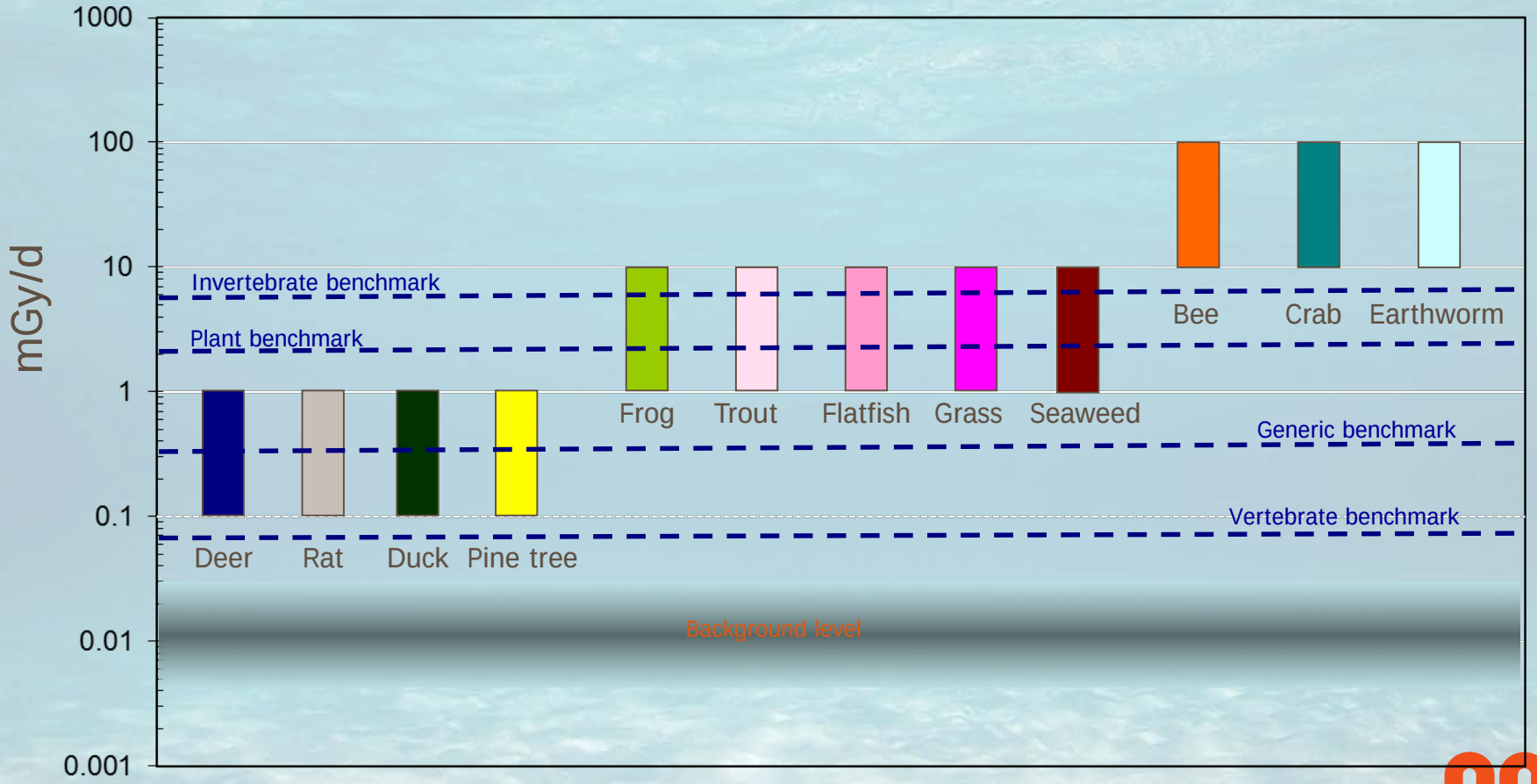
Flatfish
Crab
Brown seaweed

Freshwater

Duck
Frog
Trout

Radiation Safety: ICRP 108

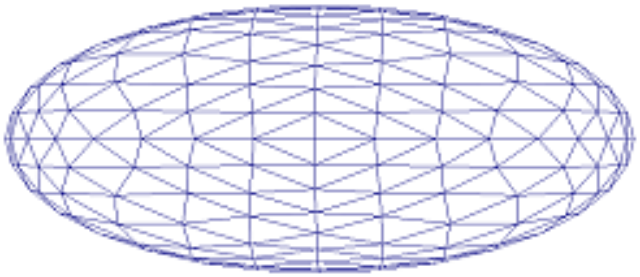
Derived Consideration Reference Levels, DCRLs

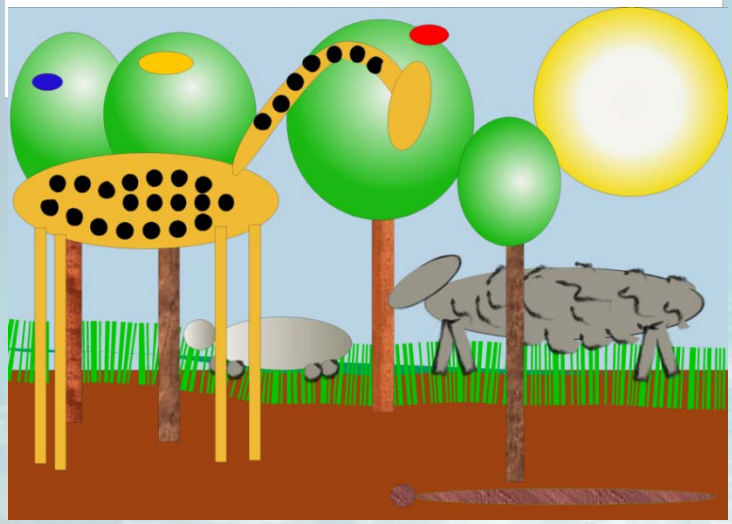


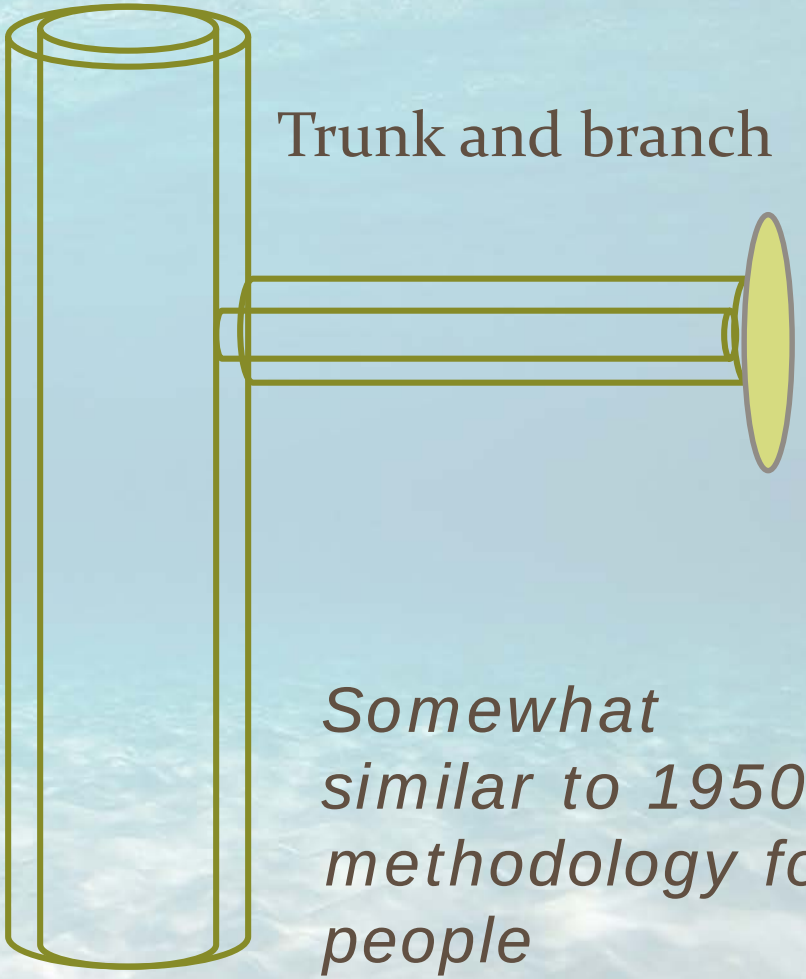
Benchmarks from other studies/systems

Dose Modeling for Non Human Biota: ICRP 108

DCCs for simple geometries

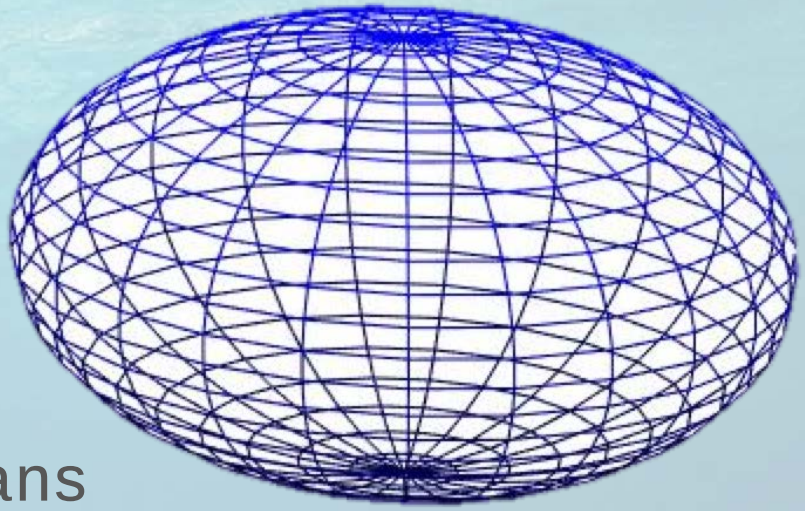






Somewhat similar to 1950s methodology for people

Application of ICRP Approach to Marine Dosimetry



- Calculate whole body dose
- Assuming
  - Organism modeled:
    - As simple shape - no organs
    - ***Human tissue composition***
    - ***Human tissue densities***
- Simple and quick assessment

We don’t know as much as we think we do

CHALLENGES IN CALCULATING DOSE TO BIOTA

CONCEPT

Source Term

AIR

SOIL & SEDIMENT

WATER

HERBIVORES

PLANTS

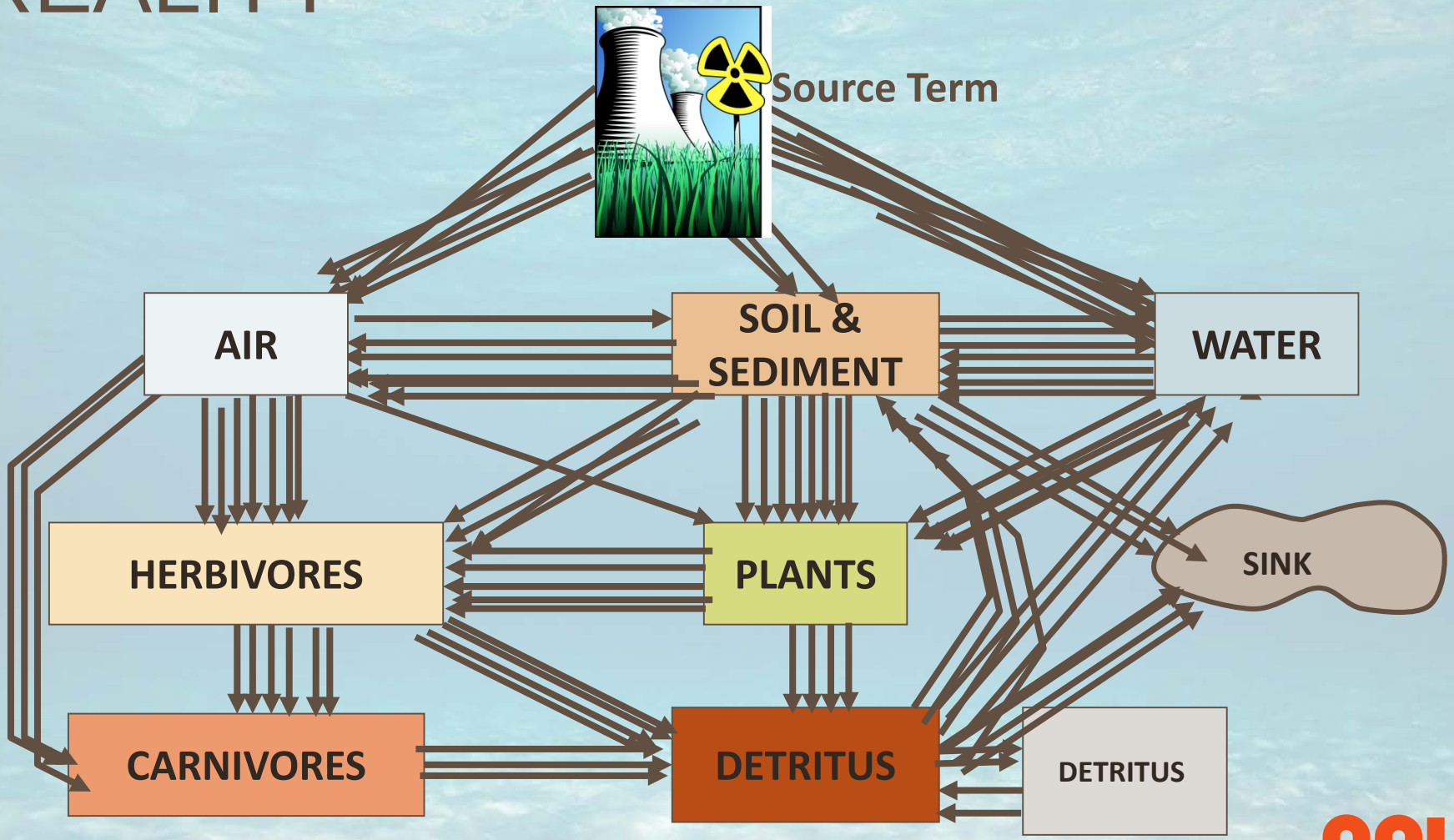
SINK

CARNIVORES

DETRITUS

DETRITUS

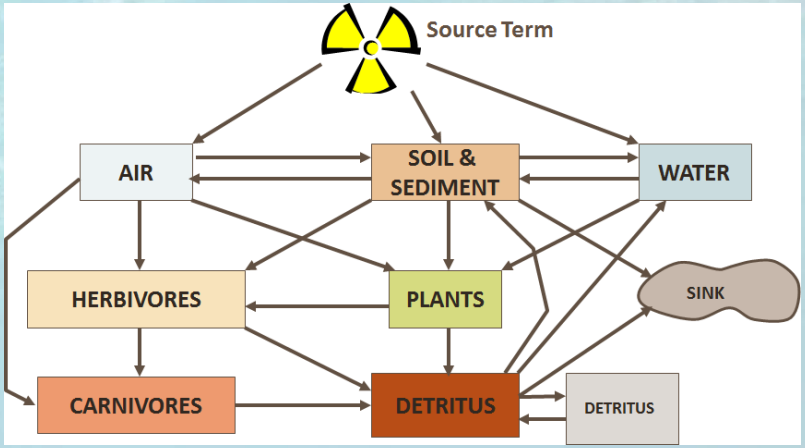
REALITY


Source Term
AIR
SOIL & SEDIMENT
WATER
HERBIVORES
PLANTS
SINK
CARNIVORES
DETRITUS
DETRITUS

Information Gaps Still Exist

- International Atomic Energy Agency (IAEA) TECDOC 1616 (2009), and
- IAEA Technical Reports Series No. 472 (2010)

- Identified data gaps in radionuclide transfer for
  - Foodstuffs
  - Wildlife
  - Specific radionuclides
  - Specific elements



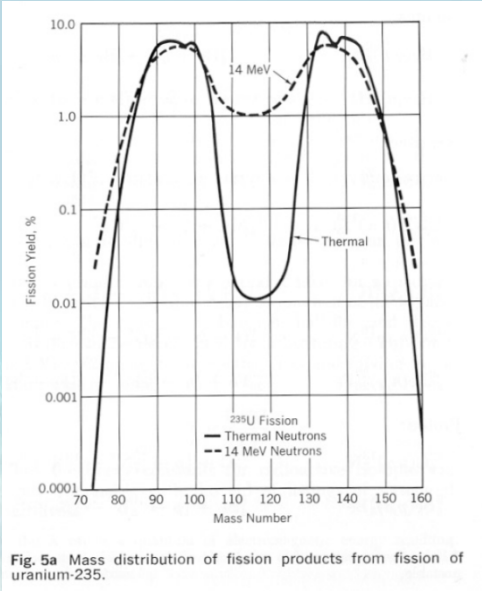
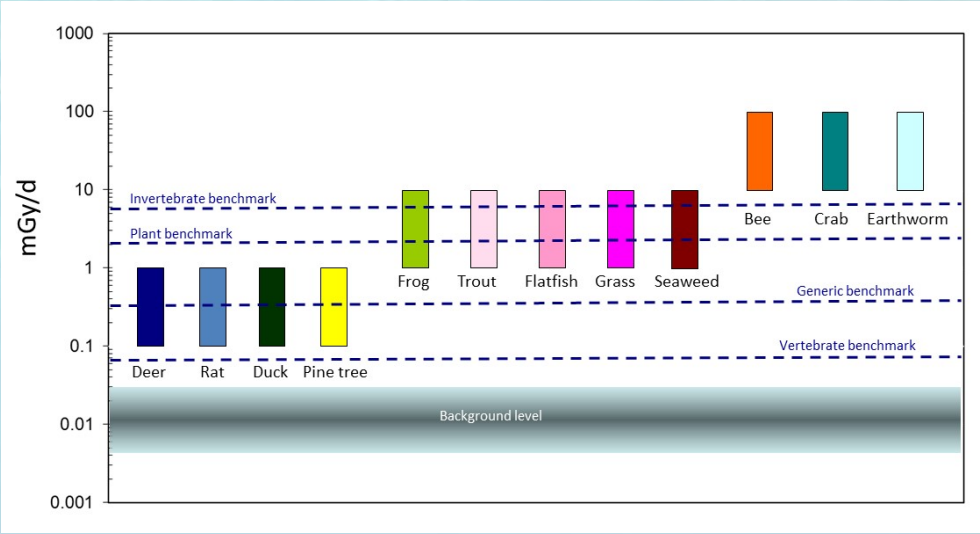


Fig. 5a Mass distribution of fission products from fission of uranium-235.

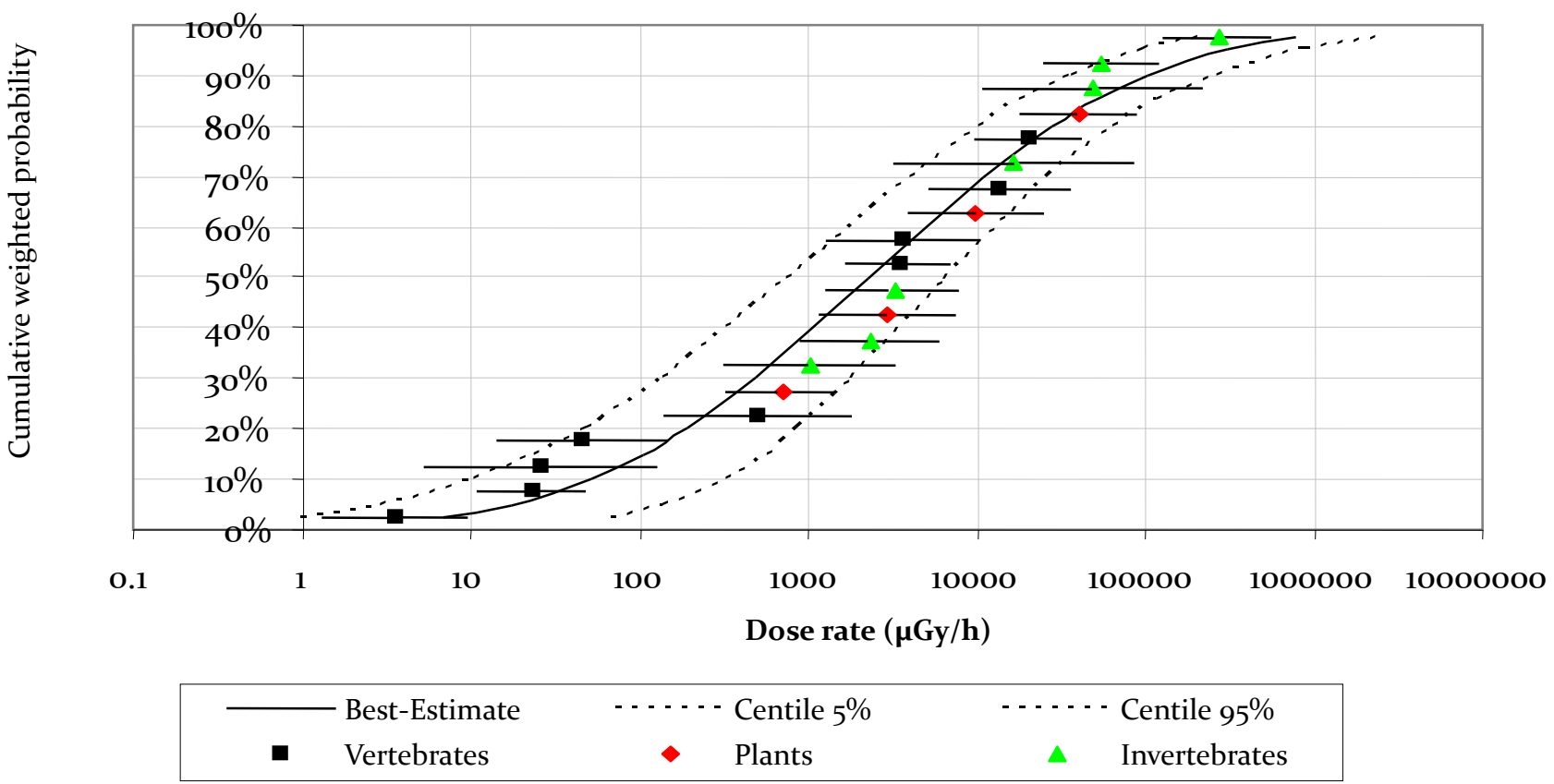
Oregon State University

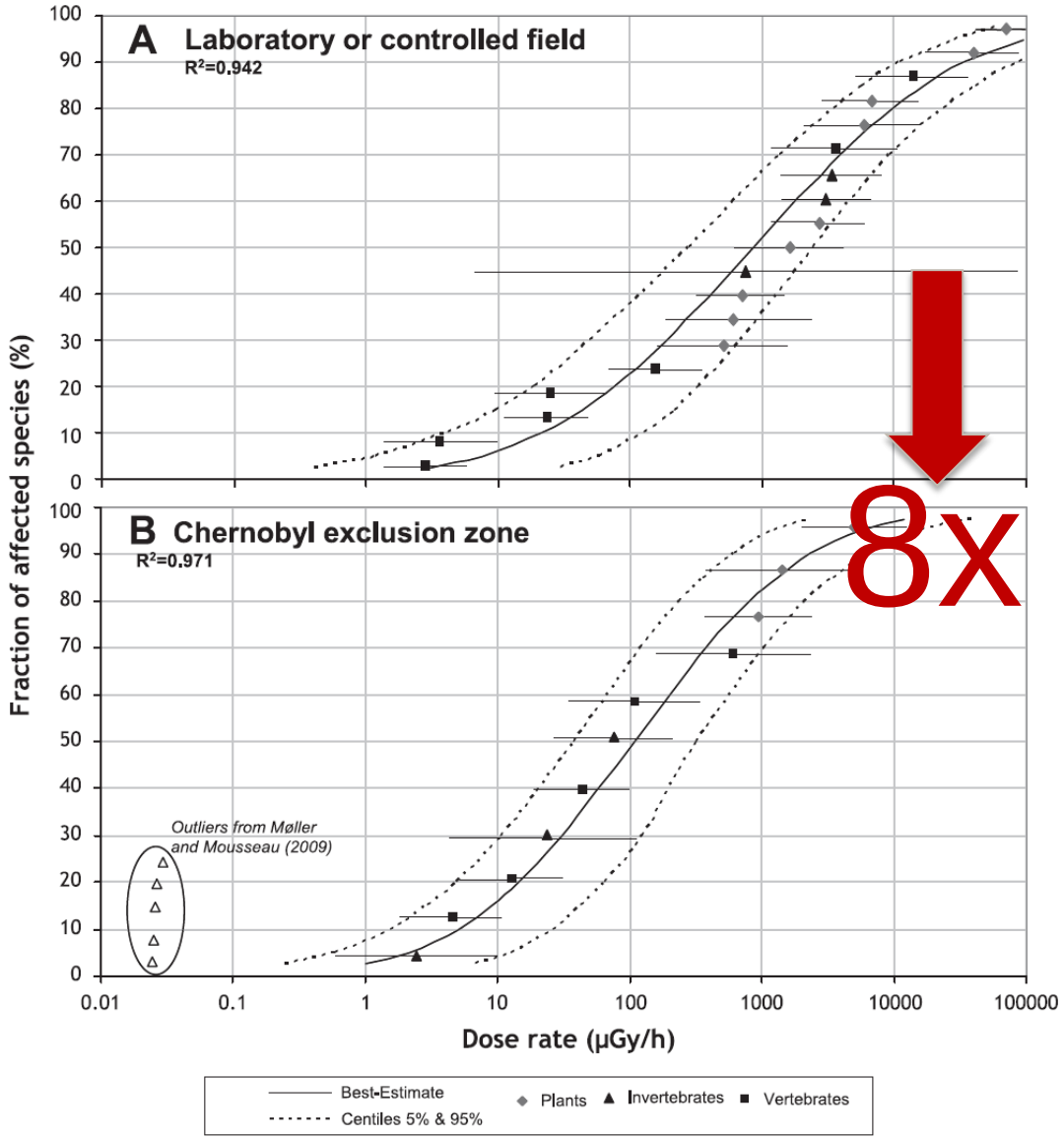


How accurate is our information?

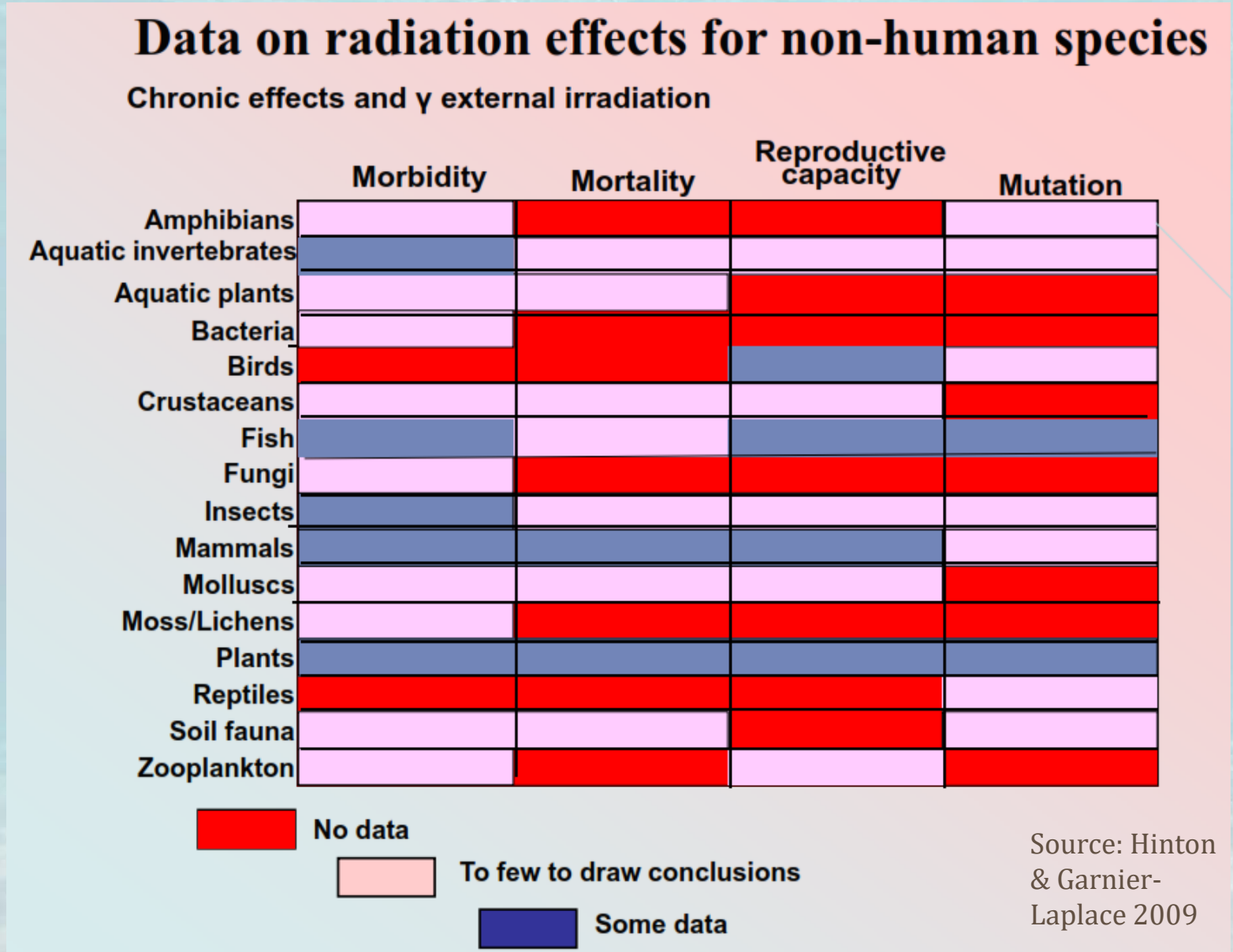
SPECIES RADIOSENSITIVITY

Species Radiosensitivity




A Laboratory or controlled field
R²=0.942
B Chernobyl exclusion zone
R²=0.971
8x
Outliers from Møller and Mousseau (2009)
Fraction of affected species (%)
Dose rate (µGy/h)
0.01
0.1
1
10
100
1000
10000
100000
Best-Estimate
Centiles 5% & 95%
Plants
Invertebrates
Vertebrates

Substanial Data Gaps Remain



Source: Hinton & Garnier-Laplace 2009

Estimation of Fish Dose Rates

"Standard approach"

- Discard gut contents
- Calculate dose based on homogenized ellipsoids

What if absorption (f_1)is small, and most radionuclide content resides in GI tract?

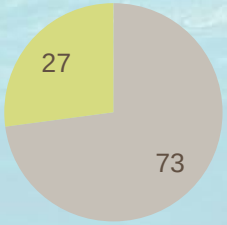
- Especially likely to be true for actinides and/or hot particles.

Mat Johansen
Elizabeth Ruedig
Nick Beresford
MODARIA – Vienna – May 2013

GI tract burden can be substantial-- example data for mullet (*Crenimugil crenilabis*, *Neomyxus chaptalii*)

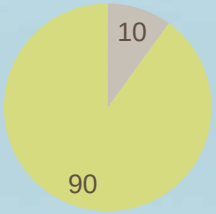
Samples taken16-19 years following ceasing of testing at Pacific Proving Ground (Bikini Atoll)

^{137}Cs in Mullet

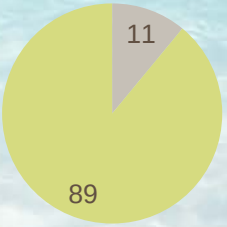


- % in Eviscerated whole
- % in GI tract + contents

^{90}Sr in Mullet



$^{239+240}$ Pu in Mullet



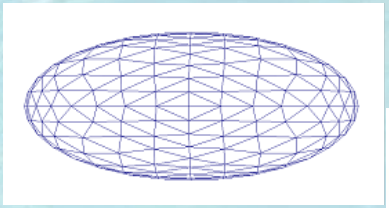
From: Dose Rate variation in Fish due to inclusion/exclusion of radionuclides in Gastrointestinal Tract
Mat Johansen
Elizabeth Ruedig
Nick Beresford

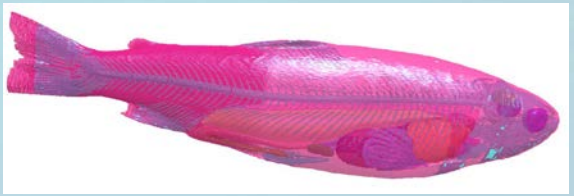
MODARIA – Vienna – May 2013

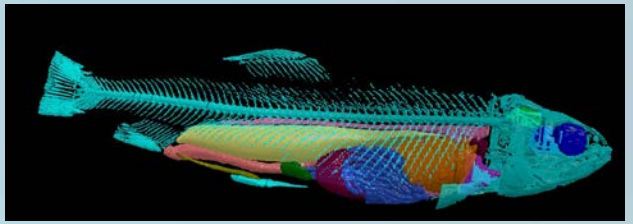
OSU Oregon State University

Dose Modeling: Next Step for Biota: Voxels?

- Current practice
  - 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
- Is the increased accuracy worth the expense?
- Can we obtain the data to run the models?







Tissue Properties Are Also Important

- Elemental Analysis
  - Varies between tissues

Average Organic Elemental Weight Percentages in Honeybee Tissues

	Weight (%) Nitrogen	Weight (%) Carbon	Weight (%) Hydrogen	Weight (%) Oxygen
Venom Sac	11.1±0.2	48.9±0.3	6.6±0.2	33.3±0.4
Intestine	6.2±0.4	49.1±0.6	7.1±0.1	37.6±0.6
Rectum	4.6±0.3	50.8±0.5	7.0±0.1	37.6±0.4
Exoskeleton	7.9±0.7	50.7±0.8	7.4±0.3	33.9±1.1
Crop	0.2±0.1	36.7±0.3	6.9±0.1	56.1±0.4
Leg	11.5±0.2	48.2±0.2	6.4±0.2	33.9±0.4
Muscle	11.8±0.1	48.9±0.2	6.9±0.1	32.4±0.5

ICRU Four Component Soft Tissue

%N	%C	%H	%O
2.6	11.1	10.2	76.2

Oregon State University

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

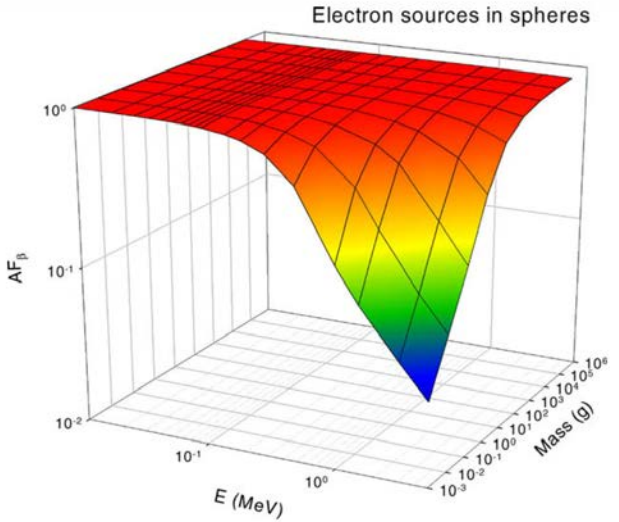


Fig. E.1. Absorbed fractions for electrons in relation to mass and energy for spheres.

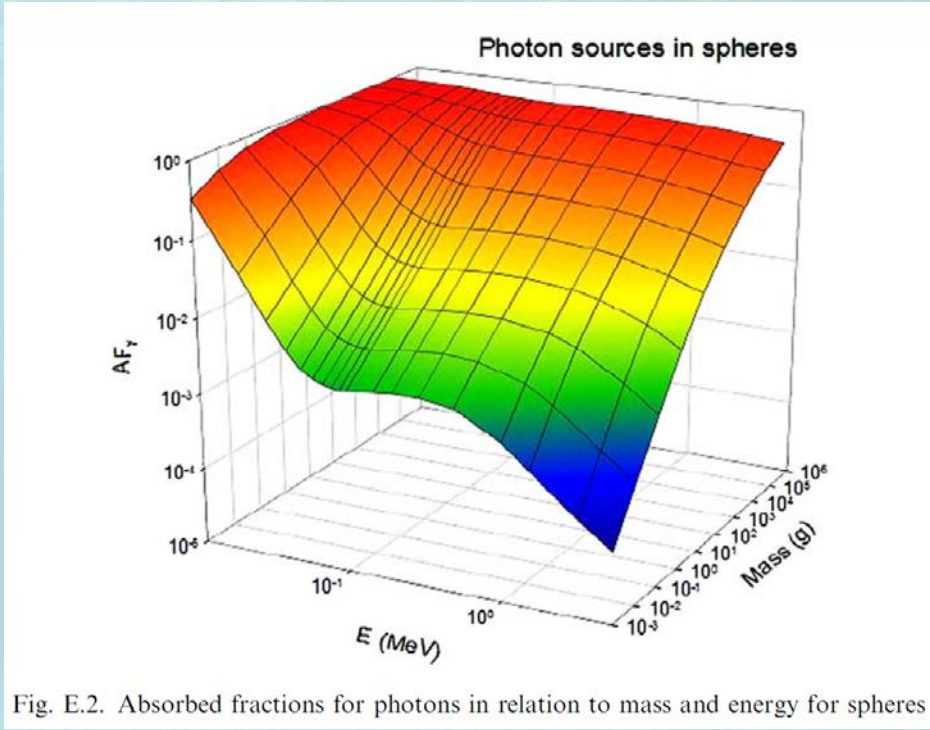
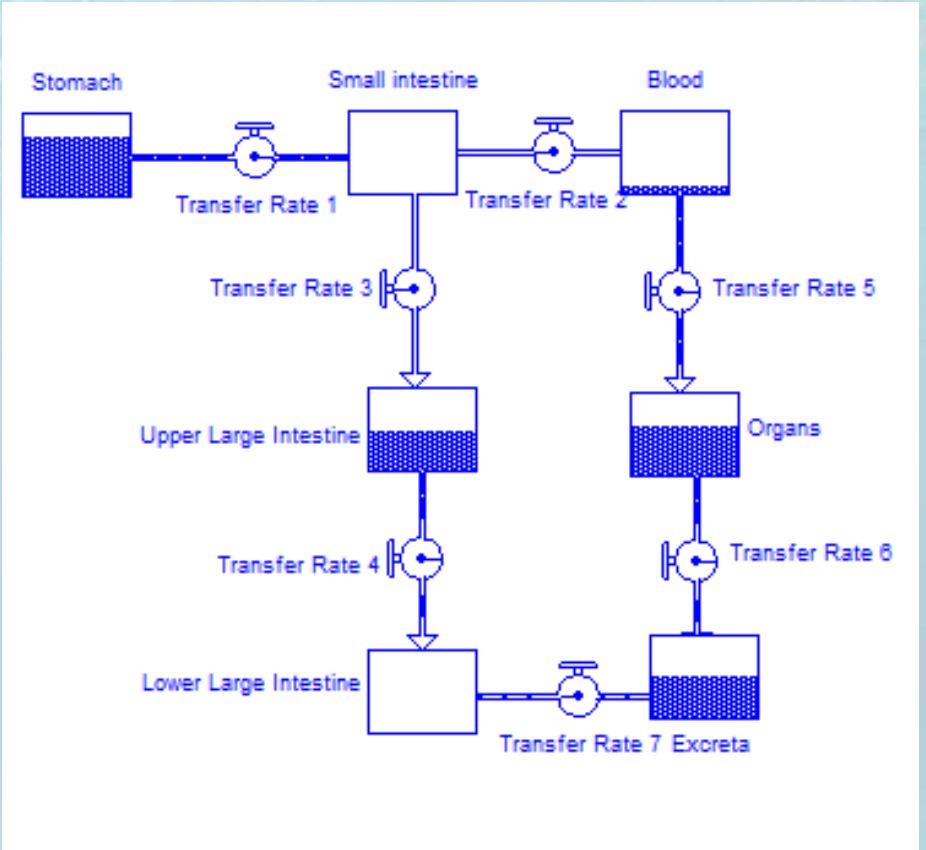


Fig. E.2. Absorbed fractions for photons in relation to mass and energy for spheres

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

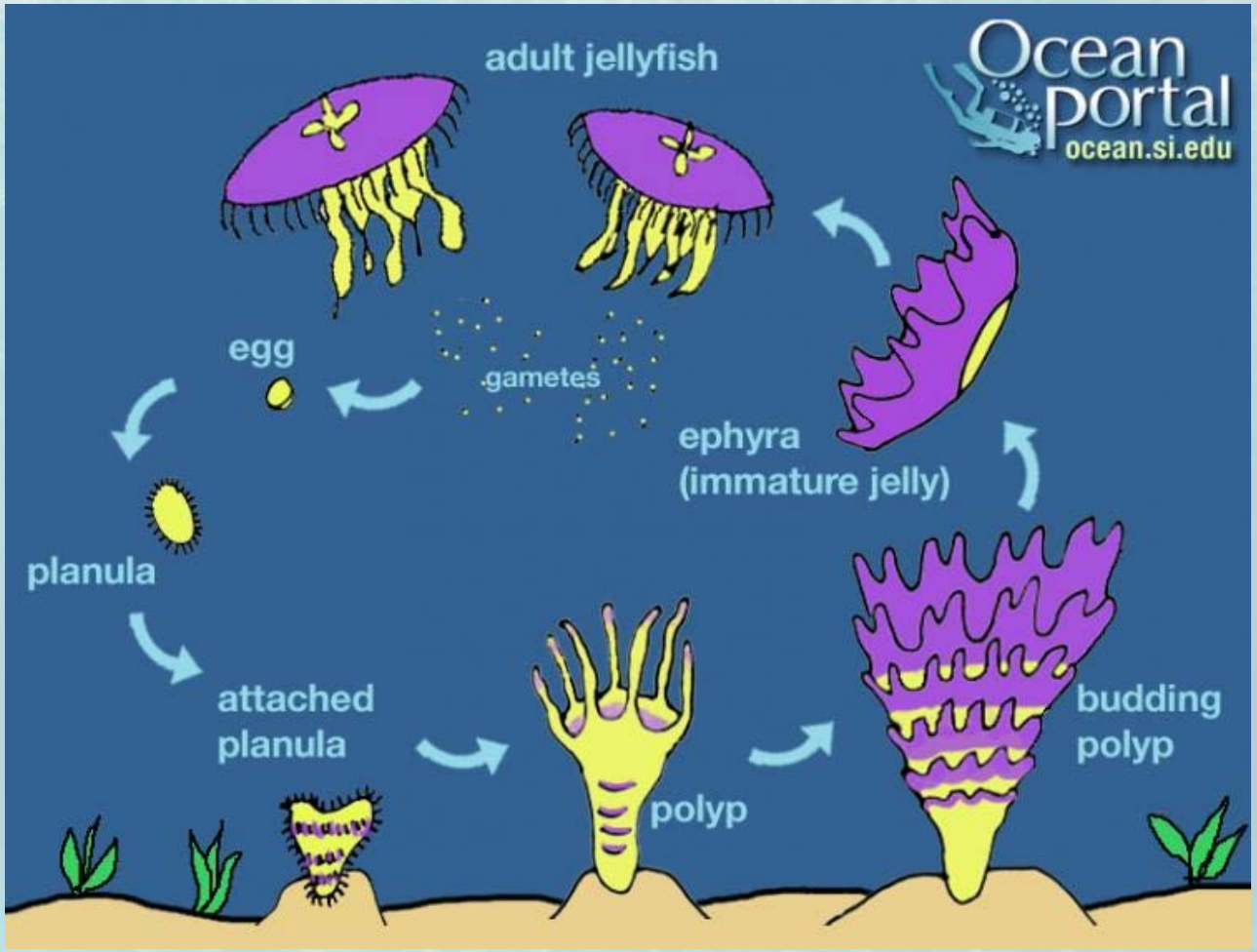
Biokinetics

- Movement of radionuclides through an organisms is dependent on their biology
- Also dependent on diet and environmental conditions



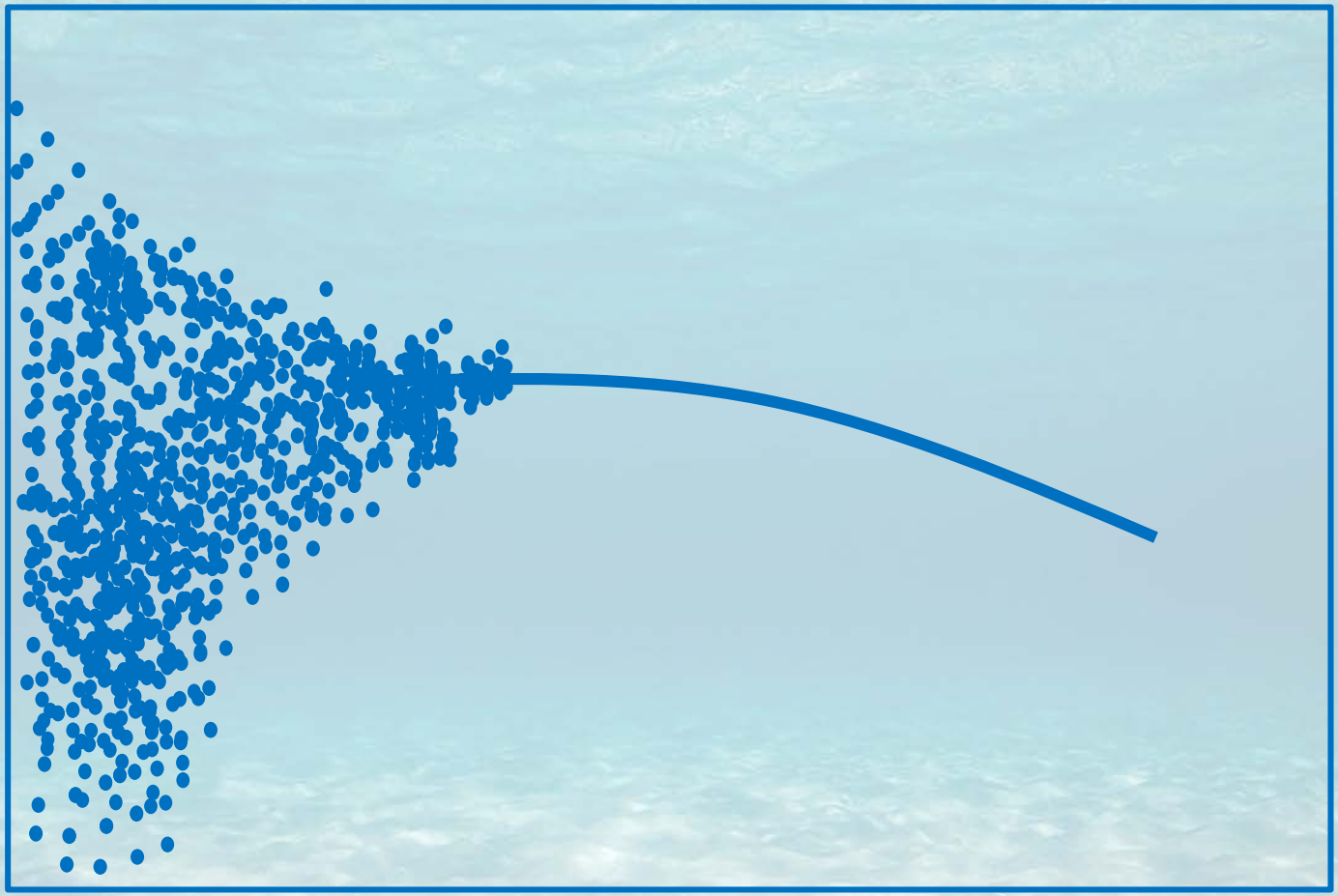
Physiology

- Life stage of biota can greatly change the physiology
- The physiology of some life stages can be challenging to model because of complexity and size

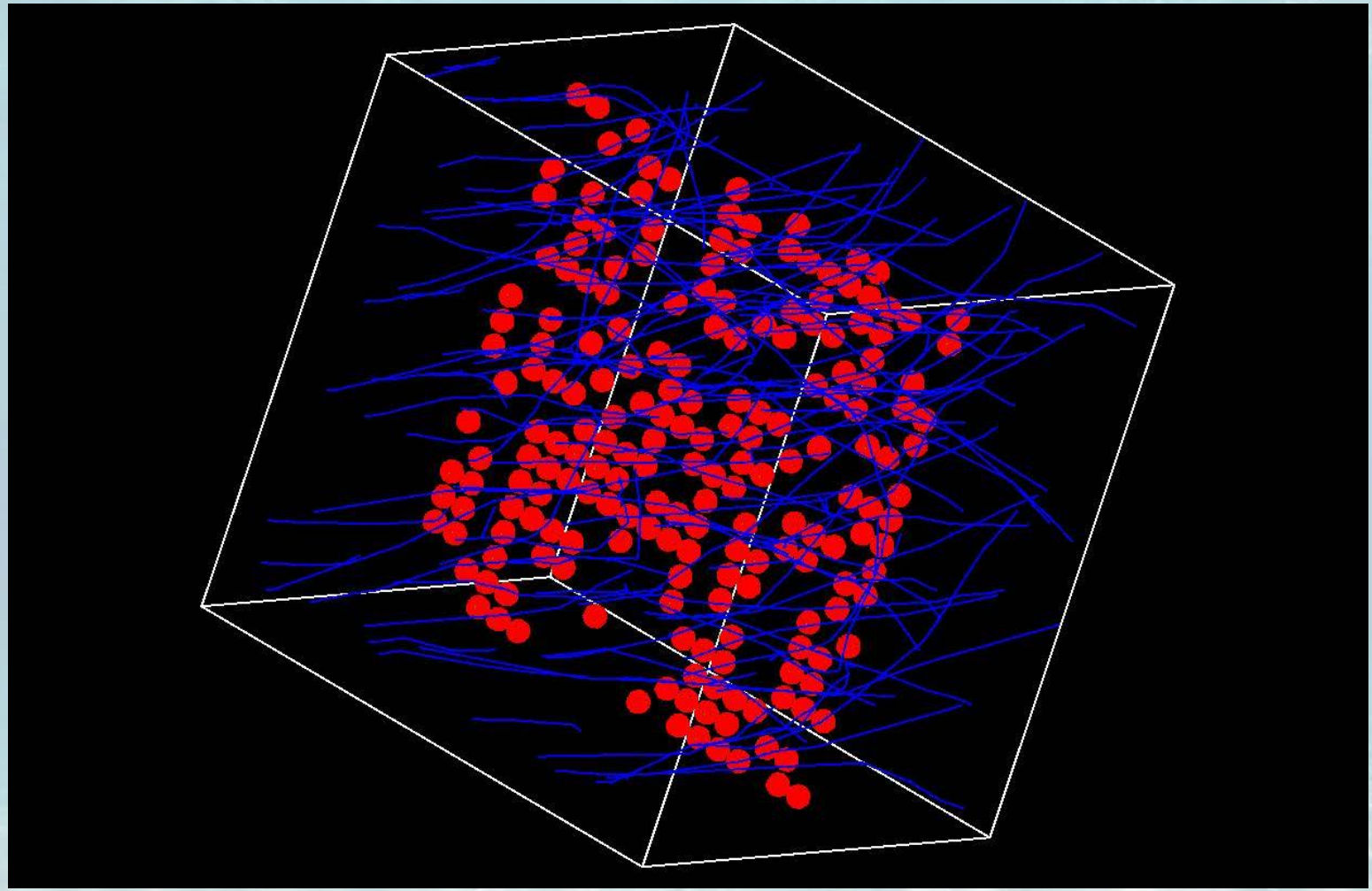


http://ocean.si.edu/ocean-photos/jellyfish-lifecycle-and-reproduction

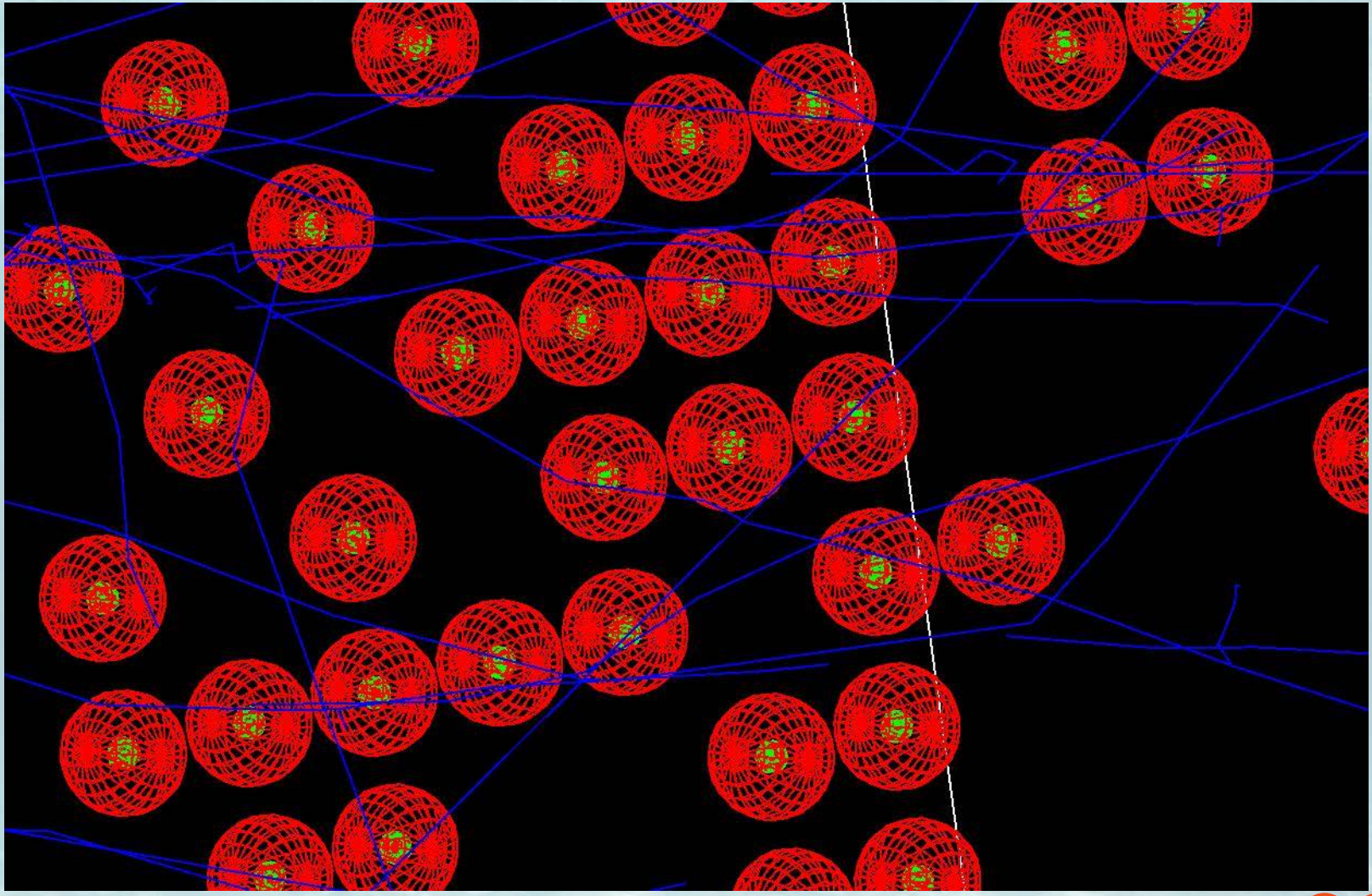
Size Matters in Dose Deposition



Radiation Tracks Through Single Cells



Cell irradiation simulation using Geant4



Averaged dose may not be the appropriate indicator for damage

What does the future hold?

Challenges in Dose Modeling Remain

- We are still gaining knowledge
- International cooperation is essential
- International agencies – ICRP, IAEA, UNSCEAR are important
- Non governmental alliances are even more important
- Universities, research centers conduct the field work – supporting them is important

One last point....

- Despite the uncertainties
- Available data suggest that
  - For properly operating facilities
  - Non human biota are unlikely to be adversely impacted.
  - IF they reside where humans are exposed

- The location of residence is important!

Thank You