The Creation and Application of Voxelized Dosimetric Models, and a Comparison with the Current Methodology as used for the ICRP RAPs

ICRP Meeting

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C5 Mission

ñC5 is concerned with radiological protection of the environment. It will aim to ensure that the development and application of approaches to environmental protection are compatible with those for radiological protection of man, and with those for protection of the environment from other hazardsò

Evolution of two 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

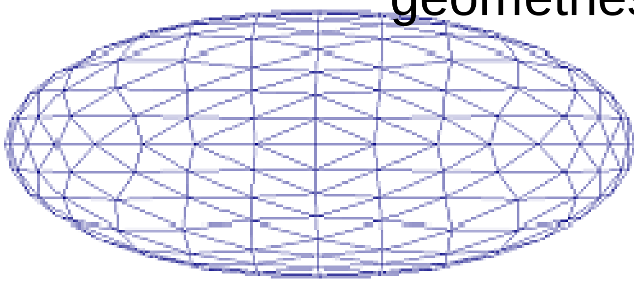
Decision-making regarding public health and environmental protection for the same environmental exposure situation by way of representative individuals and representative organisms

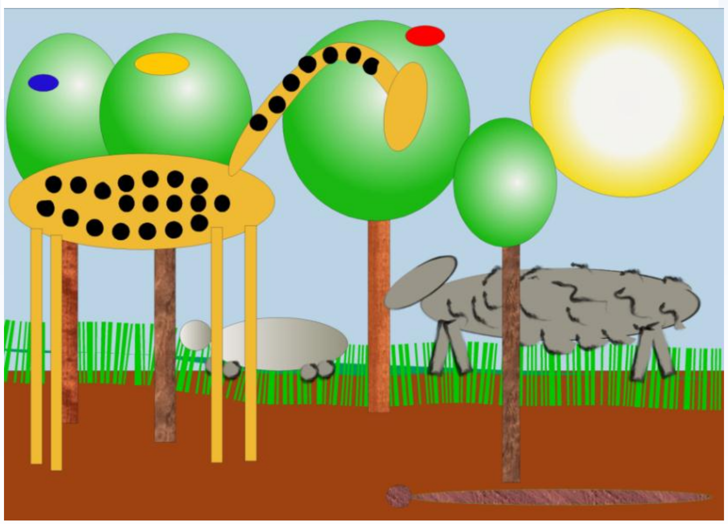
ICRP Reference Organisms and Life Stages

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-based DCFs done or near completion		

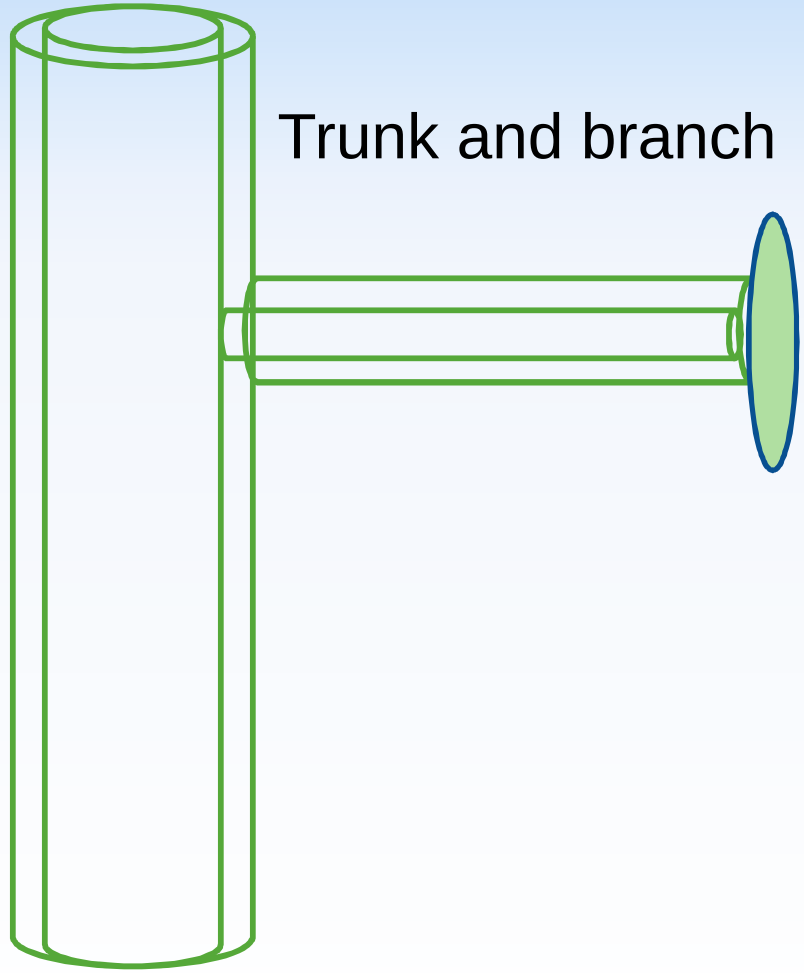
ICRP 108 Dose Calculation Approach (2008)

DCCs for simple geometries



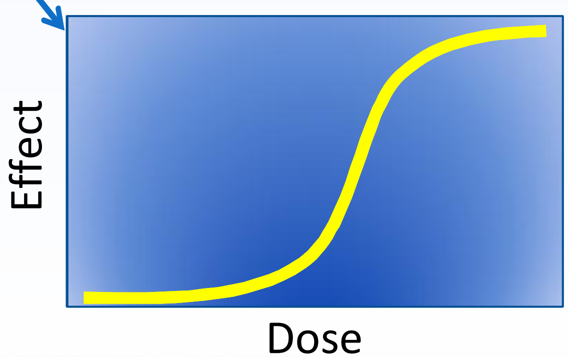


Trunk and branch



Simple Models Work Well With Current Approach to Biota Sampling & Dose Assessment[1]:

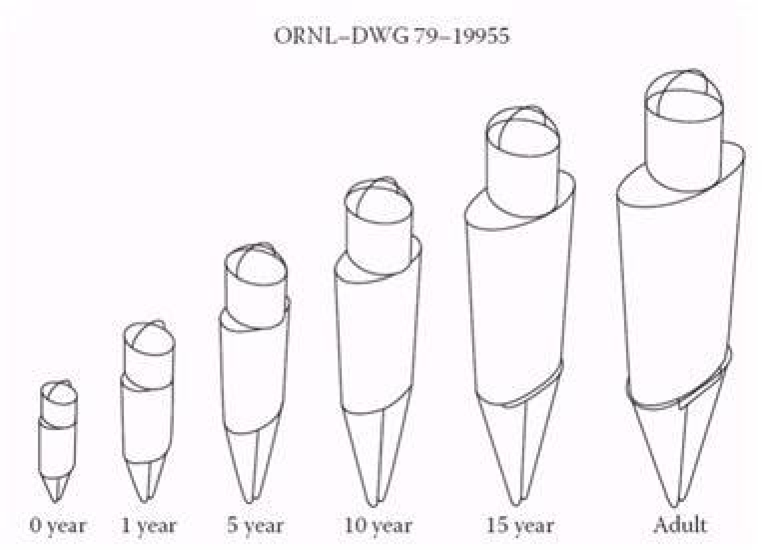
- Sample
- Simplify
- Measure
- Calculate
- Assess

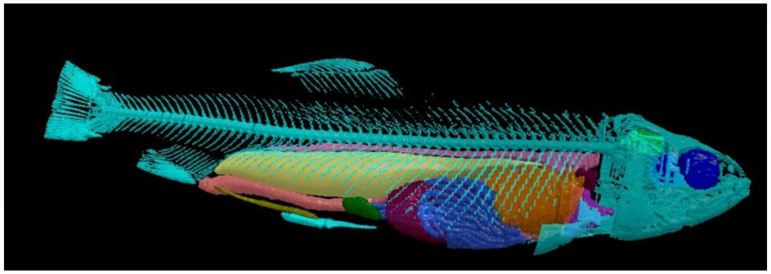


[1] *Acknowledgement to Mike Wood*

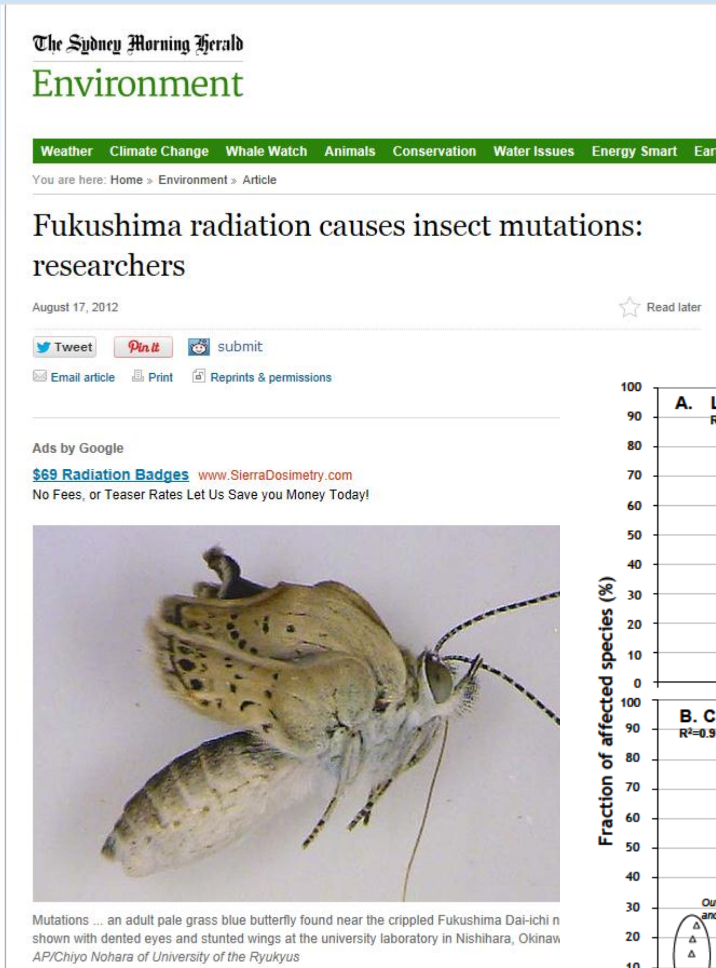
Alternate Approach to Dose Determination: Voxel Phantoms

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





Why More Refined Dosimetry?



The Sydney Morning Herald
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Fukushima radiation causes insect mutations: researchers

August 17, 2012 — Read later

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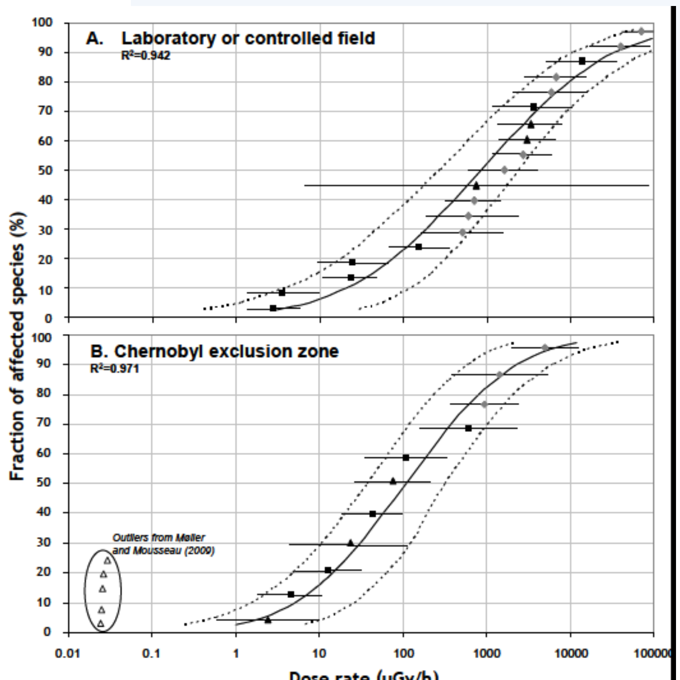
Mutations ... an adult pale grass blue butterfly found near the crippled Fukushima Dai-ichi n shown with dented eyes and stunted wings at the university laboratory in Nishihara, Okinaw
AP/Chiyo Nohara of University of the Ryukyus

- Relate dose to effect
- Guide field measurements
- Parity with human dosimetry



Procedure for Creation of Phantoms

ÅImage organism post mortem

ÅIdentify and segment organs/ structures on scan (3D Doctor[1])

ÅRun Voxelizer[1] to obtain organism geometry

ÅAdd materials, source, and tally to Voxelizer file

ÅRun MCNP[1] to obtain energy deposition in each organ for each source/target pair, at each energy and for each particle type

ÅCalculate dose conversion factors (DCFôs) for specific radionuclides

[1]*Commercial or other software*

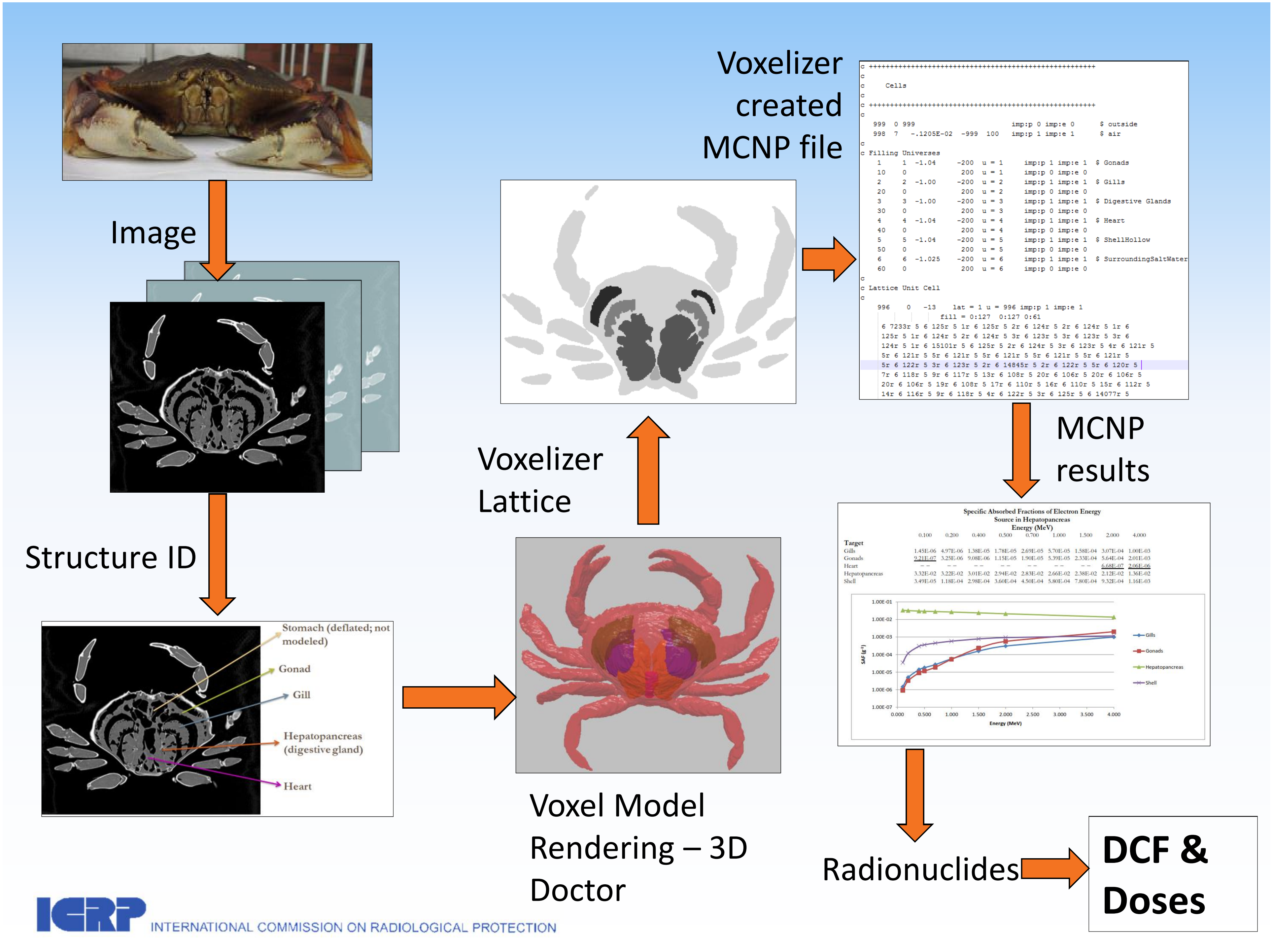


Image
Structure ID
Stomach (deflated; not modeled)
Gonad
Gill
Hepatopancreas (digestive gland)
Heart
Voxel Model Rendering – 3D Doctor
Voxelizer Lattice
Voxelizer created MCNP file
MCNP results
Specific Absorbed Fractions of Electron Energy
Source in Hepatopancreas
Radionuclides
DCF & Doses
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Comparison Voxel : Simplified

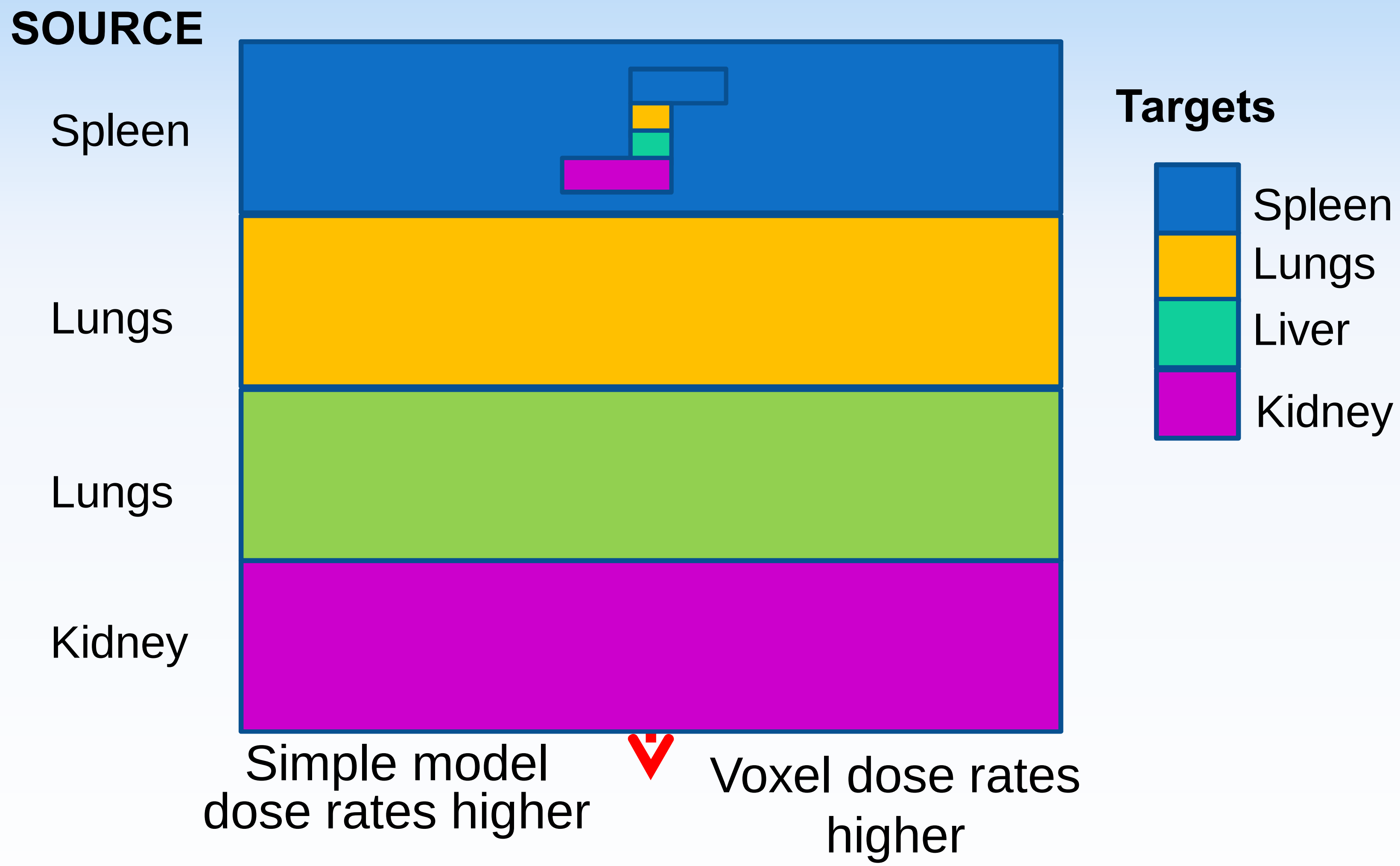
Compare Calculated Dose Rates

- Experimental conditions, 1 MBq:
  - 7 radionuclides ^{14}C, ^{36}Cl, ^{60}Co, ^{90}Sr, ^{131}I, ^{137}Cs, ^{210}Po
  - 4 RAPS (flatfish, trout, crab, rat)
- Radionuclides distributed
  - Highly partitioned into single organ (SŸ T)

    Or
  - Homogeneously in total organism mass

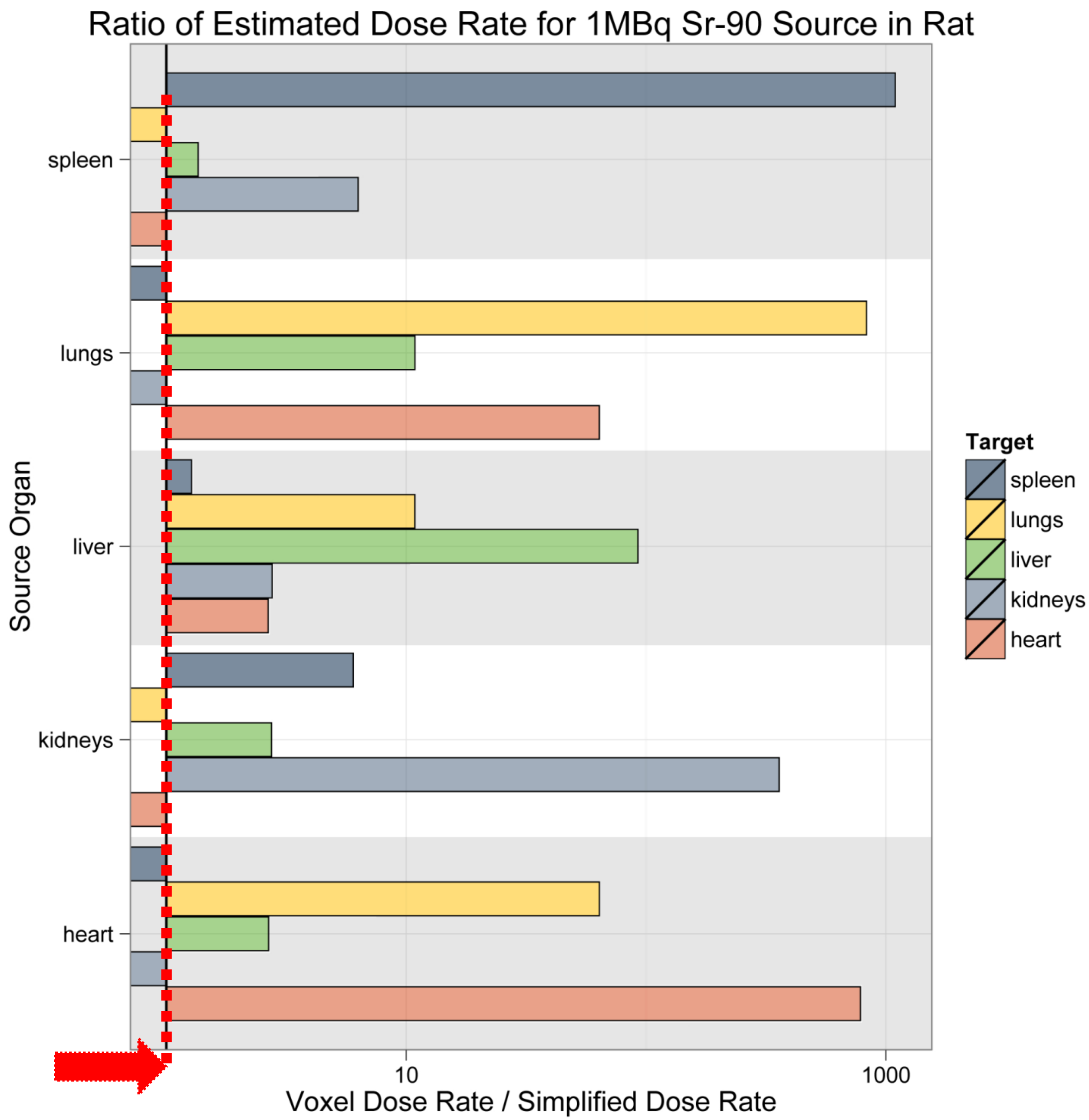
- Partitioning represents extreme, but not unlikely occurrence for many radionuclides

Ratio


SOURCE
Spleen
Lungs
Lungs
Kidney
Targets
Spleen
Lungs
Liver
Kidney
Simple model
dose rates higher
Voxel dose rates
higher

^{90}Sr: Rat

- Includes ^{90}Y
- Red line indicates perfect agreement between models
- Likely partitioned into organs
- Simplified model would likely underestimate organ dose



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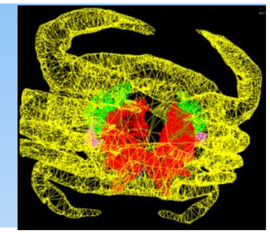
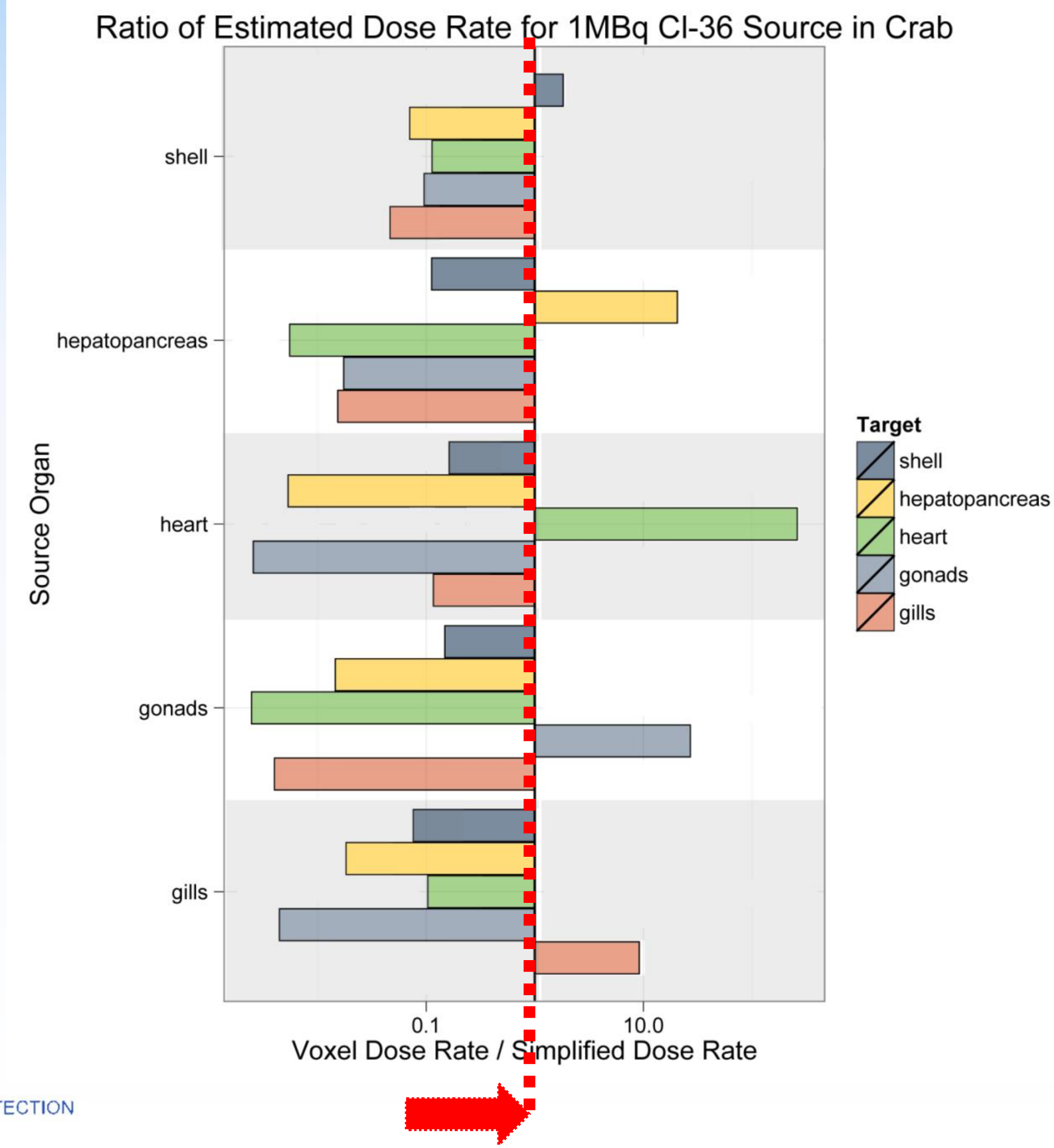
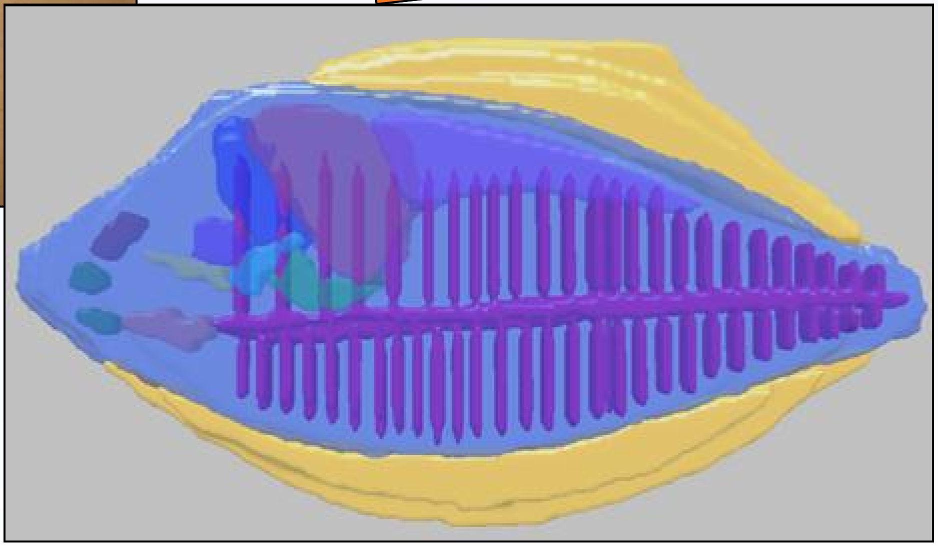
Example: Cl-36 in Crab



- ^{36}Cl -beta emitter with short range
- Probably uniformly distributed in tissues
- In this simulation, homogeneous model generally predicts higher dose rates
- Homogenous model *is largely conservative*



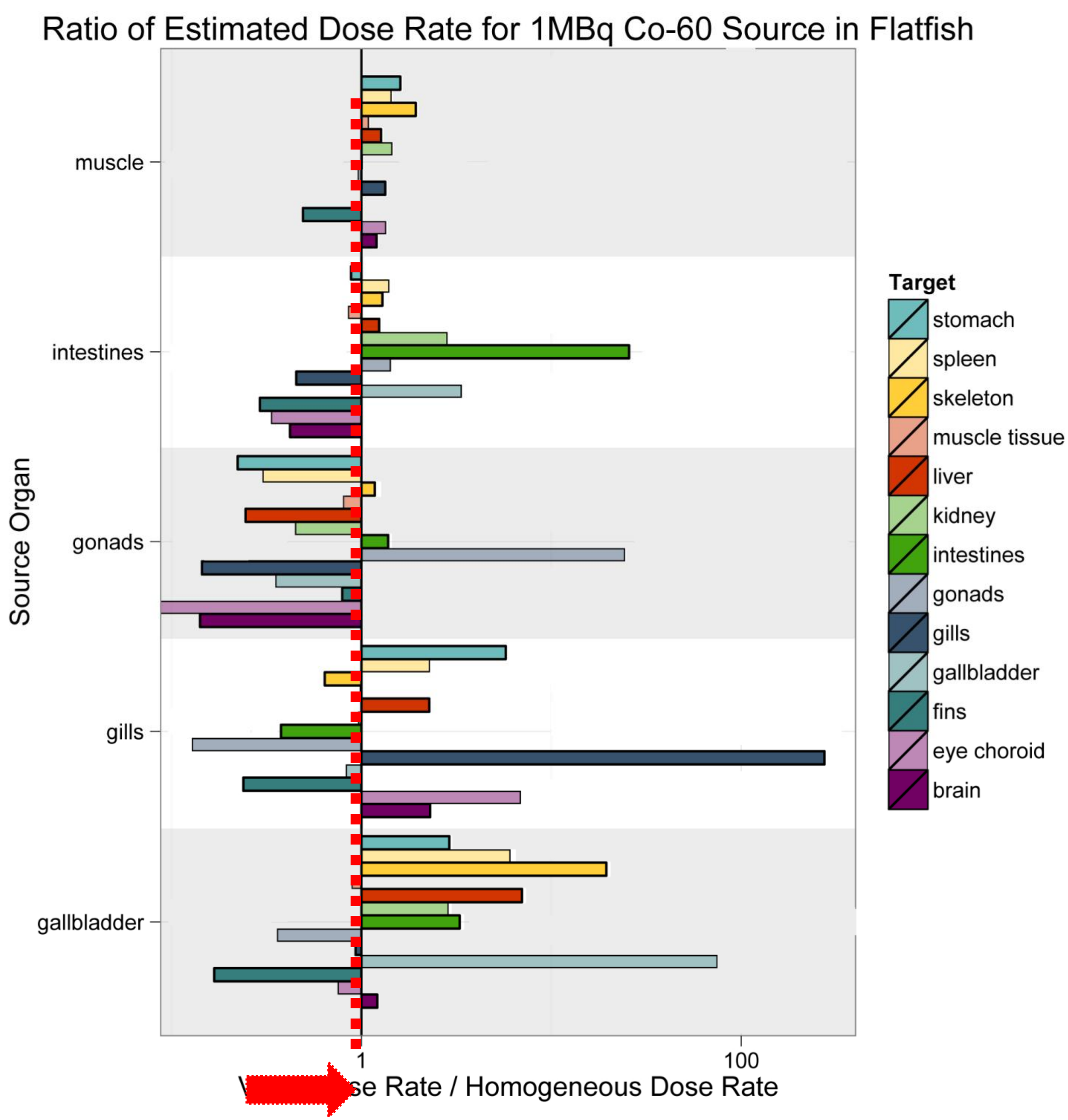
Limanda Limanda (Sand Dab)



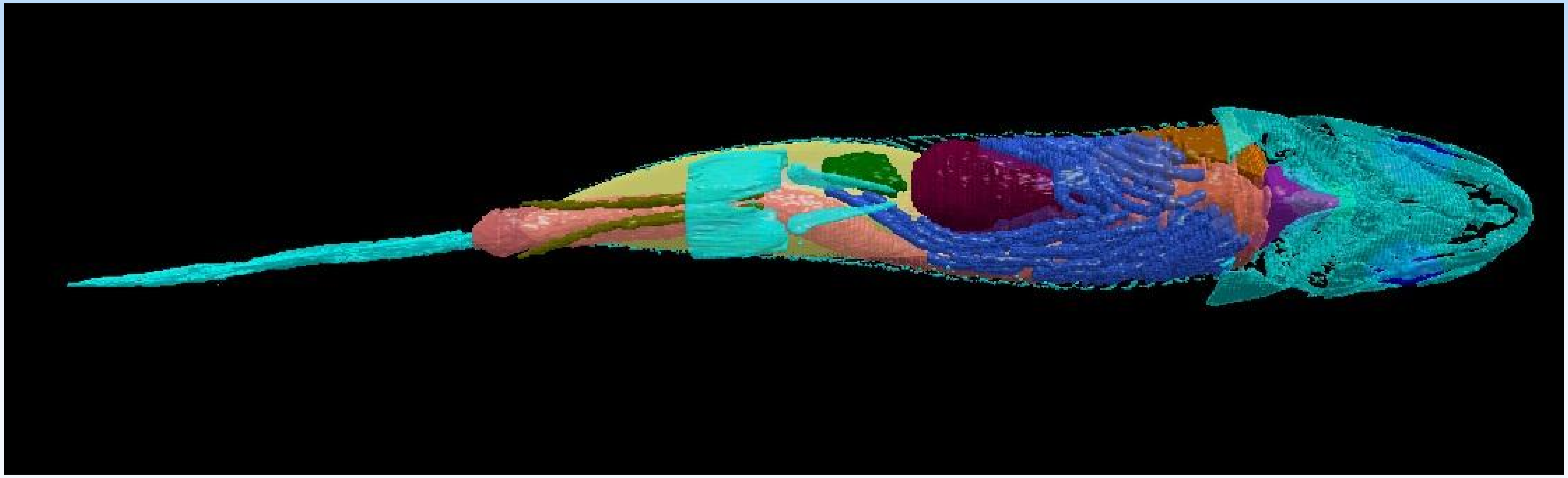
Source: Photo courtesy of Andrew Marriott, published on MLIN website

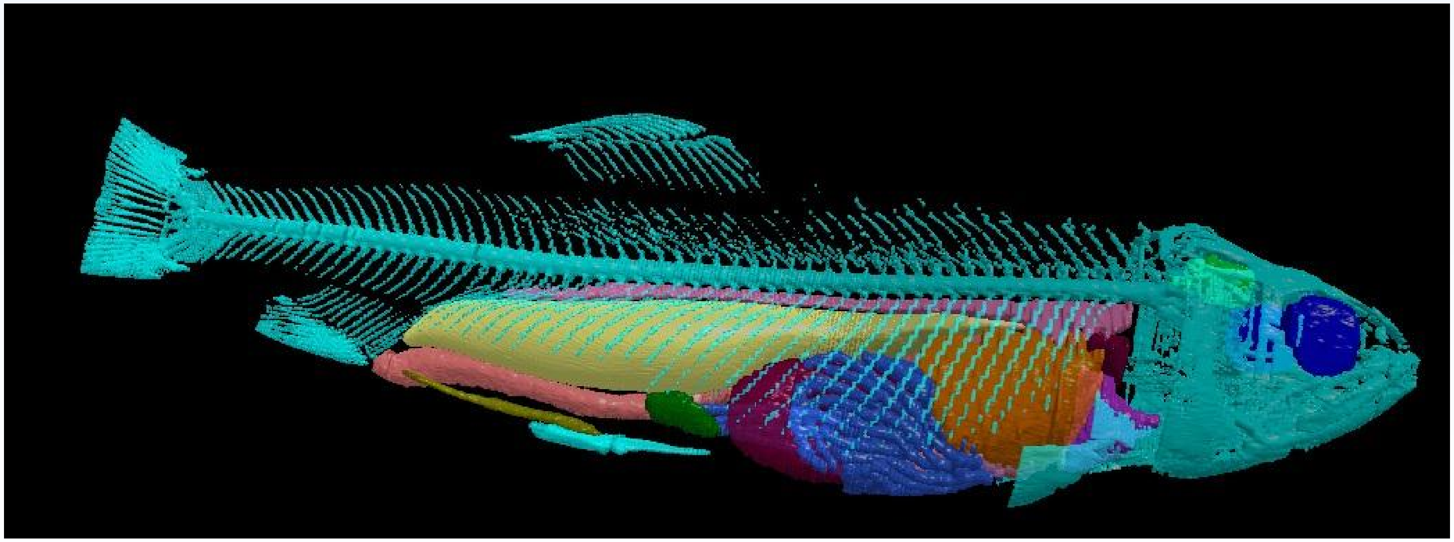
^{60}Co Flatfish

- ^{60}Co -beta/gamma emitter
- Shown to concentrate in kidneys up to 200 fold
- In this simulation, no immediately discernible trends
- Likely mass and position of source organ



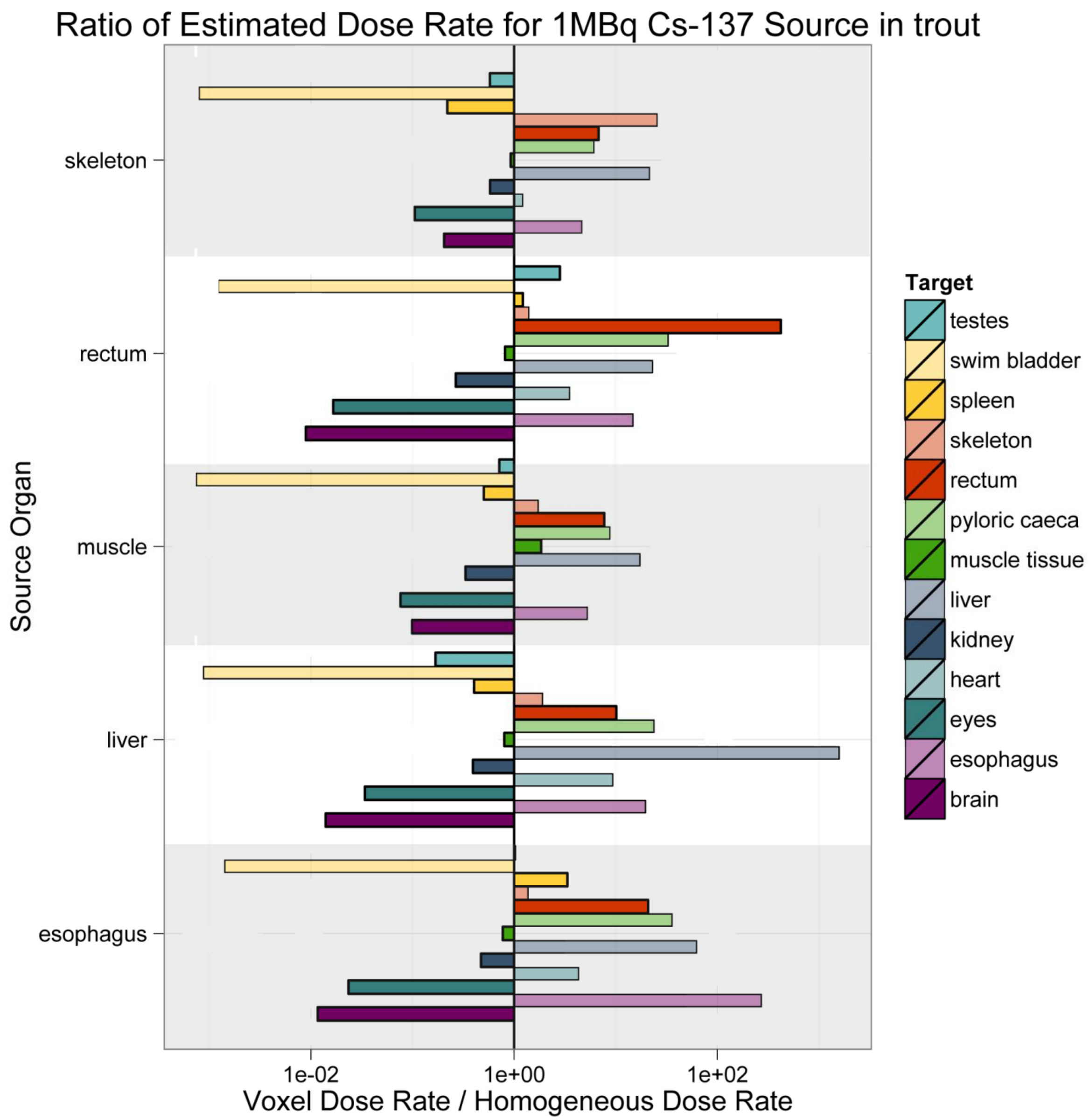
Trout Phantom

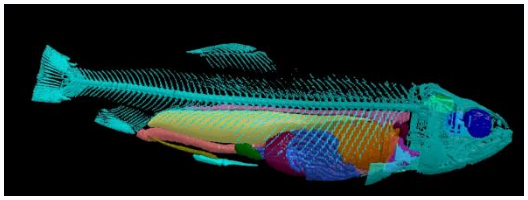




^{137}Cs Trout

- Strong beta/gamma emitter
- Distributes in soft tissues
- In this simulation, voxel model *not conservative if activity partitioned strongly into muscle tissue*





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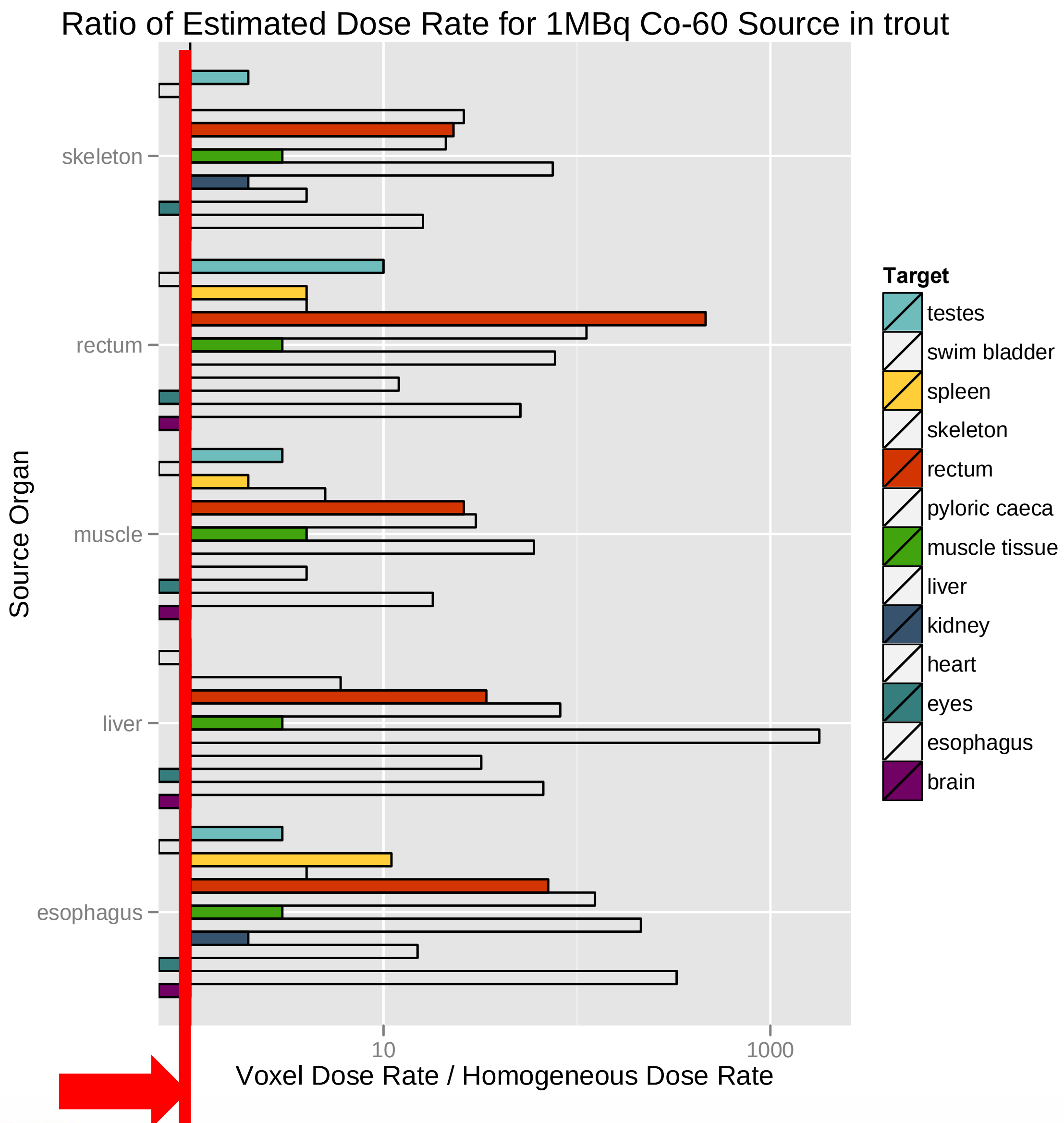
Example: ^{60}Co in Trout

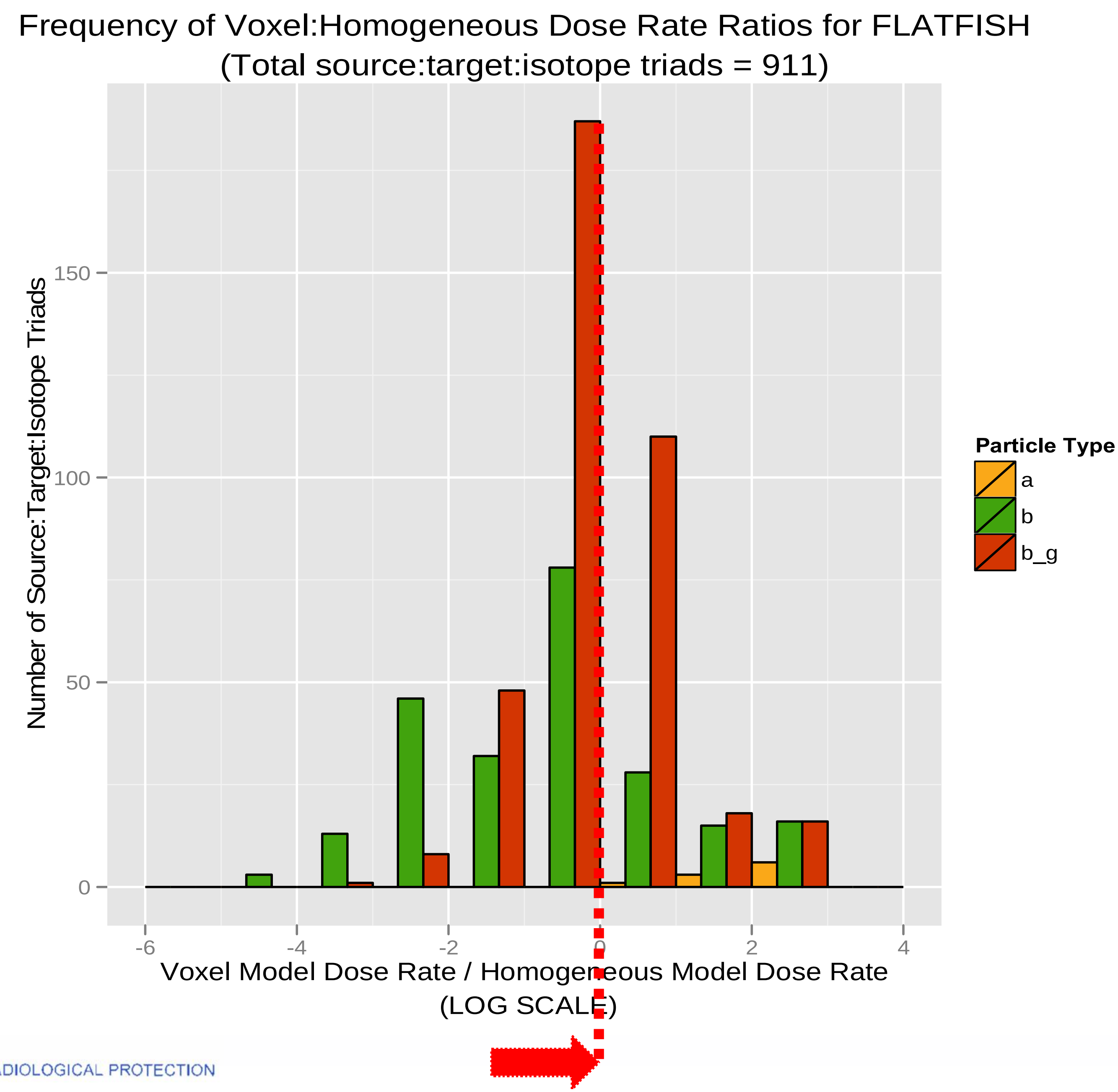
- ^{60}Co -beta/gamma emitter
- In this simulation, voxel model frequently predicts higher dose rates
- Homogenous model *not conservative*



Overall Comparison

Flatfish:

- ^{14}C, ^{36}Cl, ^{60}Co, ^{90}Sr, ^{131}I, ^{137}Cs, ^{210}Po
- Compared 871 source/target values
- Homogeneous model
  - Conservative mainly for pure beta emitters
  - Less so for others



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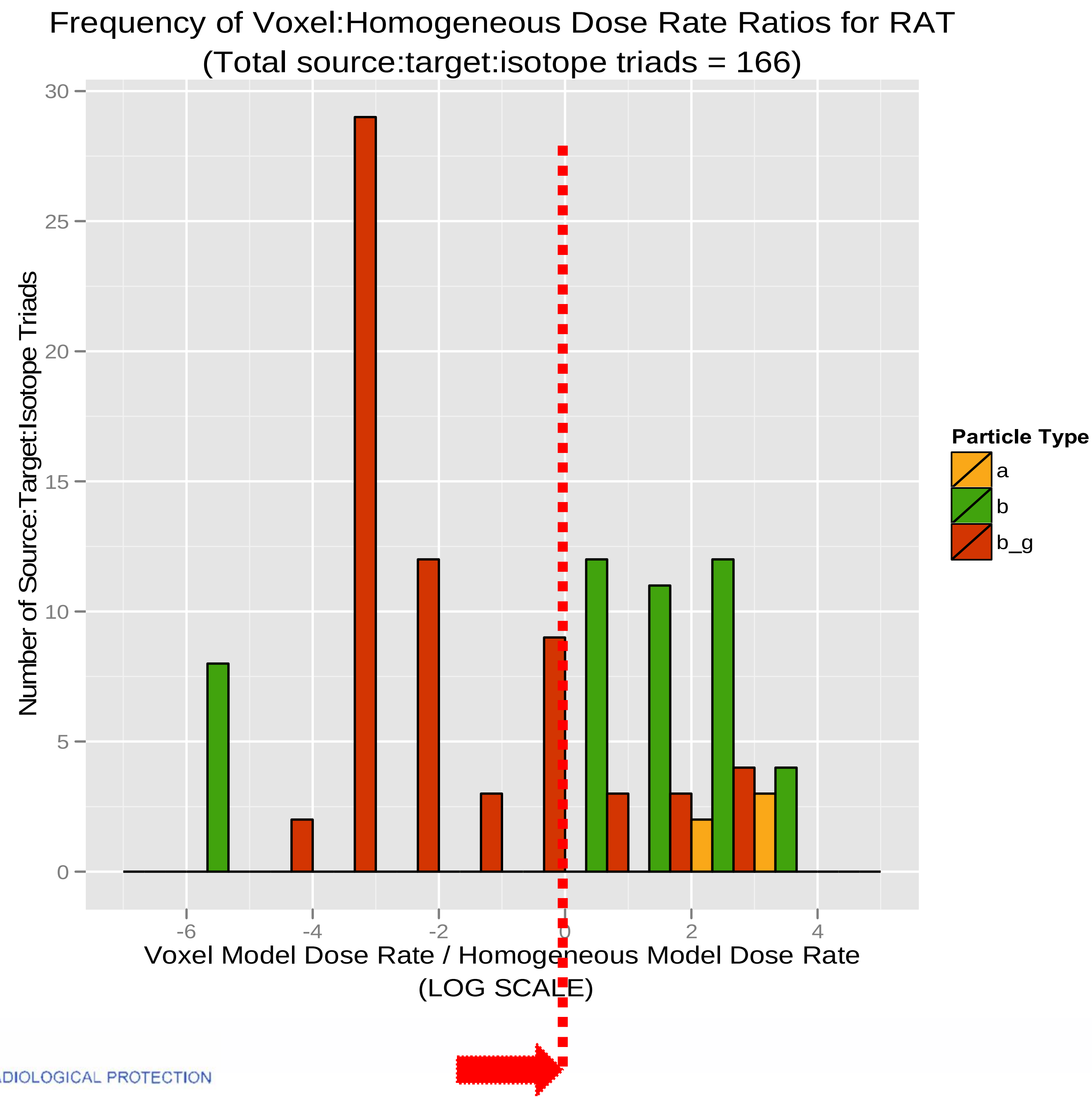
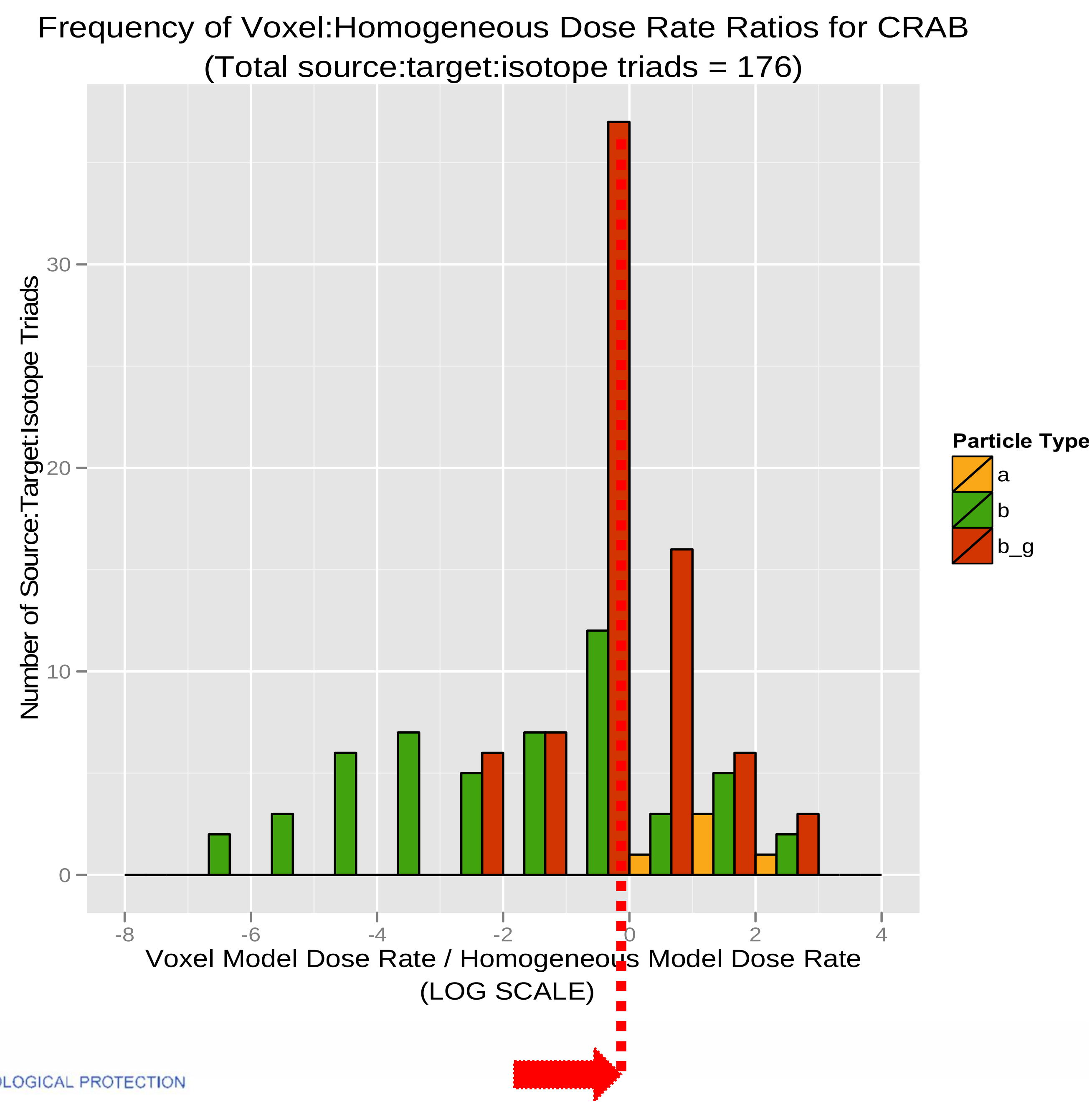
Rat:

- ^{14}C, ^{36}Cl, ^{60}Co, ^{90}Sr, ^{131}I, ^{137}Cs, ^{210}Po
- Compared 166 source/target values
- Homogeneous model
  - Conservative mainly for beta gamma emitters
  - Not conservative for alpha and most pure beta



Crab:

- ^{14}C, ^{36}Cl, ^{60}Co, ^{90}Sr, ^{131}I, ^{137}Cs, ^{210}Po
- Compared 176 source/target values
- Homogeneous model
  - Conservative mainly for beta gamma emitters
  - Not conservative for alpha and most beta gamma emitters



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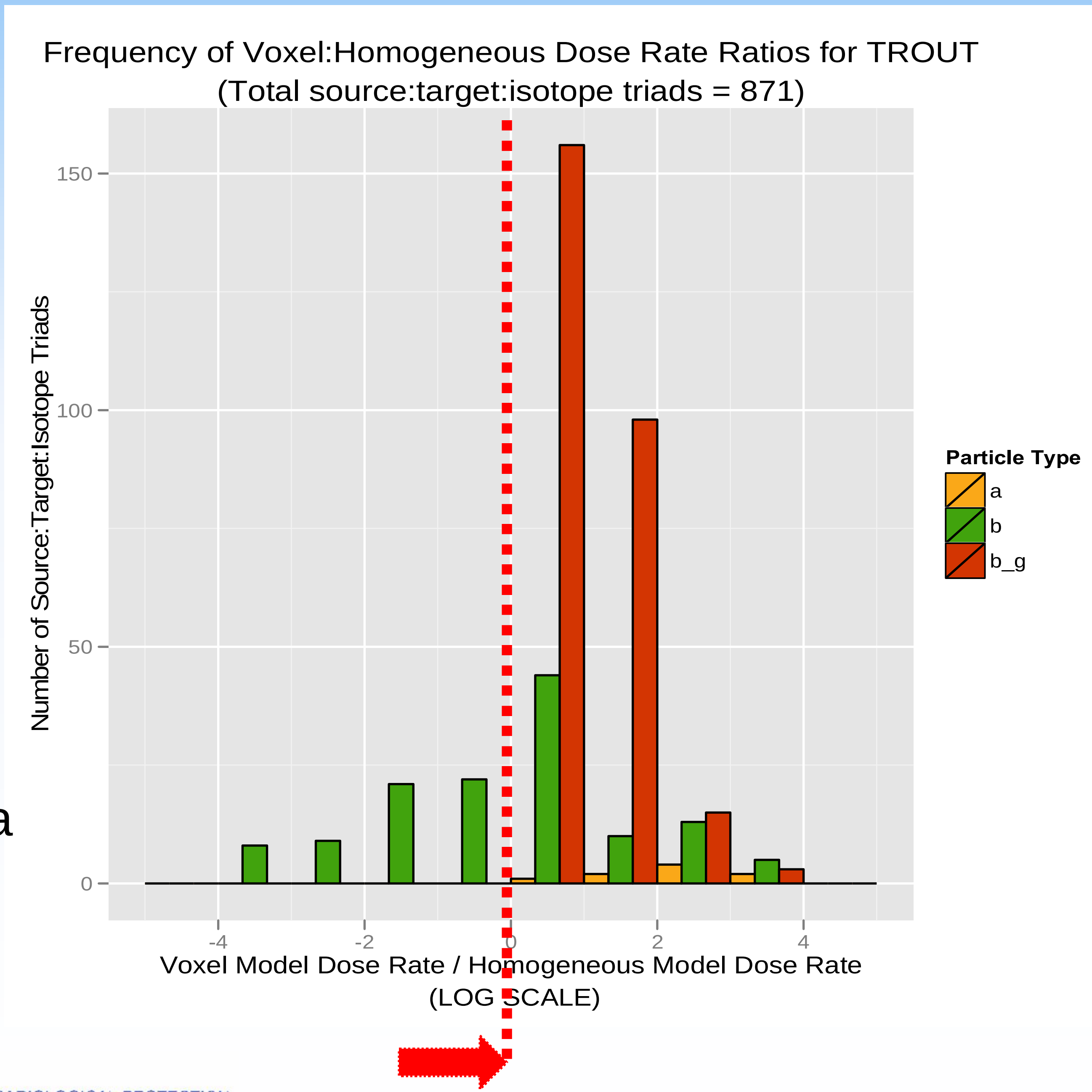
Trout:

- ^{14}C, ^{36}Cl, ^{60}Co, ^{90}Sr, ^{131}I, ^{137}Cs, ^{210}Po
- Compared 871 source/target values
- Homogeneous model
  - Conservative only for pure beta emitters
  - Not so for others



Summary

- Simplified models are straight forward means to calculate dose
  - They may not be appropriately conservative (when radionuclides are highly partitioned into organs)
  - They may be *too* conservative under other circumstances
  - Organism (and organ) size is important

Ongoing Work with Voxel Models: Bee and Worm

- Preliminary AF data obtained, but no good composition data for bee and worm
  - Dissections
  - Tissue Analysis
  - Remake models
  - New AF
  - Comparisons

Bee and Worm

- Under development
- Created using micro CT
- System used in research institutes

- Challenge is finding data on
  - Tissue densities
  - Elemental composition
- Example ï bee has microscopic iron deposits in fat

Conclusions

- Results of simplified vs voxelized models do not agree well
- Examples shown are extreme cases, but suggest further need for exploration into differences between voxelized and homogeneous dose rate calculations
  - Partition coefficients
  - External and internal dose contributions
- *We need to methodically assess when/where detailed dose calculations are required.*

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