

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

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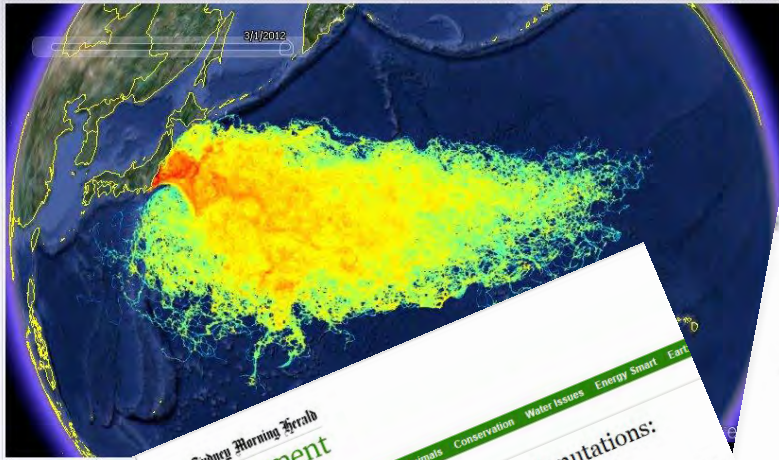
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Radiation Dose and Effect - Overview

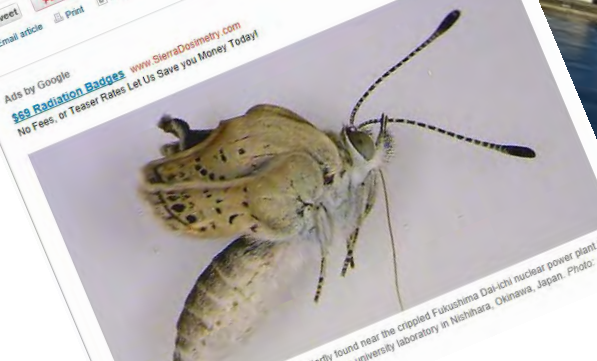
- Considerable interest in assessing impact of radionuclides released to marine environment
- What is the process?
- Are there any substantive scientific issues?

Relating *releases* → dose → effect

Radioactive Seawater Impact Map (update: March 2012)



The Sydney Morning Herald
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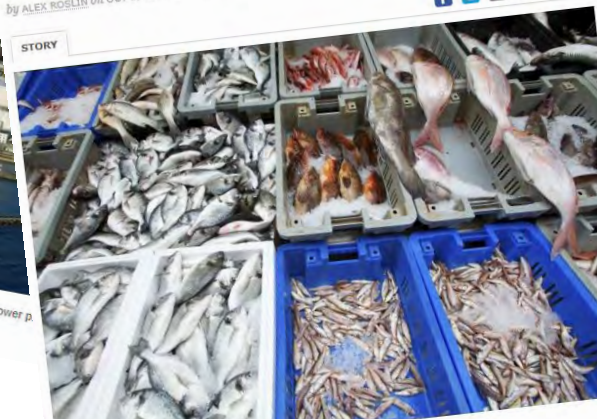
Aquatic Fukushima Radiation Plume to Reach U.S. Coast in 2014



TEPCO's (TEPCO) Tsunami-crippled Fukushima Daiichi nuclear power plant is seen from the air on March 11, 2013. (Photo : Reuters)

Cancer risk linked to radiation levels in fish species after Fukushima

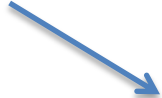
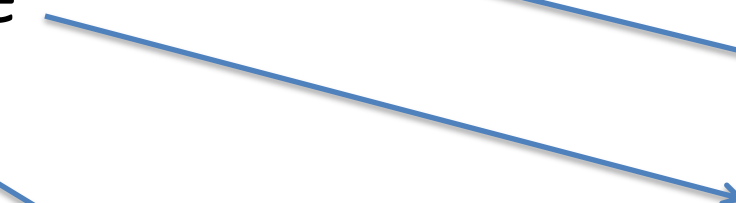
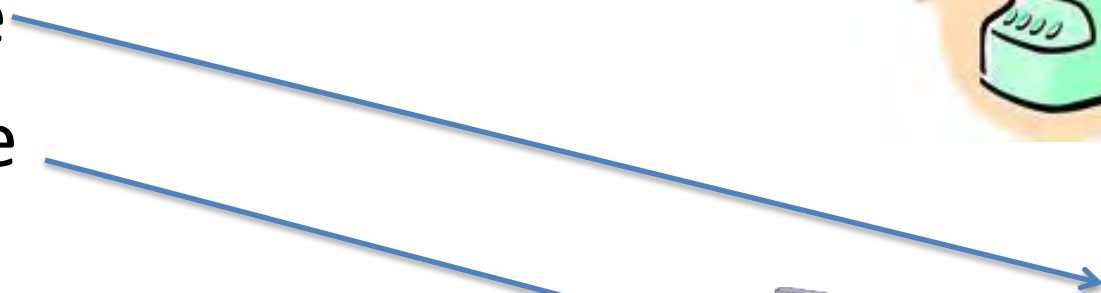
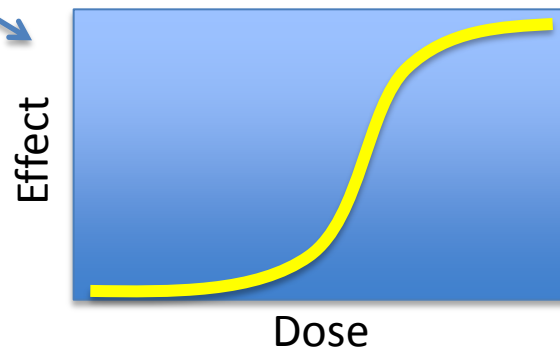
by ALEX ROSLIN ON OCT 2, 2013 at 11:00 AM



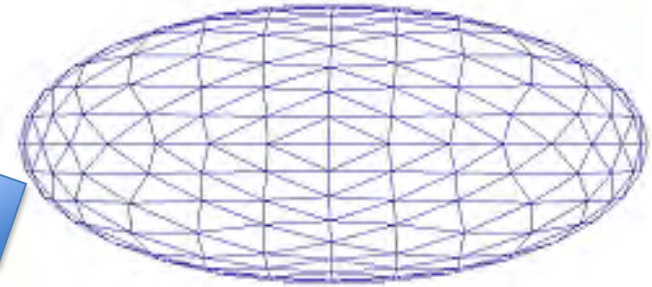
Relating *releases* → dose → effect

Current Approach to Dose & Risk Assessment:

- Sample
- Simplify
- Measure
- Calculate
- Assess

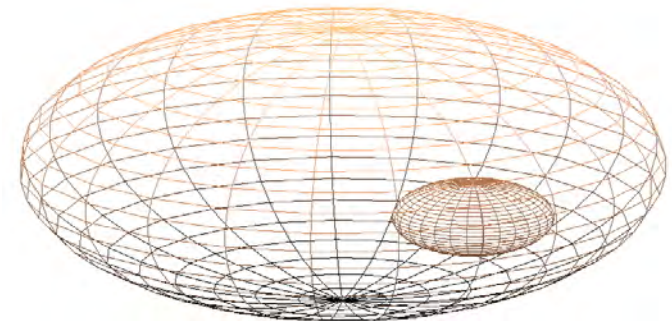


How We Currently Calculate Biota Dose



or

per ICRP, USDOE, EU...



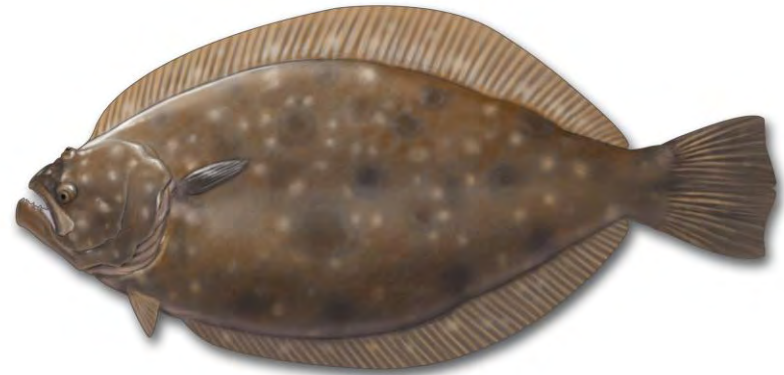
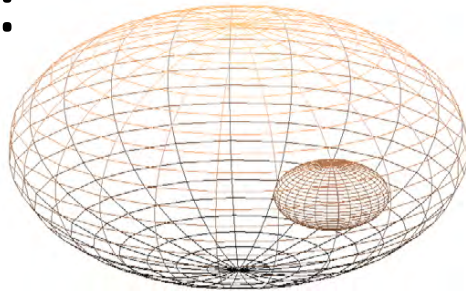
Organisms are spheroid-*ish* shape,.....

maybe with a spheroid-*ish* internal organ(s)

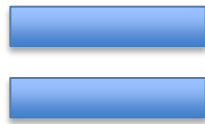
- Radionuclides distributed homogeneously
- No radionuclides in gut or gills
- Tissue composition and density is uniform

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,...

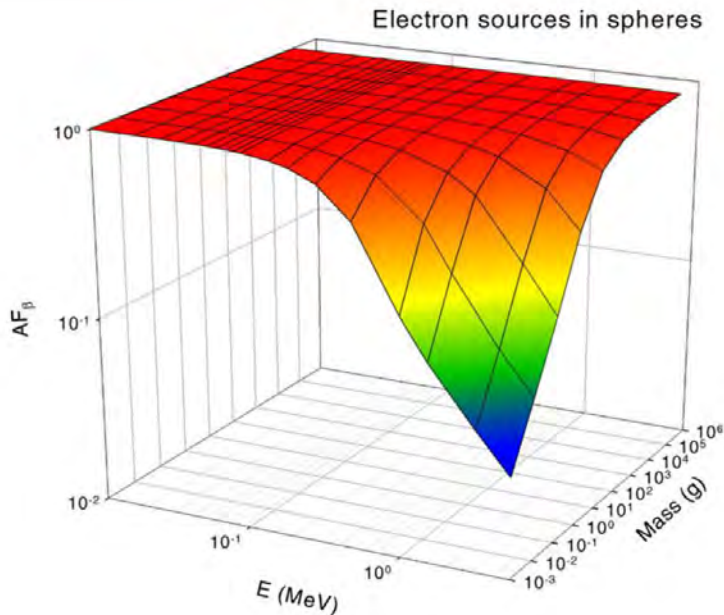


Fig. E.1. Absorbed fractions for electrons in relation to mass and energy for spheres.

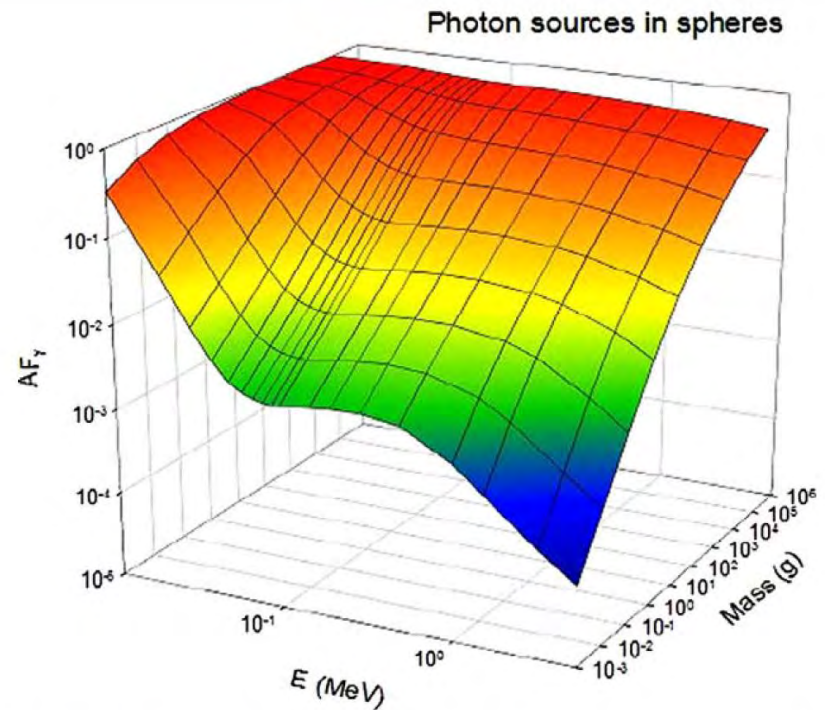
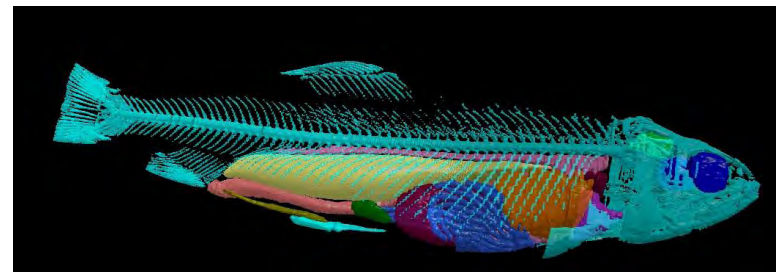
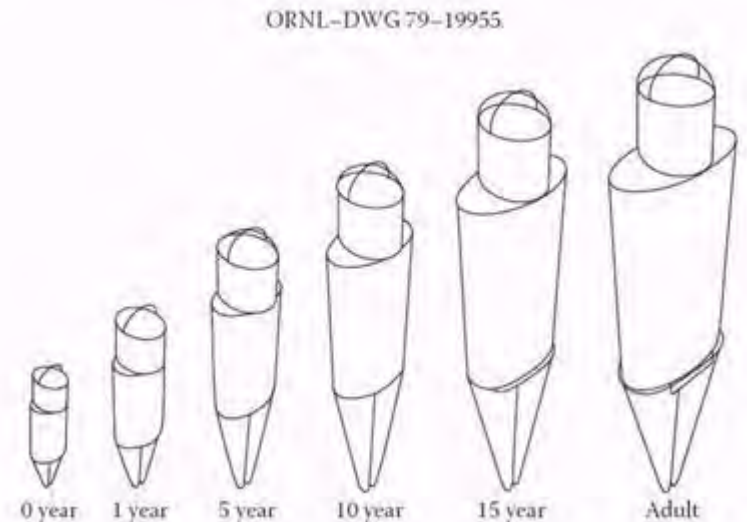


Fig. E.2. Absorbed fractions for photons in relation to mass and energy for spheres.

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 Doctor¹)
- Run Voxelizer¹ to obtain organism geometry
- Add materials, source, and tally to Voxelizer file
- Run MCNP¹ 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

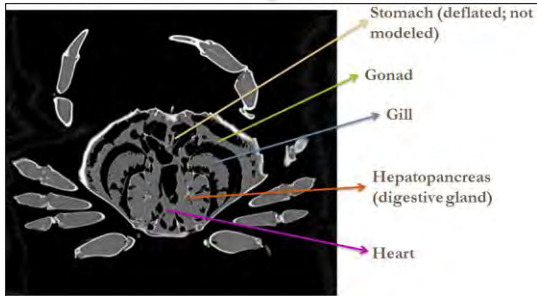
¹Commercial or other software



Image



Structure ID



Voxelizer Lattice

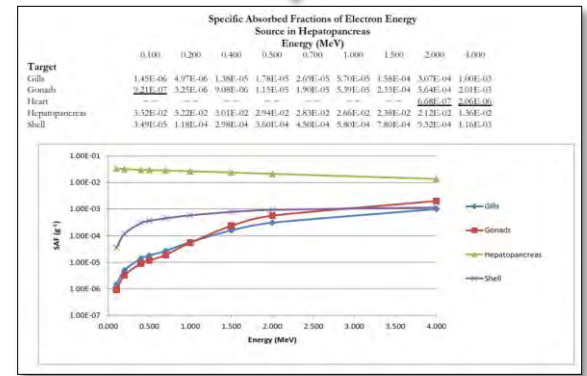


Voxelizer created MCNP file

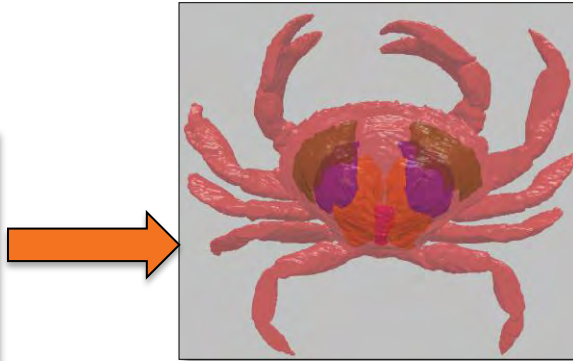
```

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



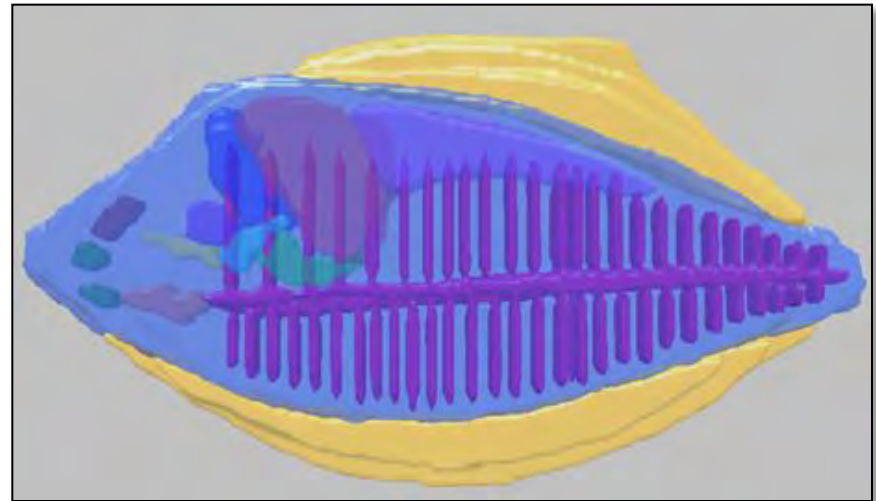
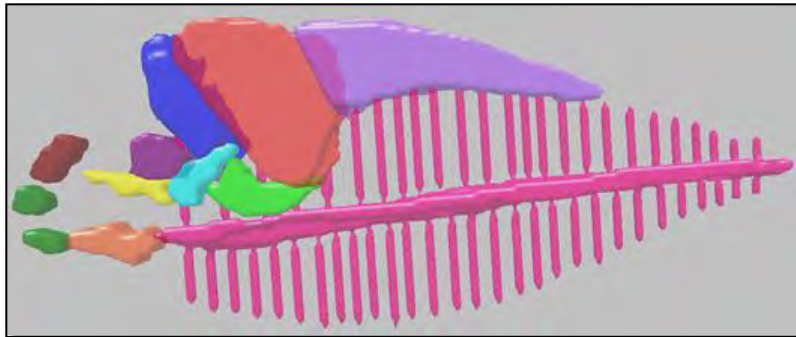
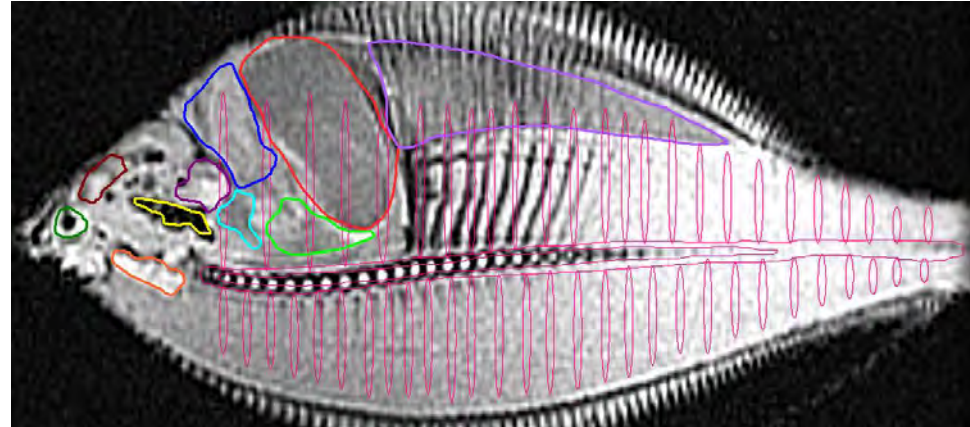
Voxel Model Rendering – 3D Doctor



Radionuclides

DOSE/DCF

Limanda Limanda (Sand Dab)



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

November 5, 2013

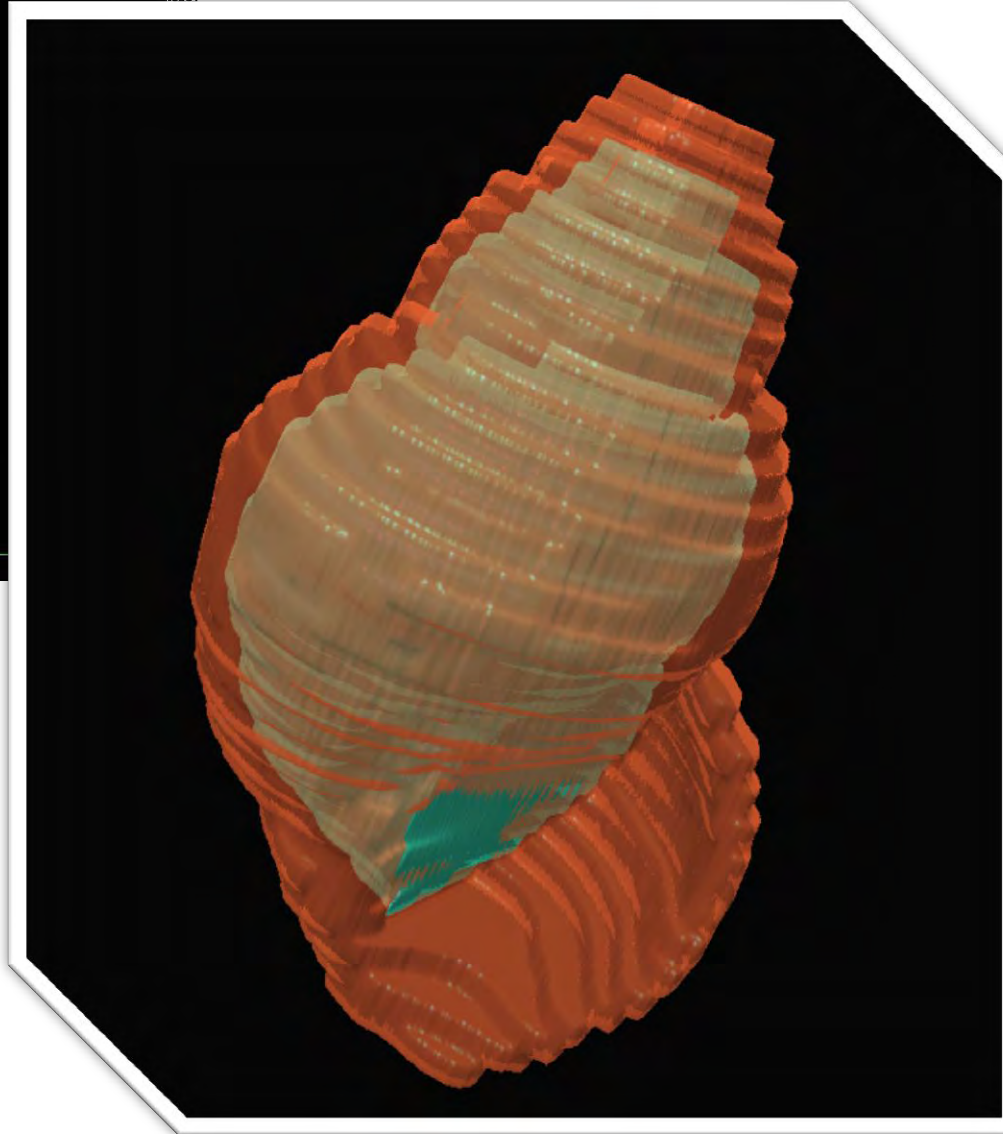
Flatfish model shown with muscle tissue
and fins (above) and without (left)

Snail Model



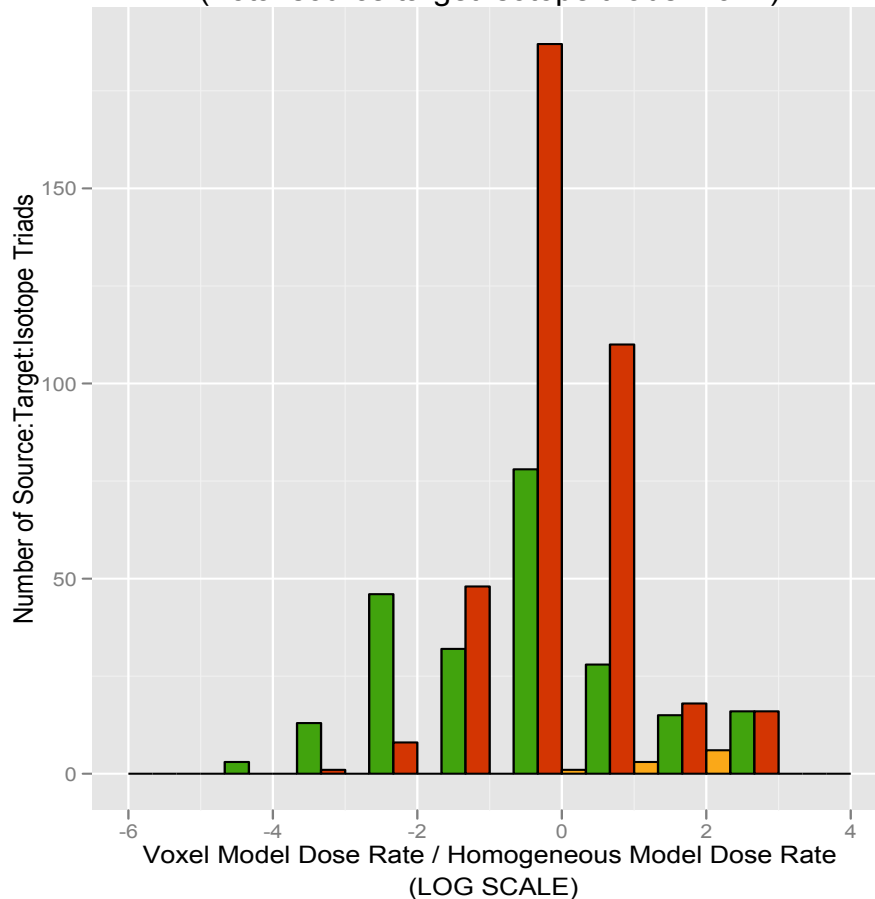
Above: CT image of snail

Right: 3D Doctor rendering of snail model



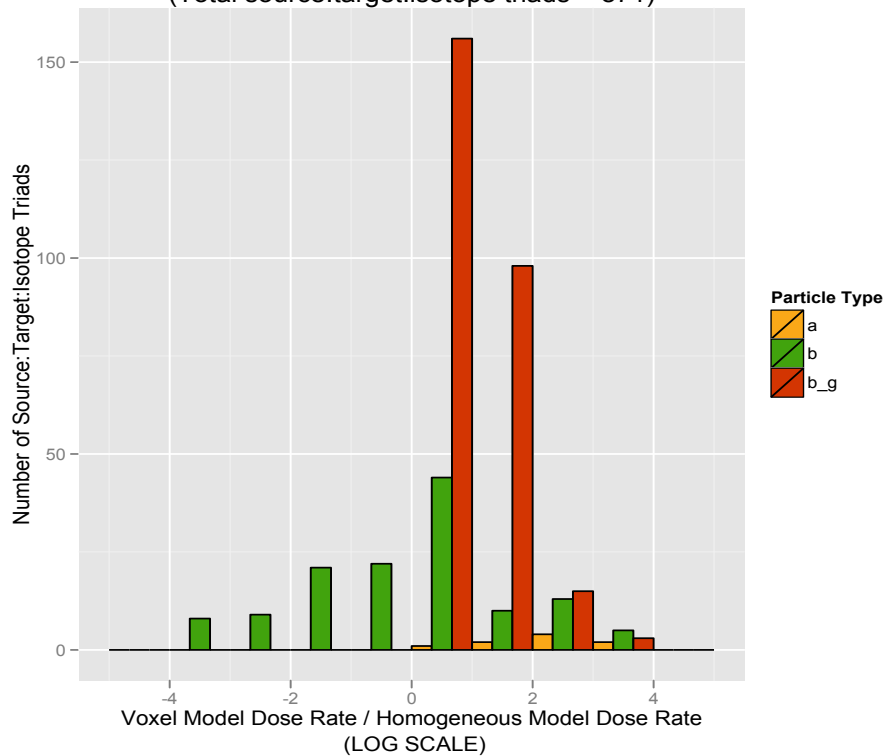
Voxel : Simplified Model Comparison for Flatfish

Frequency of Voxel:Homogeneous Dose Rate Ratios for FLATFISH
(Total source:target:isotope triads = 911)



- 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*

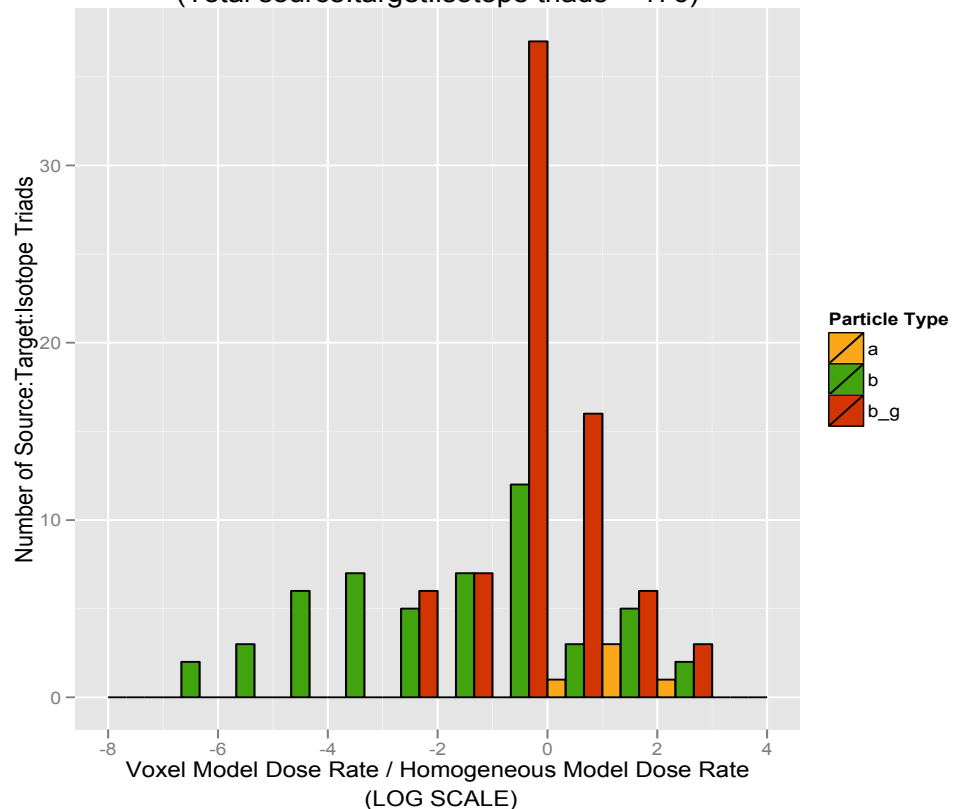
Frequency of Voxel:Homogeneous Dose Rate Ratios for TROUT
(Total source:target:isotope triads = 871)



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

Other Organisms

Frequency of Voxel:Homogeneous Dose Rate Ratios for CRAB
(Total source:target:isotope triads = 176)

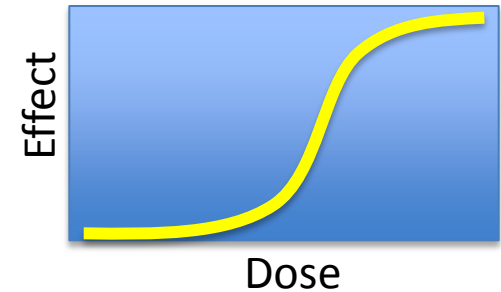


Why Consider Voxel Models?

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

Relating *releases* → dose → effect

Radiation Effects Data: Chronic External Gamma Information



	Morbidity	Mortality	Reproductive Capacity	Mutation
Amphibians	Some data	No Data	No Data	Some data
Aquatic Inverts	Some data	Some data	Some data	Some data
Aquatic Plants	Some data	No Data	No Data	No Data
Bacteria	Some data	No Data	No Data	No Data
Birds	No Data	No Data	Some data	Some data
Crustaceans	Some data	Some data	Some data	No Data
Fish	Some data	Some data	Some data	Some data
Fungi	Some data	No Data	No Data	No Data
Insects	Some data	Some data	Some data	Some data
Mammals	Some data	Some data	Some data	Some data
Molluscs	Some data	Some data	Some data	No Data
Moss/Lichens	Some data	No Data	No Data	No Data
Plants	Some data	Some data	Some data	Some data
Reptiles	No Data	No Data	No Data	Some data
Soil Fauna	Some data	Some data	Some data	No Data
Zooplankton	Some data	No Data	Some data	No Data

Some data

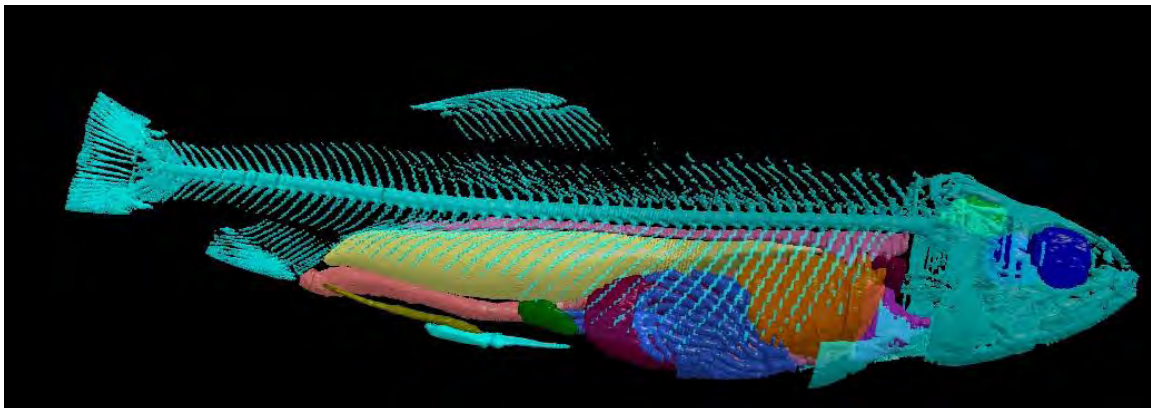
Too few for conclusions

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.

