Relating radiation dose to effect: The importance of accurate dosimetry in assessing the impact of radioactivity on marine organisms

K. Higley[1], E. Ruedig[2], E. Caffrey[1], M Gomez-Fernandez[1], M. Comolli[1], D. Neville[1]

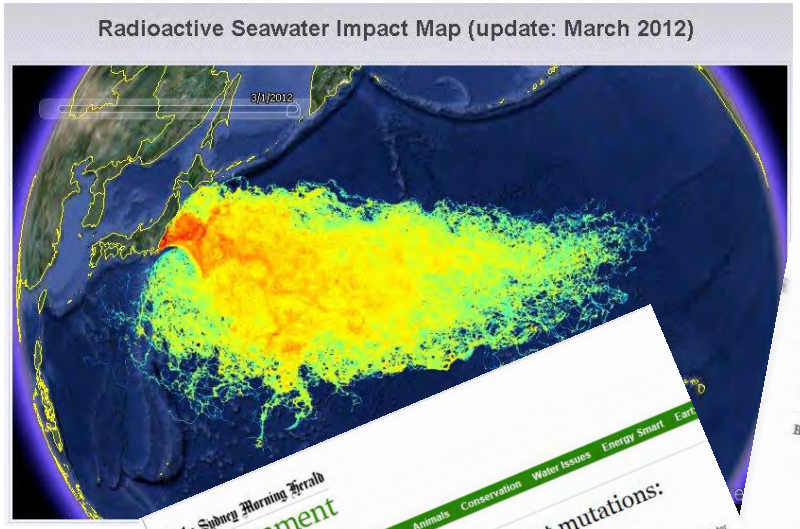
[1]Oregon State University, Dept.of Nuclear Engineering and Radiation Health Physics;
[2]Colorado State University, Environmental and Radiological Health Sciences

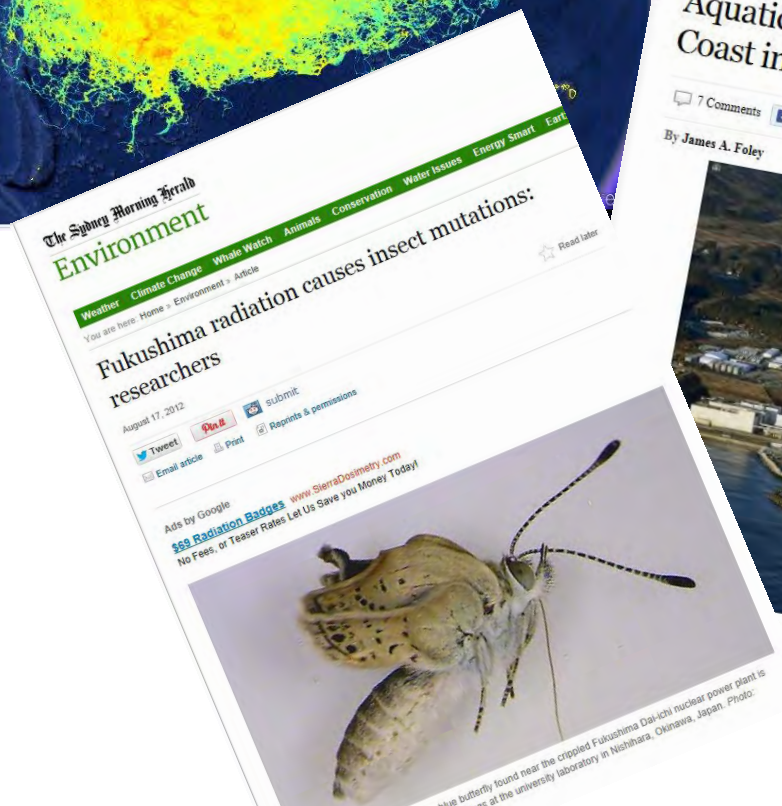
PICES 2013 Annual Meeting: 11-20 October Nanaimo, Canada

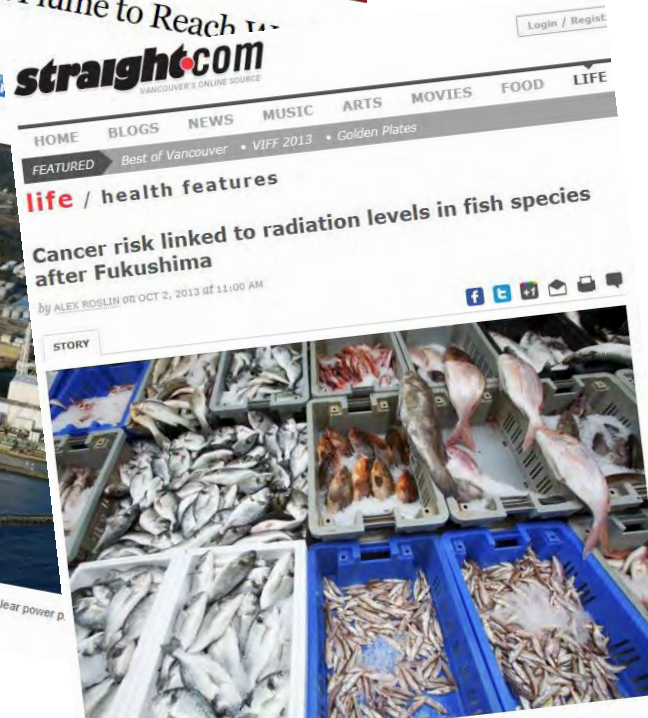
Radiation Dose and Effect - Overview

- Considerable interest in assessing impact of radionuclides released to marine environment
- What is the process?
- Are their any substantive scientific issues?

Relating *releases* → dose → effect



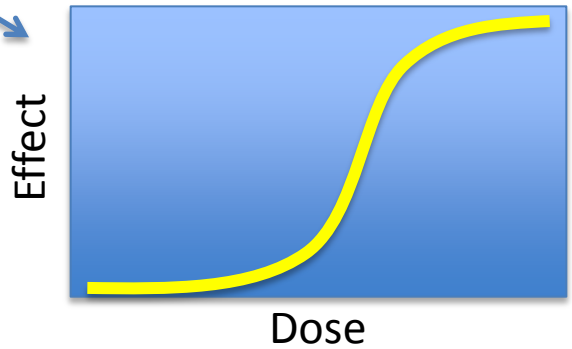




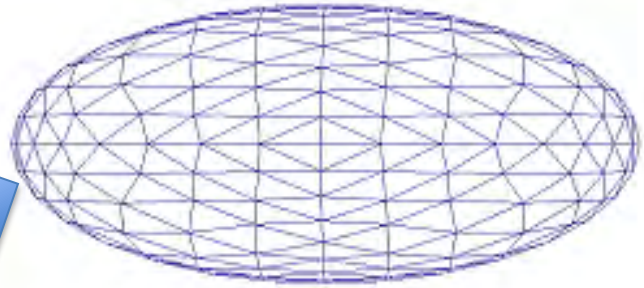
Relating ***releases*** → dose → effect

Current Approach to Dose & Risk Assessment:

- Sample
- Simplify
- Measure
- Calculate
- Assess

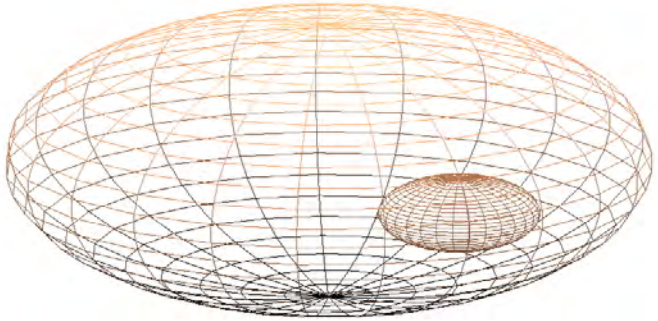


How We Currently Calculate Biota Dose



per ICRP, USDOE, EU…

or

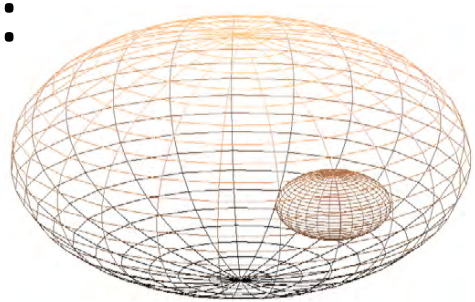


Organisms are spheroid-*ish* shape,…..
maybe with a spheroid-*ish* internal organ(s)

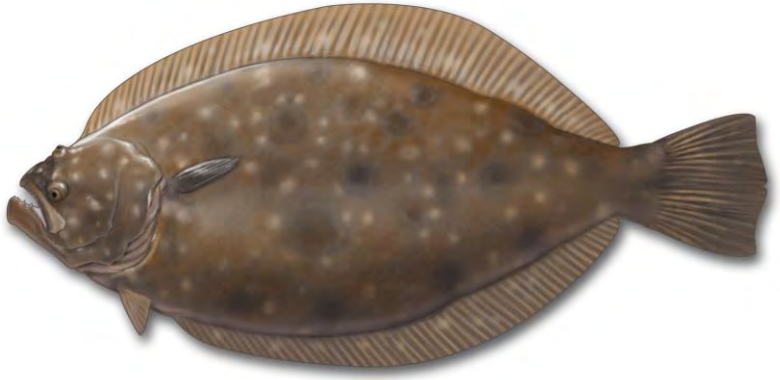
- Radionuclides distributed homogeneously
- No radionuclides in gut or gills
- Tissue composition and density is uniform

Dose Calculations, continued

So this:



=



=

And this

=

Or this

When determining dose

The Problem: Dose depends on: Radiation type, energy, organism size, source location, density, Z,…

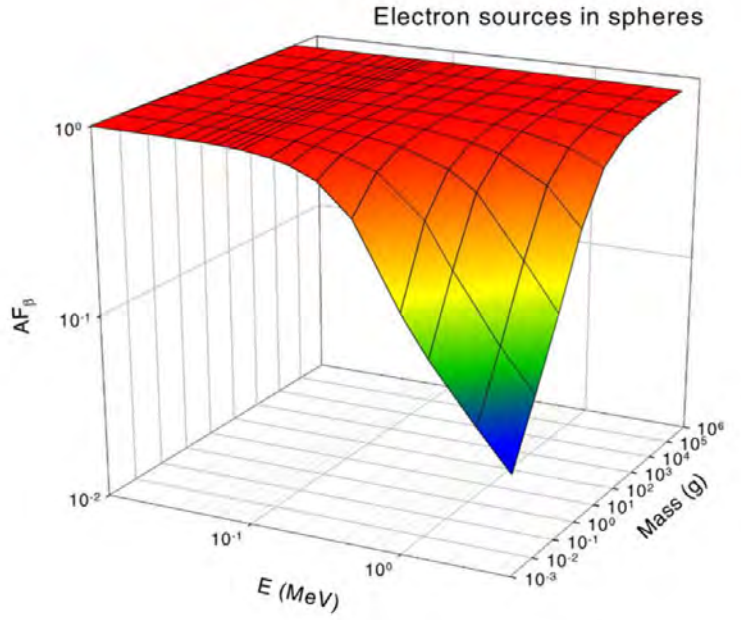


Fig. E.1. Absorbed fractions for electrons in relation to mass and energy for spheres.

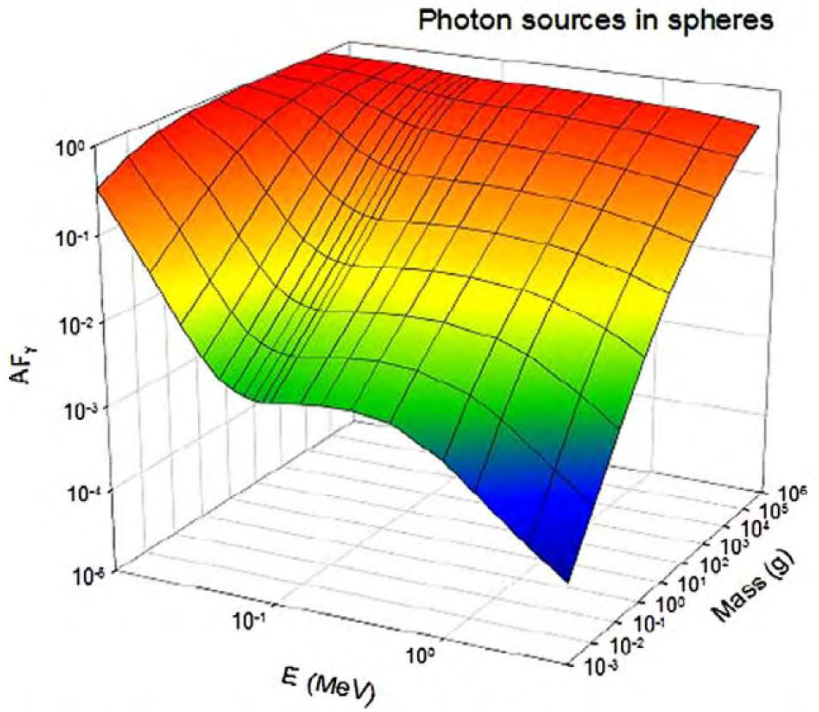
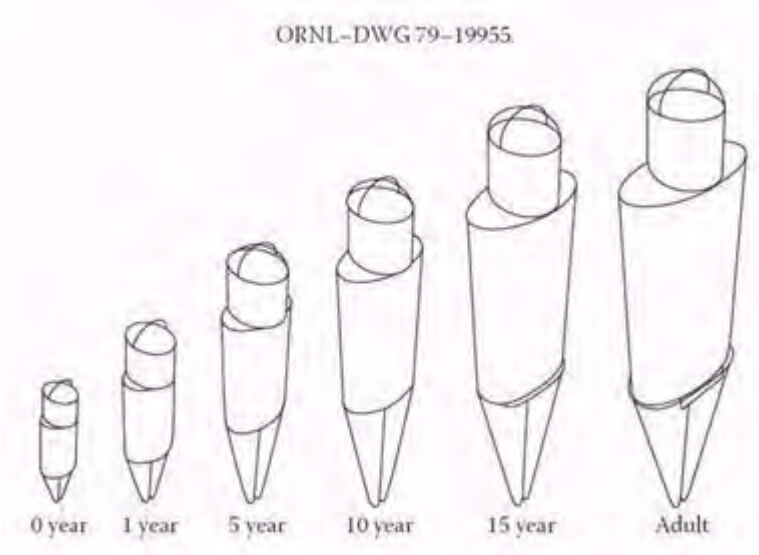


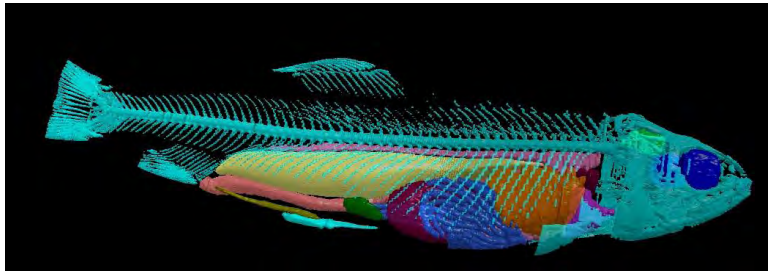
Fig. E.2. Absorbed fractions for photons in relation to mass and energy for spheres.

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

Alternate Approach to Dose Determination: Voxel Phantoms

- Similar to human dose modeling
- Accurate anatomical depiction of internal structures
- Developed from CT and MRI images
- Allows detailed analysis of radiation interactions





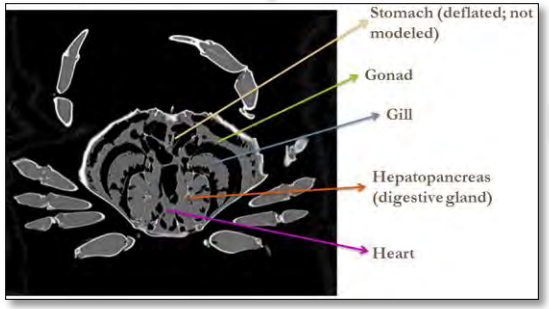
Procedure for Creation of Phantoms

- Image organism post mortem
- Identify and segment organs/ structures on scan (3D Doctor[1])
- Run Voxelizer[1] to obtain organism geometry
- Add materials, source, and tally to Voxelizer file
- Run MCNP[1] to obtain energy deposition in each organ for each source/target pair, at each energy and for each particle type
- Calculate dose conversion factors (DCF's) for specific radionuclides

[1]Commercial or other software

Image

Structure ID



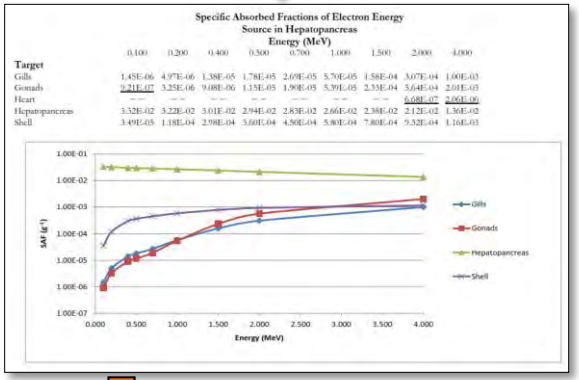
Voxel Model Rendering – 3D Doctor

Voxelizer Lattice

Voxelizer created MCNP file

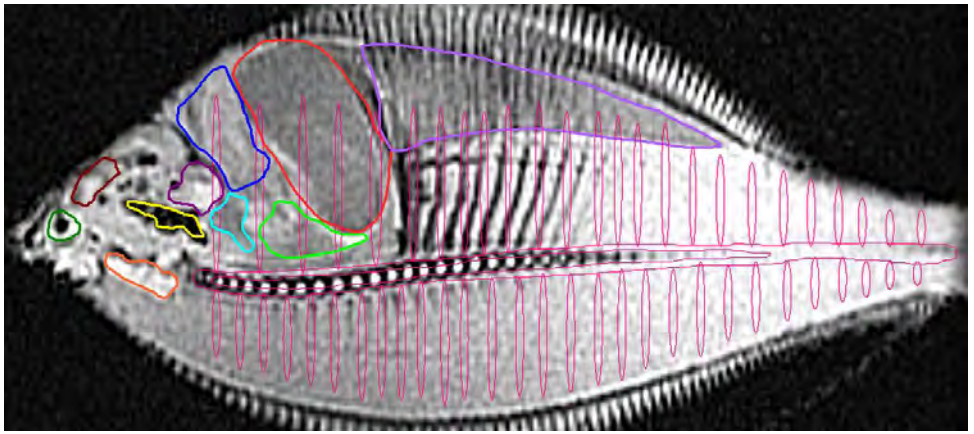
```
c +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
c
c    Cells
c
c +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
c
   999  0 999                        imp:p 0 imp:e 0       $ outside
   998  7   -.1205E-02  -999  100    imp:p 1 imp:e 1       $ air
c
c Filling Universes
    1     1  -1.04     -200  u = 1     imp:p 1 imp:e 1  $ Gonads
   10     0              200  u = 1     imp:p 0 imp:e 0
    2     2  -1.00     -200  u = 2     imp:p 1 imp:e 1  $ Gills
   20     0              200  u = 2     imp:p 0 imp:e 0
    3     3  -1.00     -200  u = 3     imp:p 1 imp:e 1  $ Digestive Glands
   30     0              200  u = 3     imp:p 0 imp:e 0
    4     4  -1.04     -200  u = 4     imp:p 1 imp:e 1  $ Heart
   40     0              200  u = 4     imp:p 0 imp:e 0
    5     5  -1.04     -200  u = 5     imp:p 1 imp:e 1  $ ShellHollow
   50     0              200  u = 5     imp:p 0 imp:e 0
    6     6  -1.025    -200  u = 6     imp:p 1 imp:e 1  $ SurroundingSaltWater
   60     0              200  u = 6     imp:p 0 imp:e 0
c
c Lattice Unit Cell
c
    996    0   -13     lat = 1 u = 996 imp:p 1 imp:e 1
                       fill = 0:127  0:127 0:61
   6 7233r 5 6 125r 5 1r 6 125r 5 2r 6 124r 5 2r 6 124r 5 1r 6
   125r 5 1r 6 124r 5 2r 6 124r 5 3r 6 123r 5 3r 6 123r 5 3r 6
   124r 5 1r 6 15101r 5 6 125r 5 2r 6 124r 5 3r 6 123r 5 4r 6 121r 5
   5r 6 121r 5 5r 6 121r 5 5r 6 121r 5 5r 6 121r 5 5r 6 121r 5
   5r 6 122r 5 3r 6 123r 5 2r 6 14845r 5 2r 6 122r 5 5r 6 120r 5
   7r 6 118r 5 9r 6 117r 5 13r 6 108r 5 20r 6 106r 5 20r 6 106r 5
   20r 6 106r 5 19r 6 108r 5 17r 6 110r 5 16r 6 110r 5 15r 6 112r 5
   14r 6 116r 5 9r 6 118r 5 4r 6 122r 5 3r 6 125r 5 6 14077r 5
```

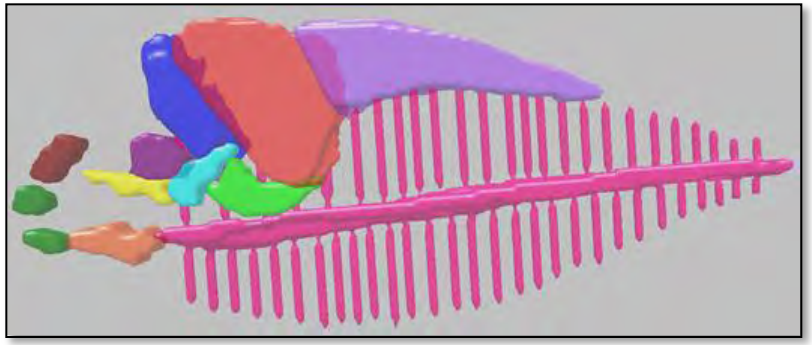
MCNP results

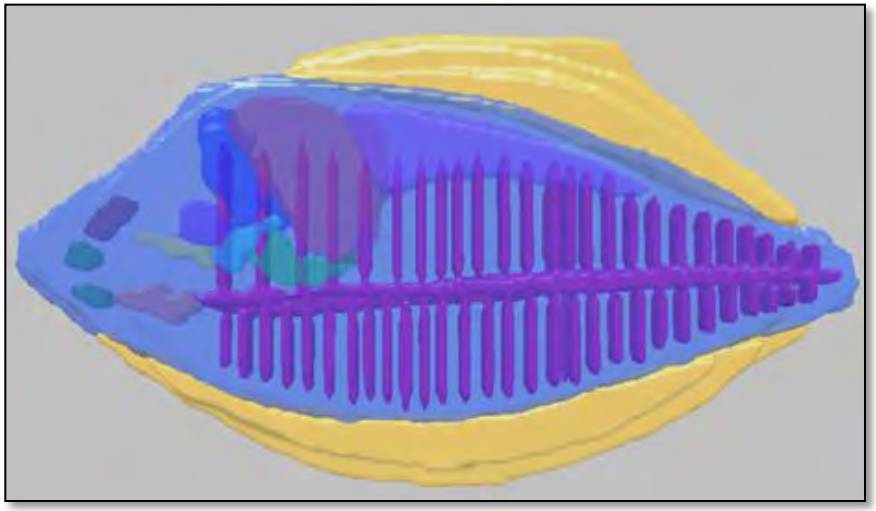


Radionuclides → **DOSE/DCF**

Limanda Limanda (Sand Dab)



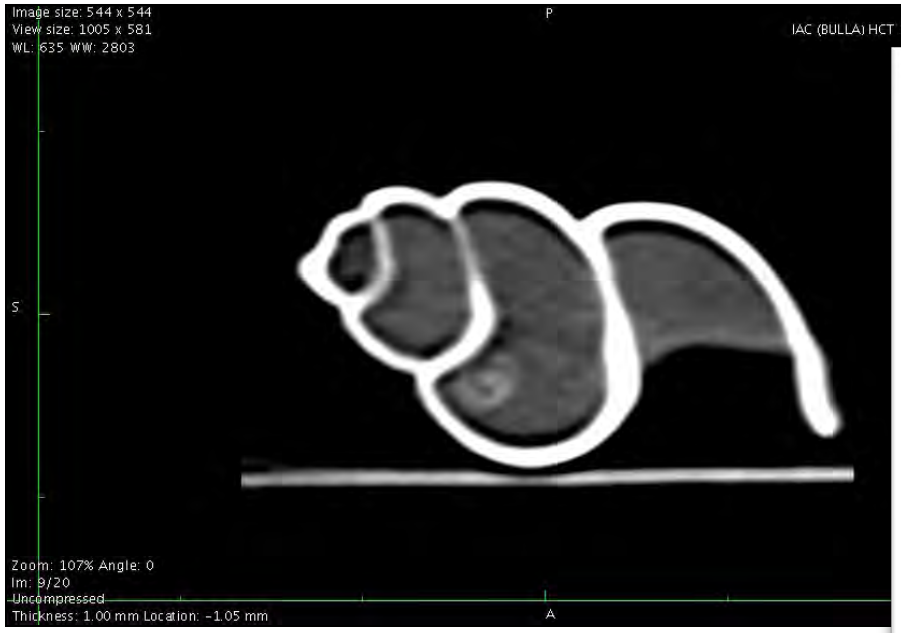


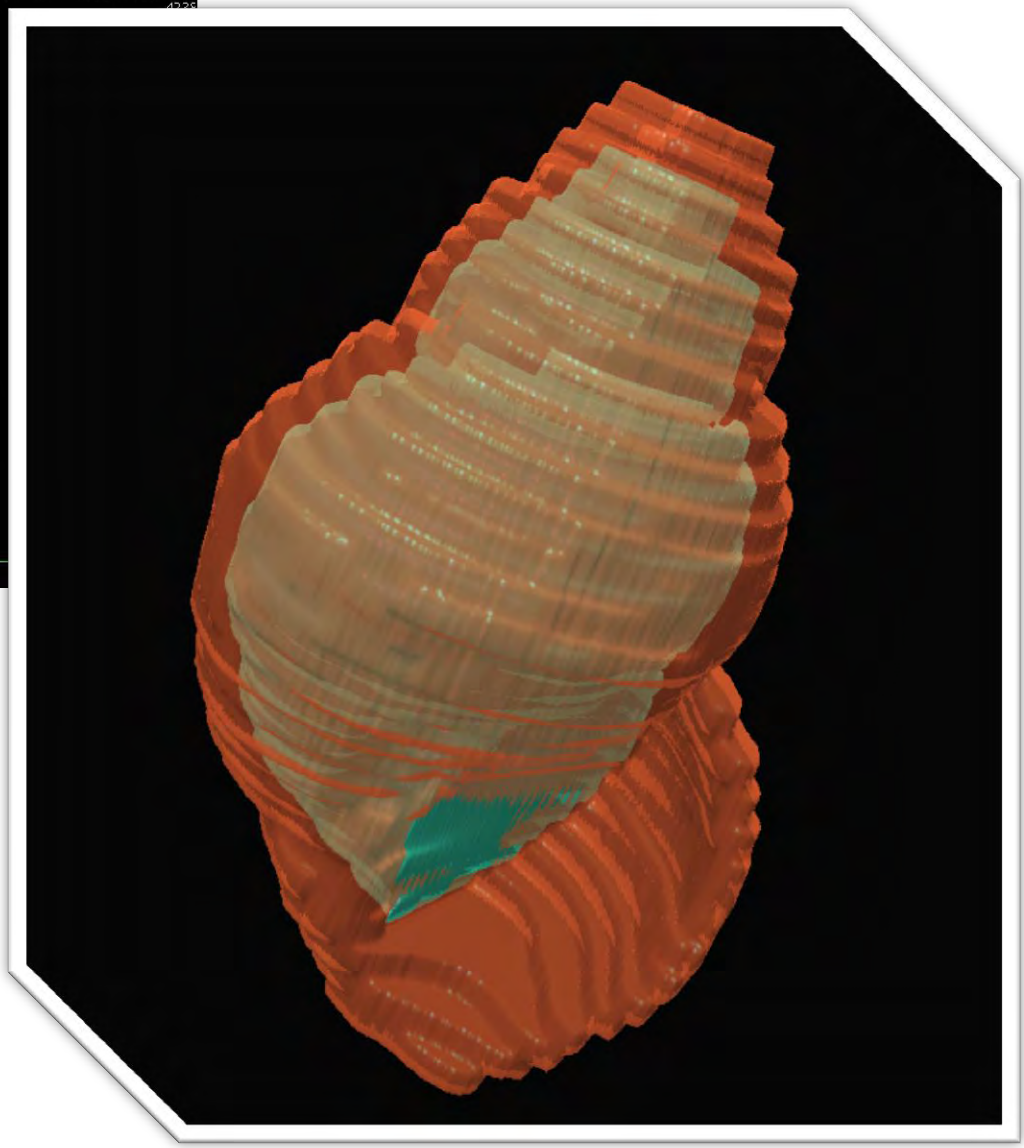


Source: Photo courtesy of Andrew Marriott, published on MLIN website

Flatfish model shown with muscle tissue and fins (above) and without (left)

Snail Model

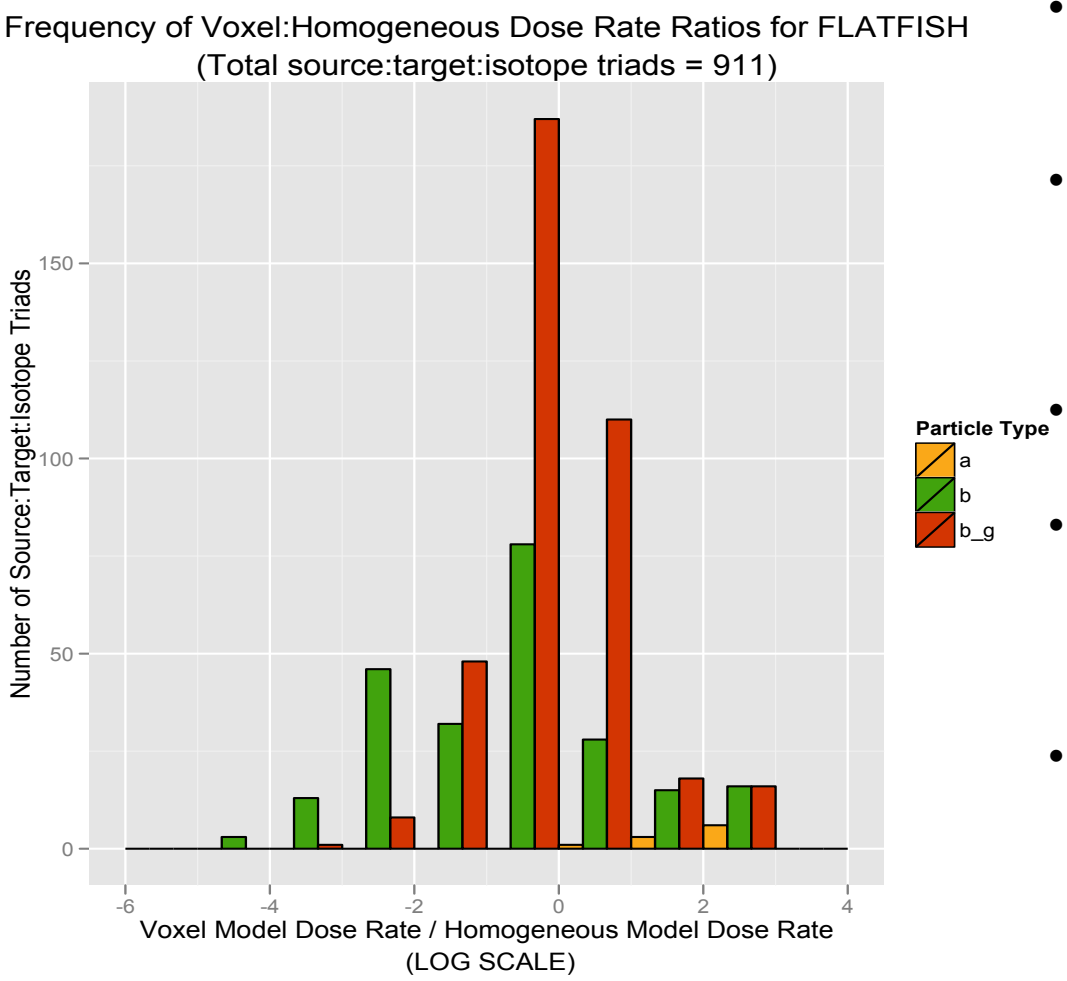




Above: CT image of snail

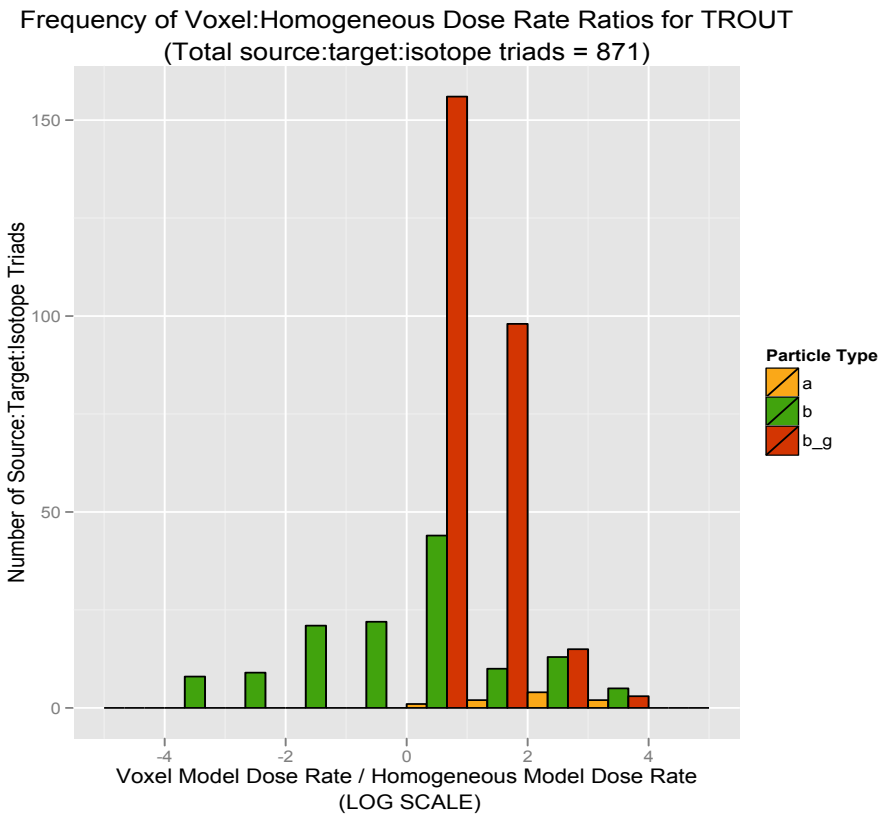
Right: 3D Doctor rendering of snail model

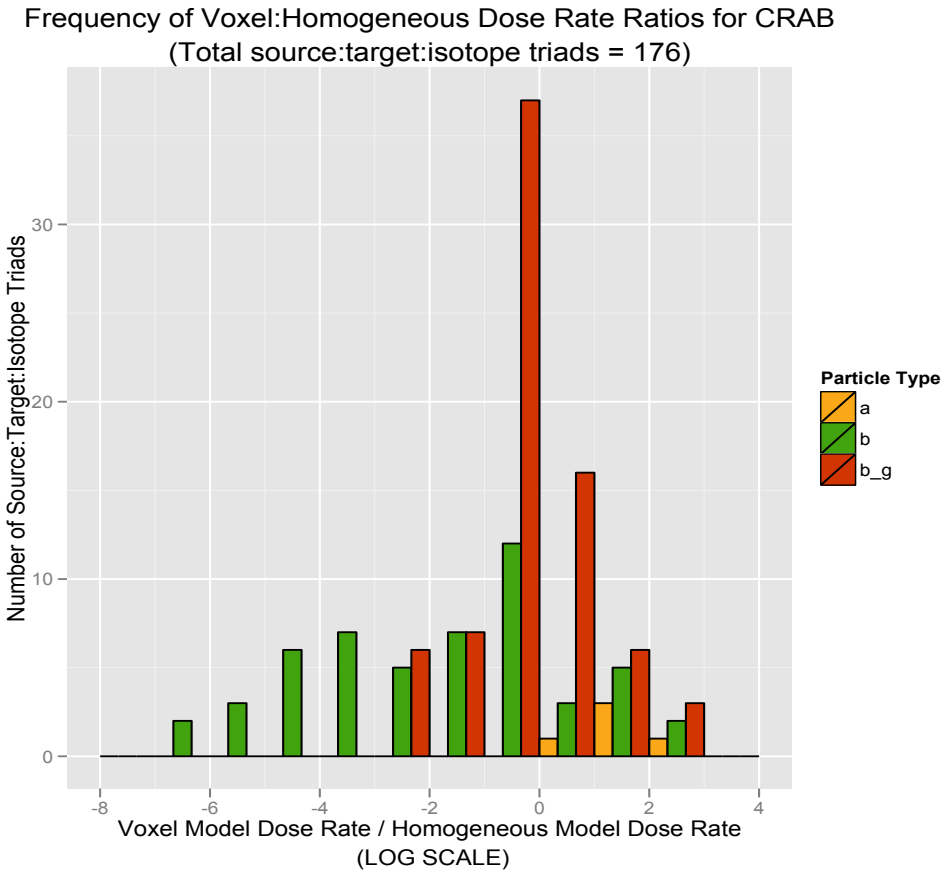
Voxel : Simplified Model Comparison for Flatfish



- Dose rates from multiple internally deposited radionuclides (e.g., Sr-90, Cl-36, Co-60)
- Compared homogeneous to highly partitioned (e.g. organ specific) distributions
- Value of 0 = no difference
- Value > 0 means voxel model predicted higher dose *& current model underestimates dose*
- Value < 0 means simple model *overestimates dose*

Other Organisms





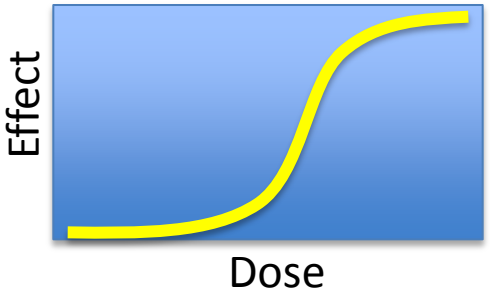
- *If radionuclide is partitioned*
- Current approach often overestimates dose from pure beta emitters
- Underestimates dose from alpha and gamma emitters

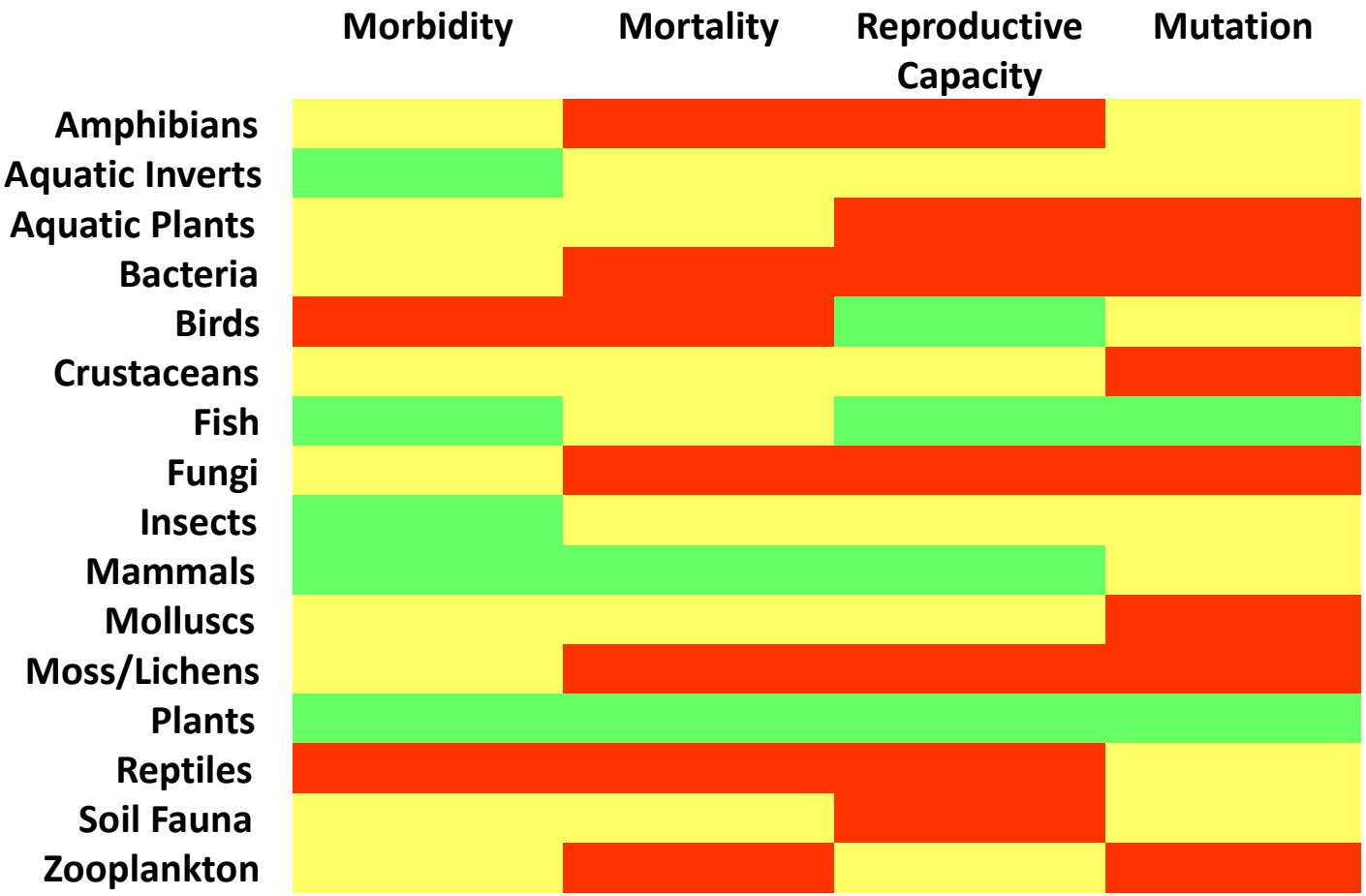
Why Consider Voxel Models?

- Labor intensive
- Require more data than currently available
- Are homogeneous models good enough?

Relating ***releases*** → dose → effect

Radiation Effects Data: Chronic External Gamma Information





Some data

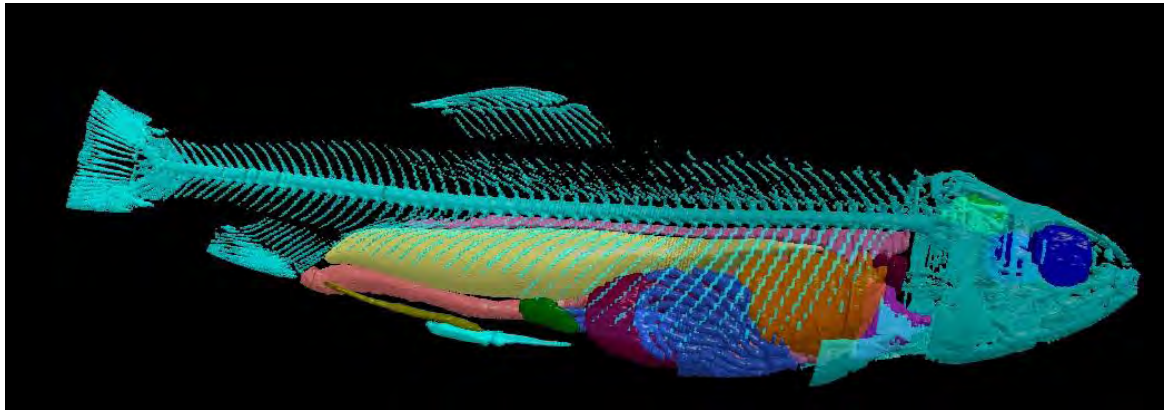
Too few for conclusions

No Data

Source: Hinton & Garnier-Laplace 2009

Recent Trout Model

- How significant is dose to the GI system from ingested radionuclides?
- Is turnover in the GI so rapid that highly localized radionuclide concentrations can be ignored?



Simple models can't address this question

Conclusions from Comparison

- Considerable difference in doses calculated by simplified and voxelized mathematical models
  - Up to factor of 10,000
- Size matters
  - Smaller organisms exhibit more deviation
- Organ partitioning of radionuclides important
  - Limited data available
  - Transit through gut potentially important
- *Limits our ability to relate dose & effect*

Conclusion

- Accurate dosimetry is crucial in relating impacts of ionizing radiation to the dose received.
- Voxel models offer a more robust method for calculating dose.