

New Reference Computational Phantoms

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New Reference ICRP Computational Phantoms

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I would like to acknowledge the work of:

Wesley E Bolch, University of Florida

Chan H Yeong Kim, Hanyang University

Choonsik Lee, National Cancer Institute

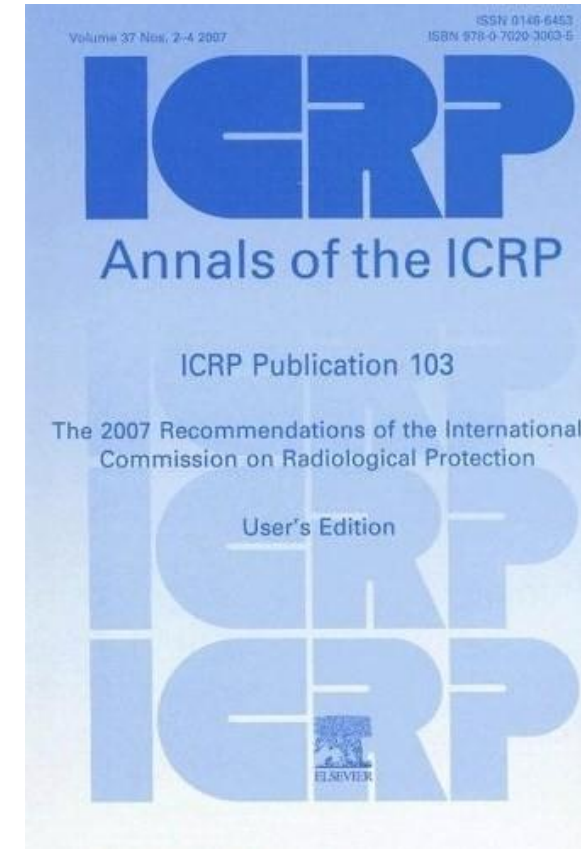
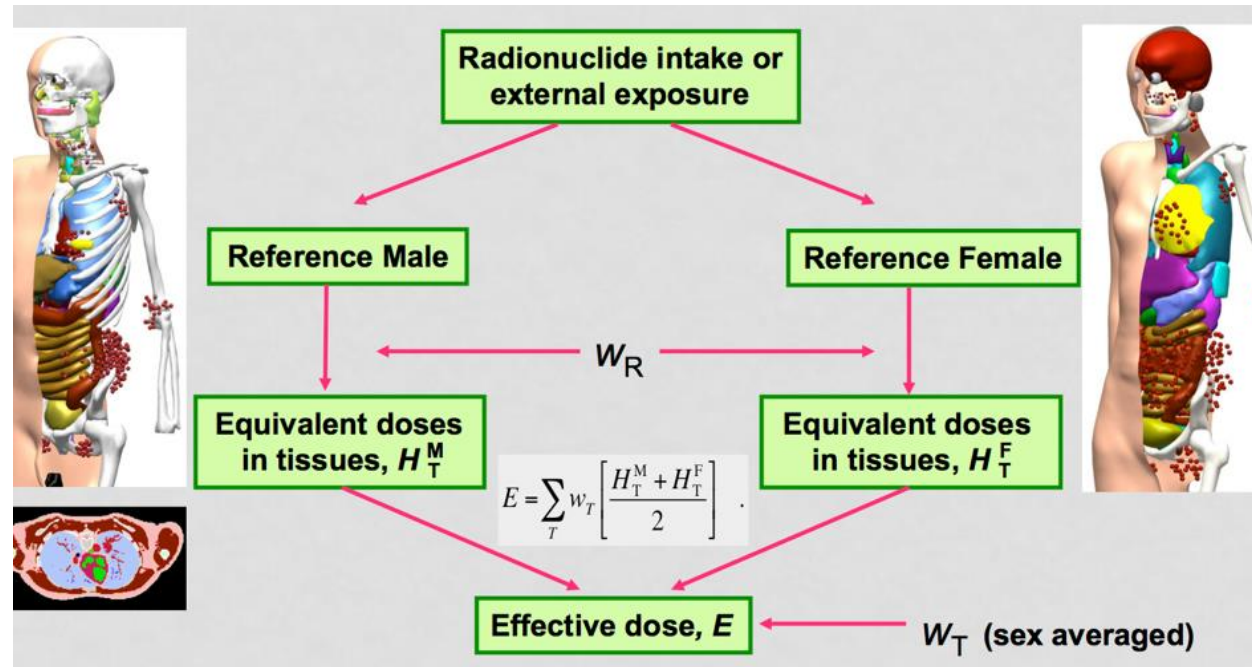
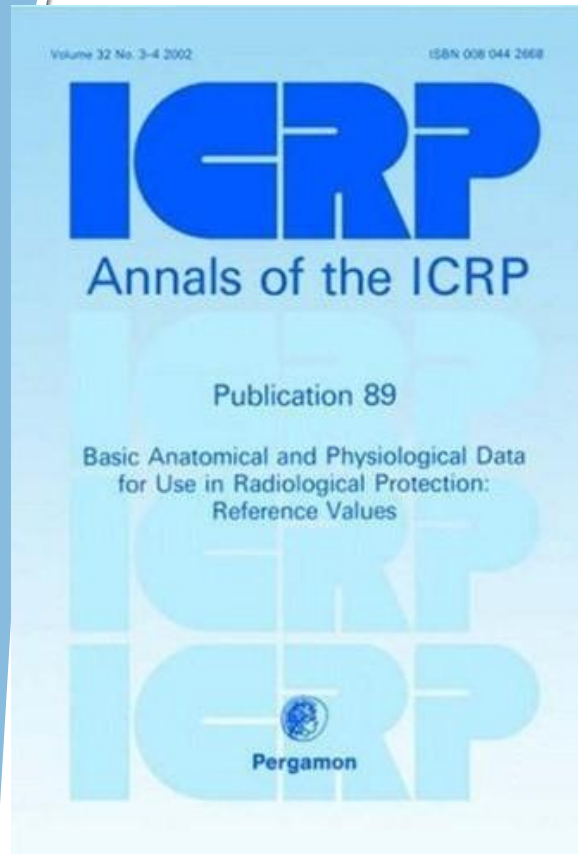
Yeon Soo Yeom, Yonsei University

Maria Zankl, Helmholtz Munich

Overview

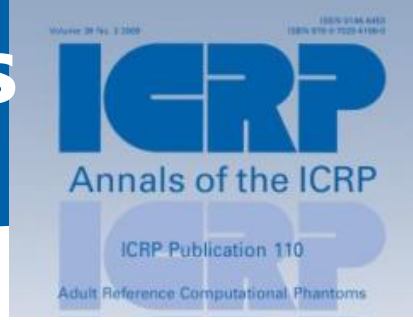
- Background – scope, use and application of computational phantoms in the development of ICRP dose coefficients
 - **Adult reference computational phantoms** - ICRP Publication 110 (2009)
 - Characteristics, applications and conceptual limitations
 - **Pediatric reference phantoms**
 - Construction, characteristics
 - Some dosimetric examples
 - **Adult mesh-type reference phantoms**
 - Construction, characteristics
 - Dosimetric consequences of the use of mesh vs. voxel phantoms

Reference computational phantoms are defined to enable calculations of the organ/tissue equivalent dose and effective dose (coefficients)



ICRP Adult Reference Computational Phantoms

Voxel Phantoms – ICRP Publication 110 (2009)



- They are voxel-based and have been derived from tomographic data of a male and a female patient
- They have organ masses of reference values, but they still have individual organ topology reflecting the tomographic data used in their construction
- **These phantoms are currently the official computational phantoms representing the ICRP adult reference male/female**
- Both models cannot represent any real individual



Applications and conceptual limitations of the ICRP adult reference phantoms

- They have limitations relating to their spatial resolution
- These limitations are addressed by using additional mathematical phantoms to represent small tissues i.e. skin, skeleton, brochi etc.
- They have been used to derive organ dose coefficients for external and internal exposures
 - External exposures, occupational (ICRP 116, 2010)
 - External exposures for astronauts (ICRP 123, 2013)
 - Environmental external exposures (ICRP 144, 2020)
 - Occupational intakes of radioinuclides: ICRP 133 (2016),
34 (2016), 137 (2017), 141 (2019)

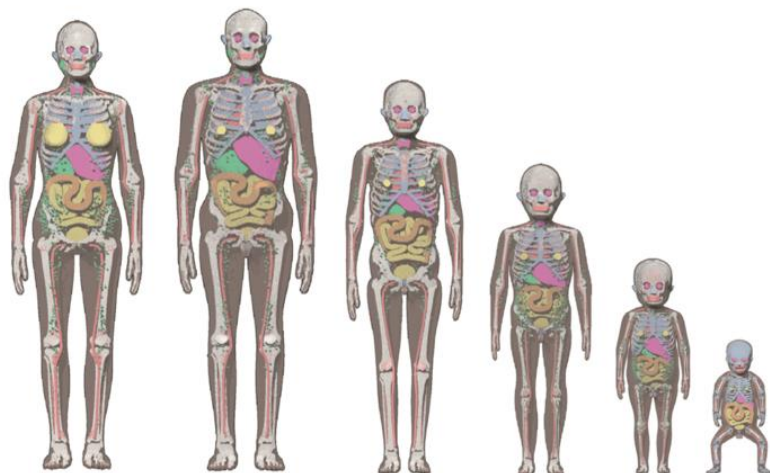
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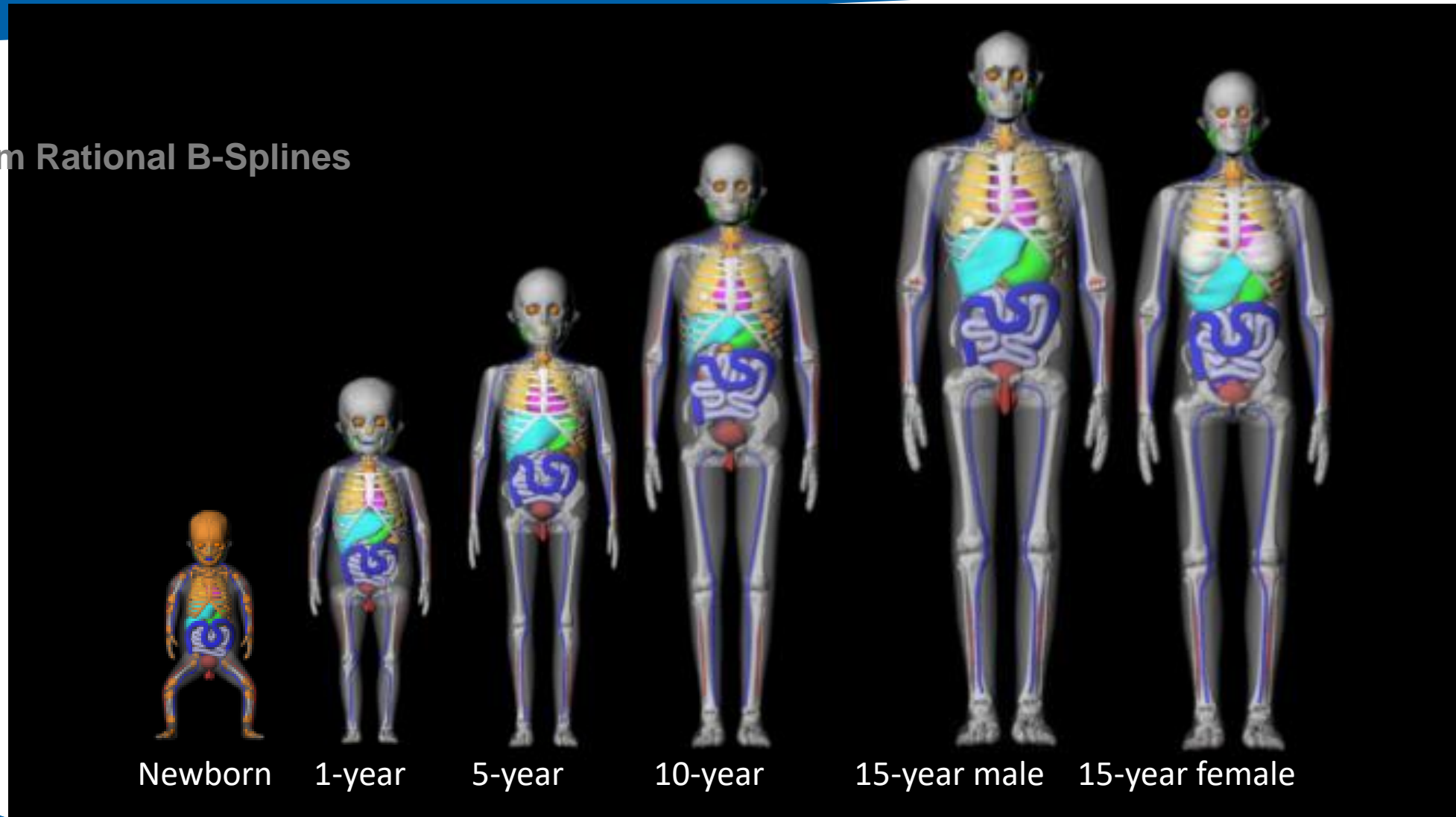
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University of Florida / National Cancer Institute Hybrid Phantoms for Children (2006-2013)

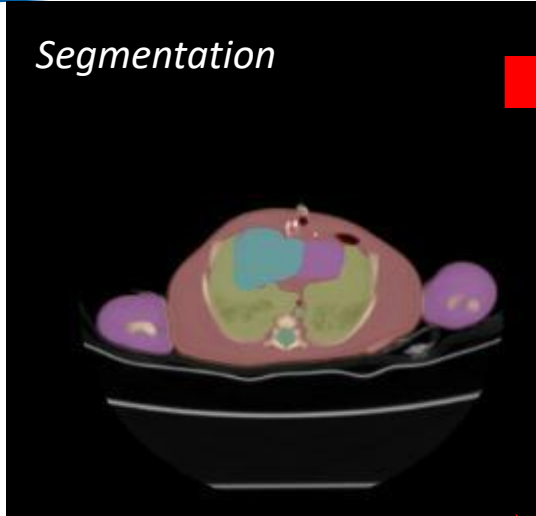
NURBS:
Non-Uniform Rational B-Splines



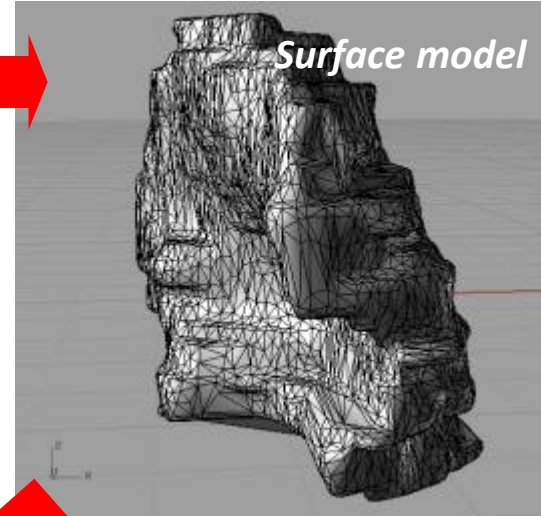
Procedure to develop hybrid phantom

Contour
organs from
CT images of
real patients

Segmentation



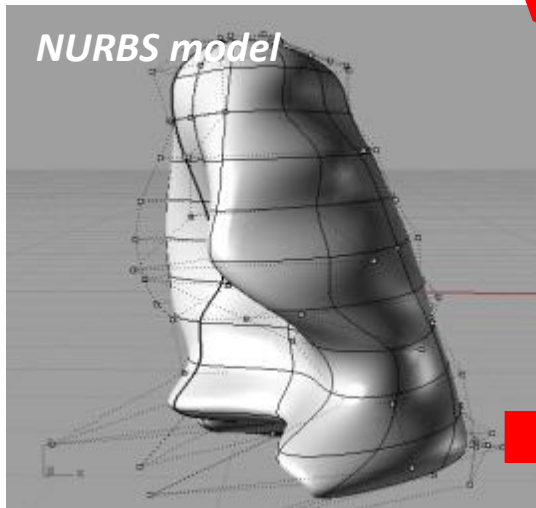
Surface model



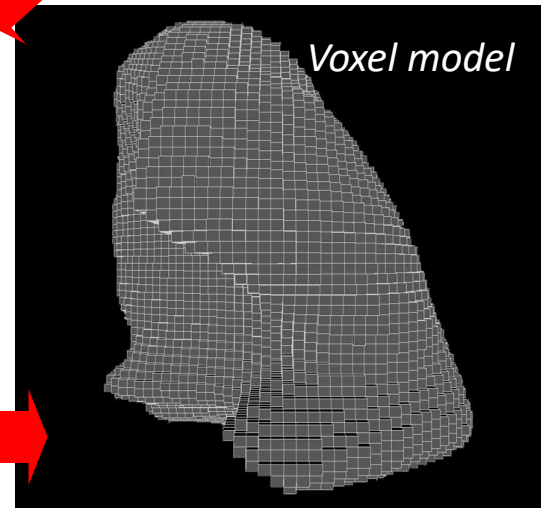
Convert
segmented
model into
polygon
mesh
surface

Smoother and
more flexible
than surface
models

NURBS model

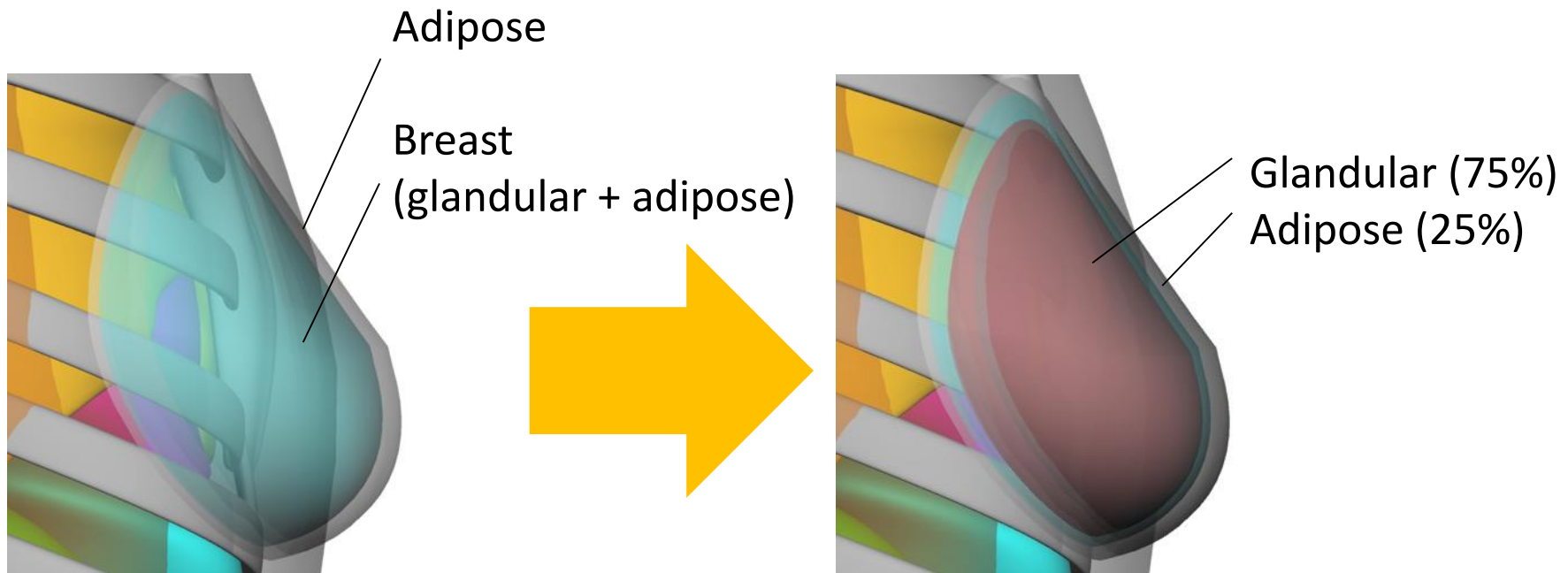


Voxel model

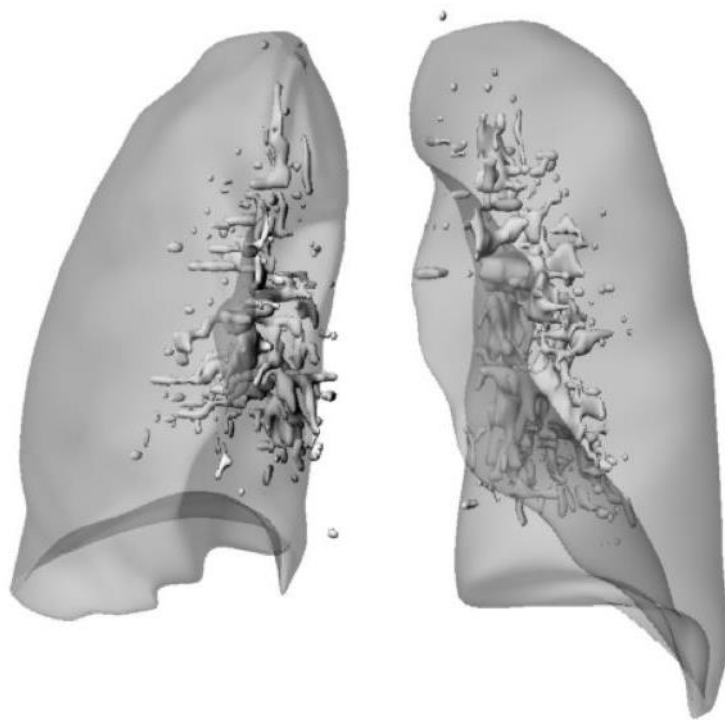


Convert to
voxel
models for
Monte Carlo
calculations

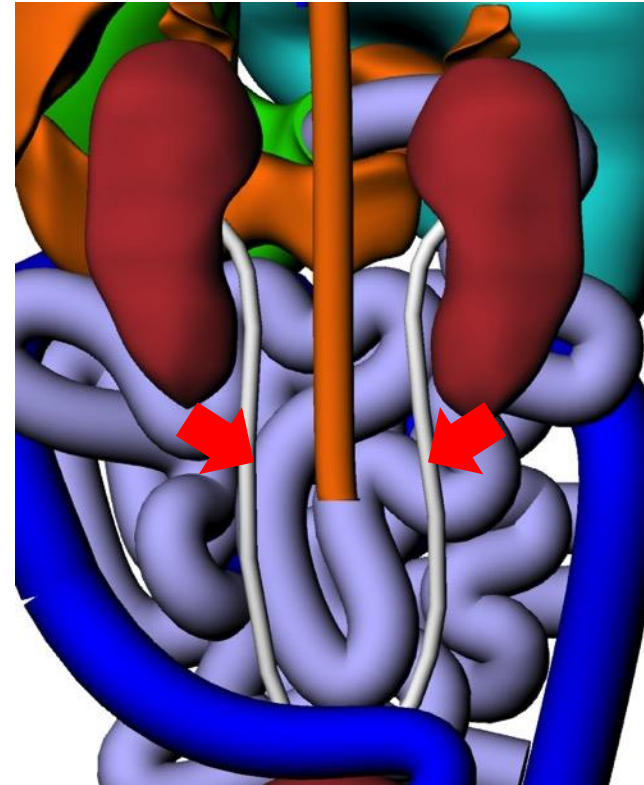
Breast model ICRP 15-year-old female



Lung blood and ureters

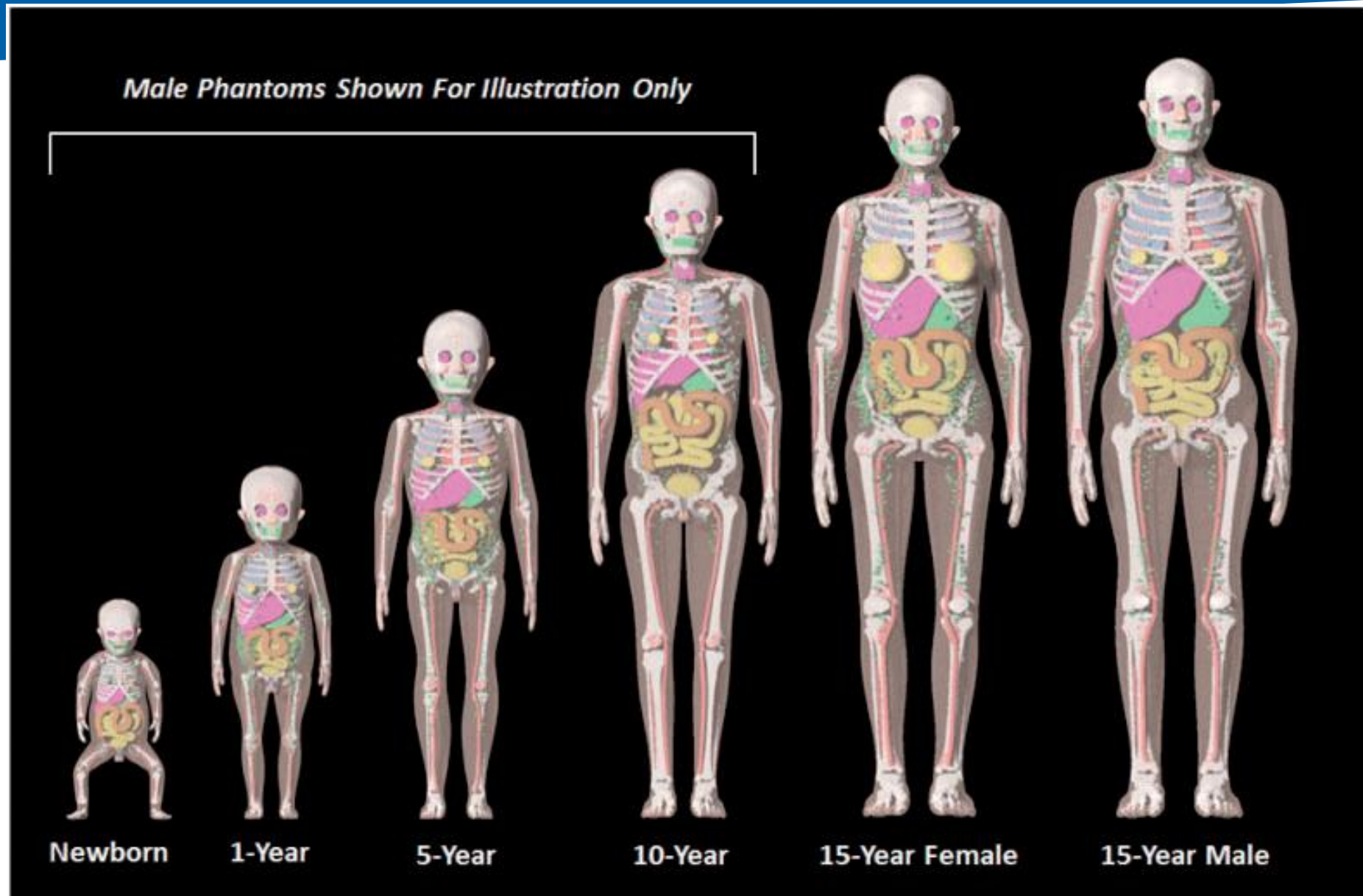


Lung model of the 15-yr
female phantom



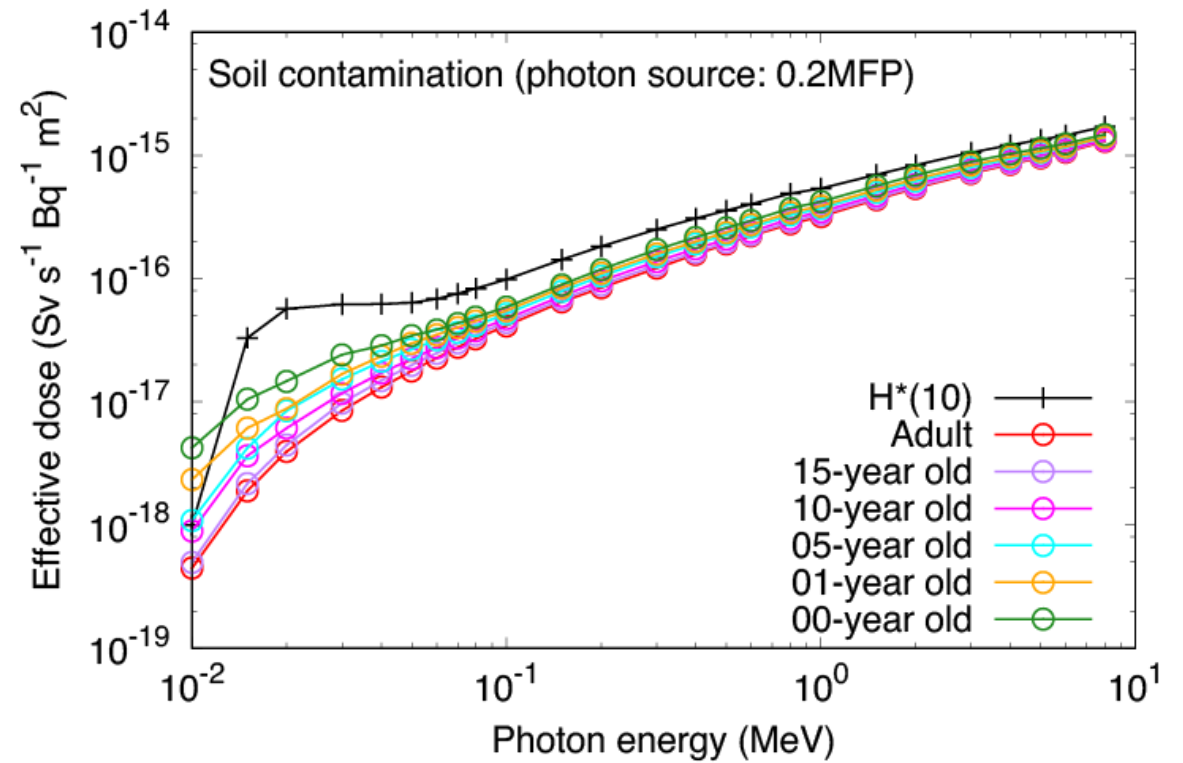
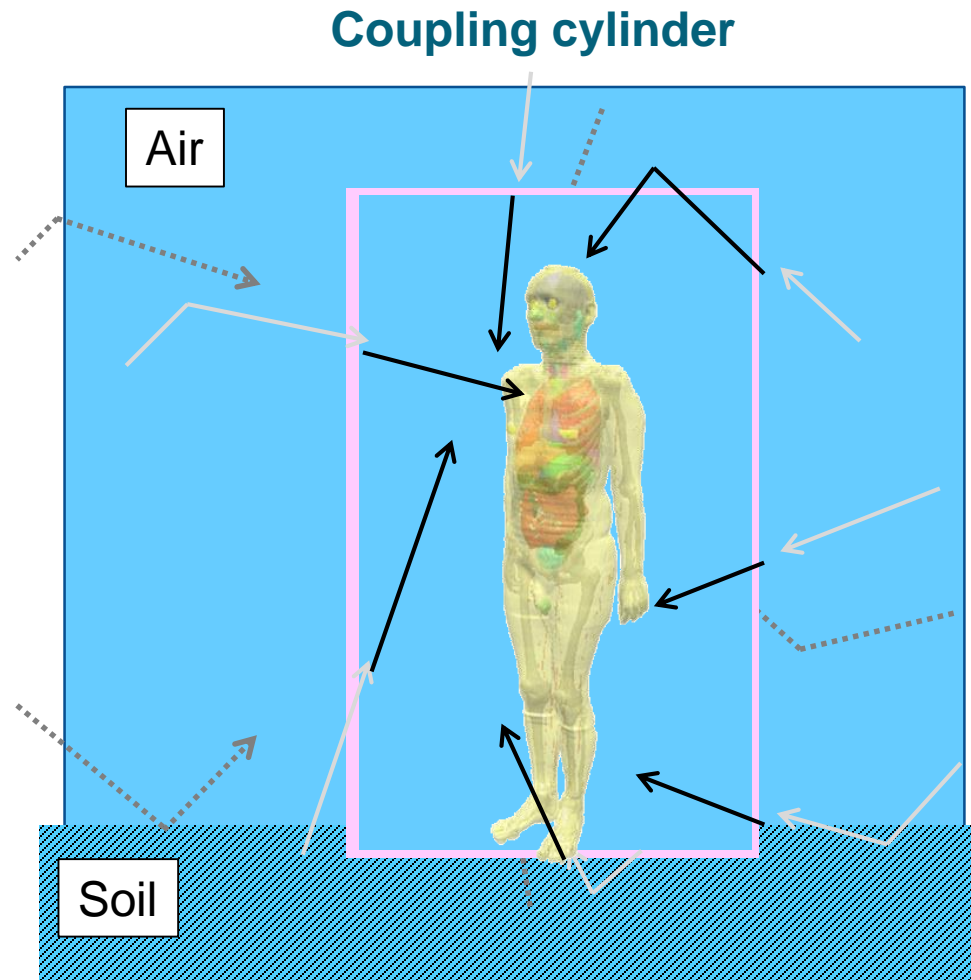
Ureter model in the ICRP
15-yr male phantom

ICRP voxel-based computational phantoms - ICRP Publ. 143

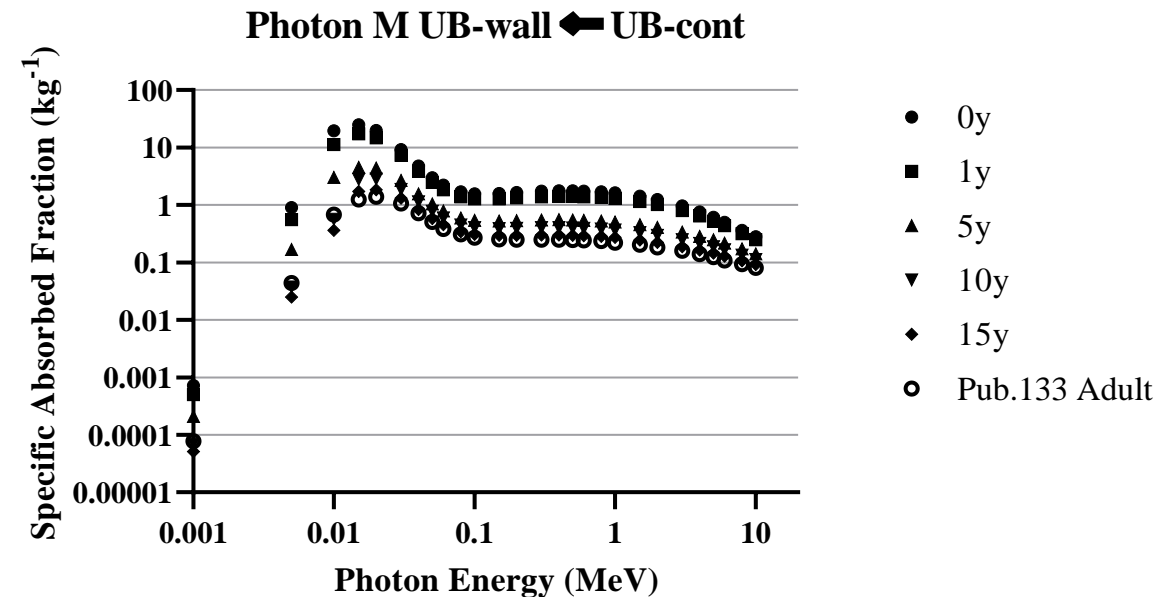
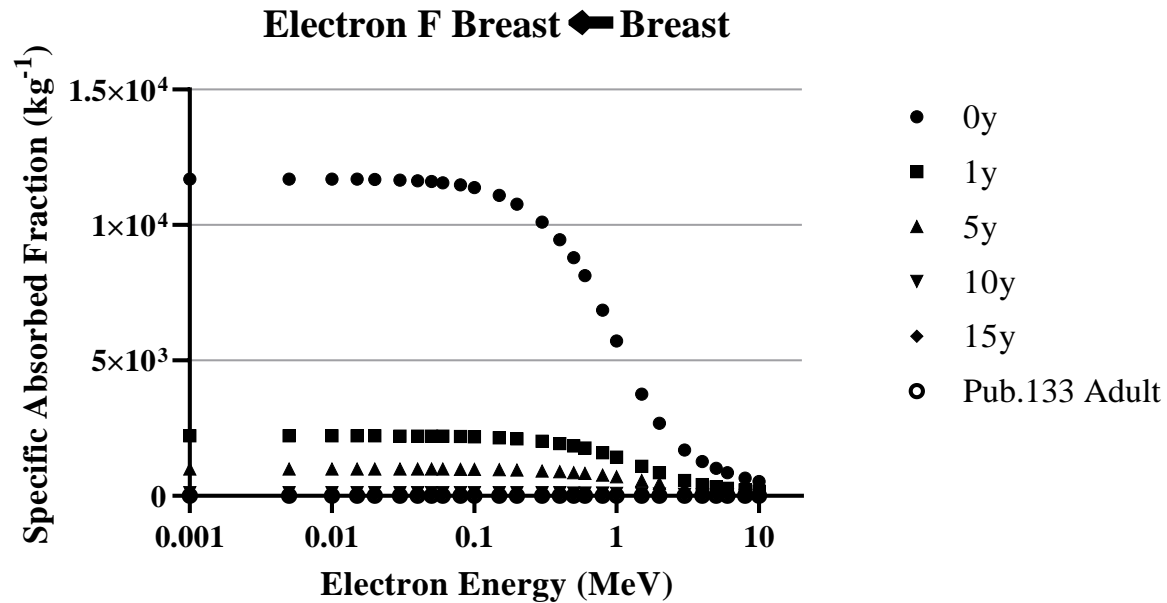


External Environmental Exposures - ICRP Publ. 144

Age dependency of effective dose coefficients

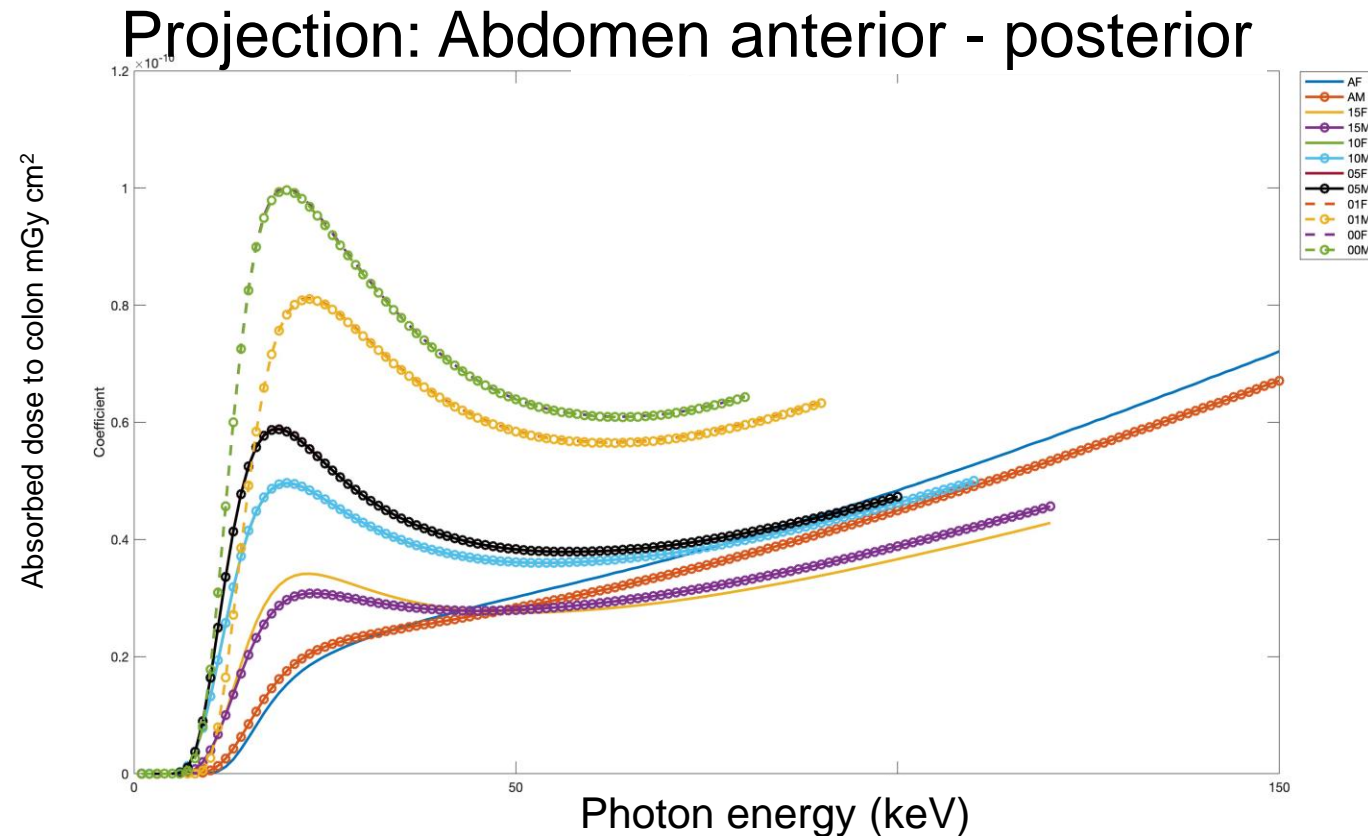


Current ICRP work: pediatric Specific Absorbed Fractions - Publication draft soon available for public consultation



Current ICRP work (2): Organ dose coefficients for diagnostic radiology; Scope

- Provide reference dose coefficients for radiographic, CT and diagnostic fluoroscopic X-ray imaging procedures



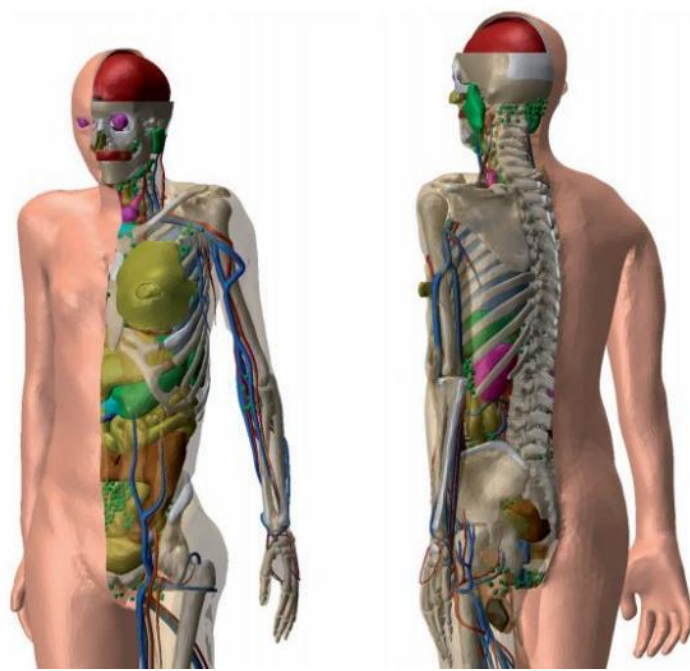
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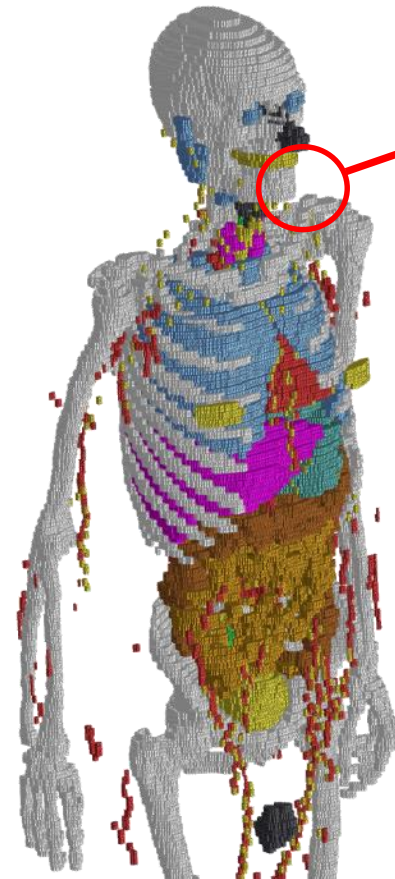
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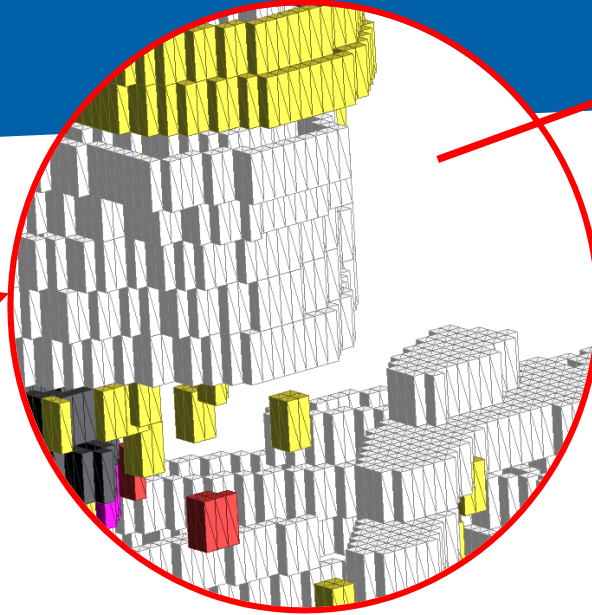
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Ann. ICRP 49(3).'

ICRP 110 Reference Phantoms - limitations due to voxel resolution



Male
Voxel size:
 $2.137 \times 2.137 \times 8 \text{ mm}^3$



Stair-stepped surfaces, not fully closed

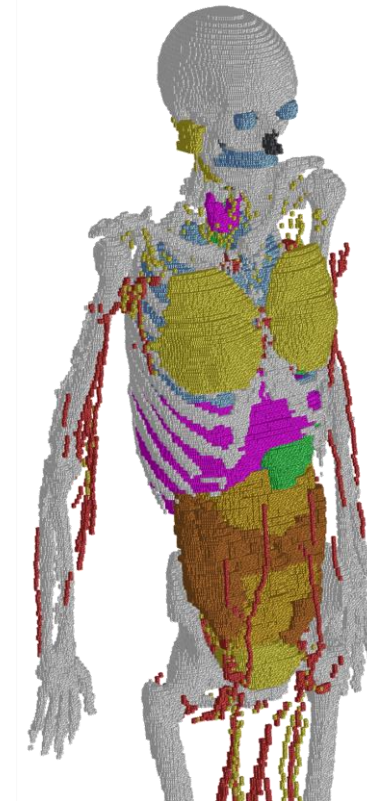
Thin/tiny objects cannot be represented (e.g. stem cell layers)



Necessity to use 12 additional stylised phantoms for dose coefficient calculations



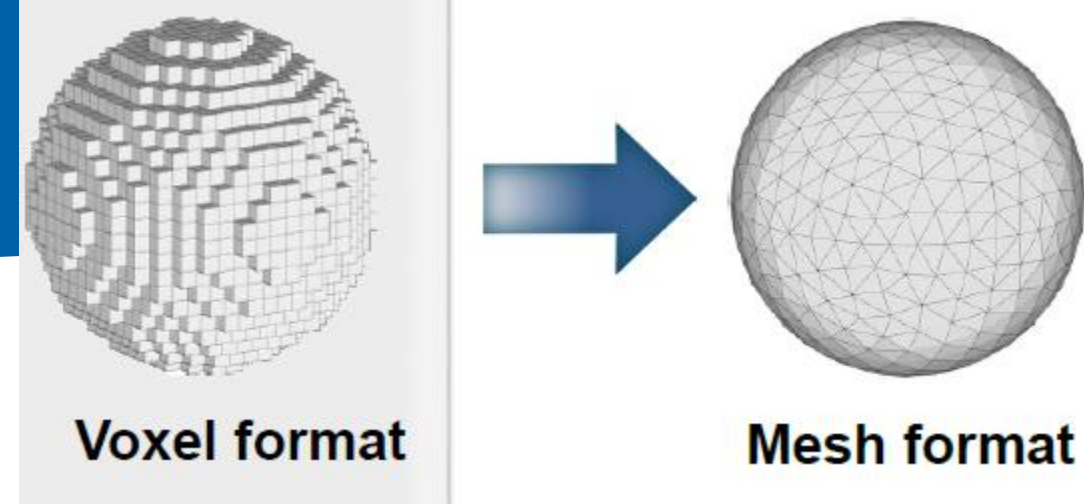
voxels



Female
Voxel size:
 $1.775 \times 1.775 \times 4.8 \text{ mm}^3$

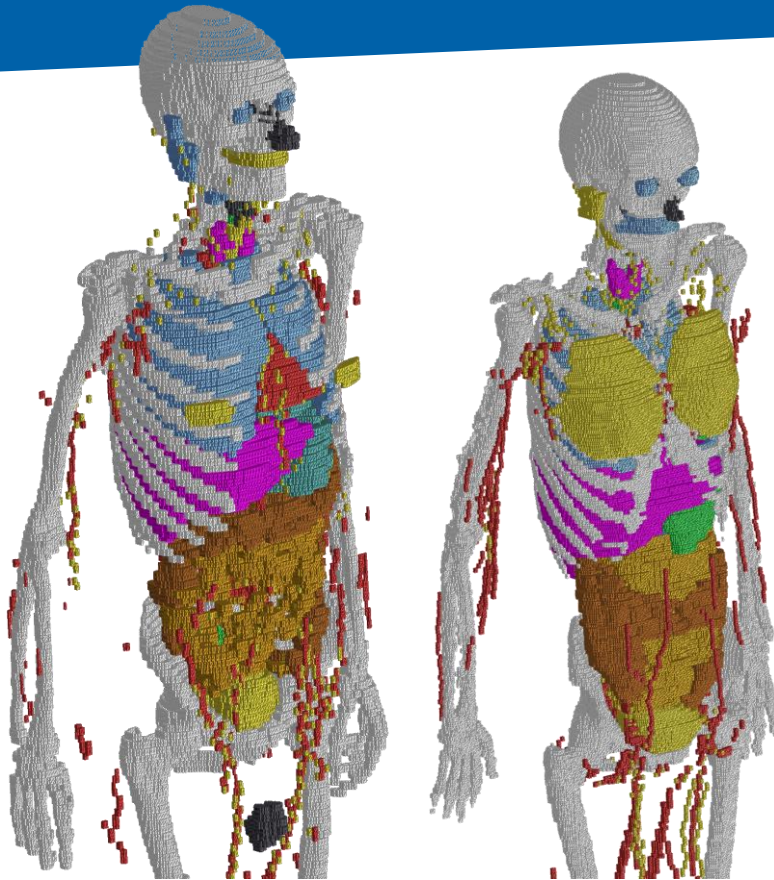
ICRP Mesh type phantoms

Scope: to produce “exact replica“ of the reference adult voxel phantoms in a high-quality polygon-mesh (PM) format to address the limitations

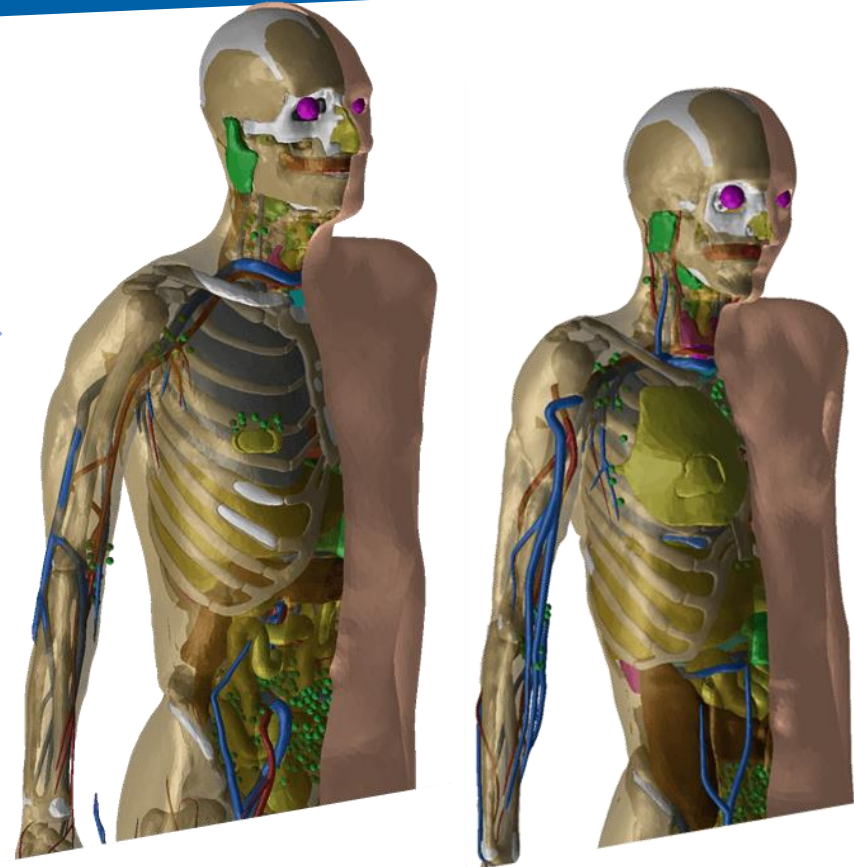
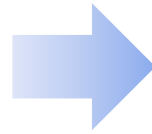


- **The developed phantoms include**
 1. continuous and fully-enclosed surfaces for skin, stomach, gall bladder, and urinary bladder;
 2. thin target layers (8-50 μm) in the alimentary and respiratory tract organs, eye lens and skin; and
 3. detailed and more accurate models for skeletal system, eyes, lymphatic nodes, blood vessels, hands, feet, etc.

MRCPs (Mesh-type Reference Computational Phantoms)



ICRP 110 Reference Phantoms



MRCPs
(Mesh-type Reference
Computational Phantoms)

Mesh-type phantoms – Complete

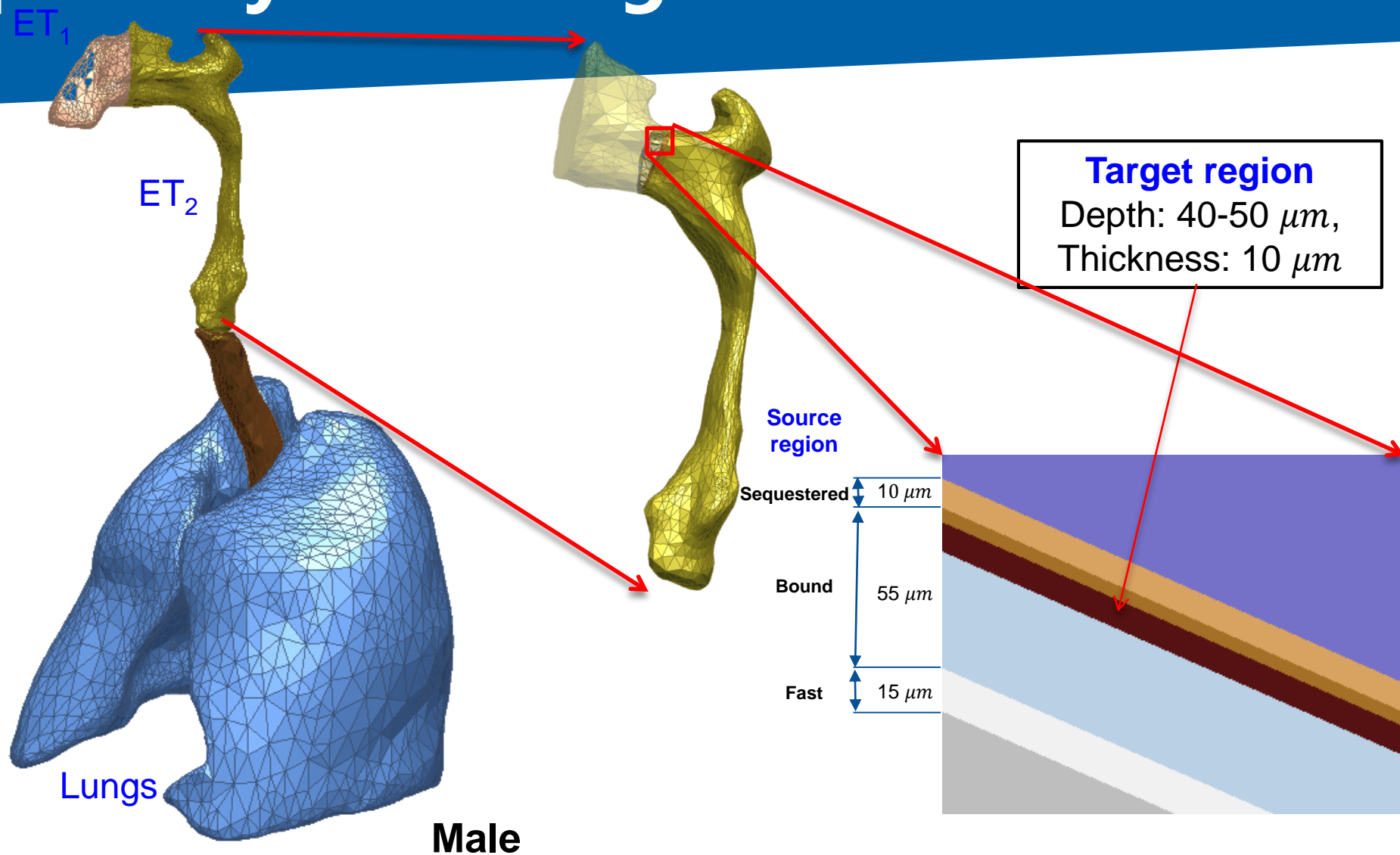
Male



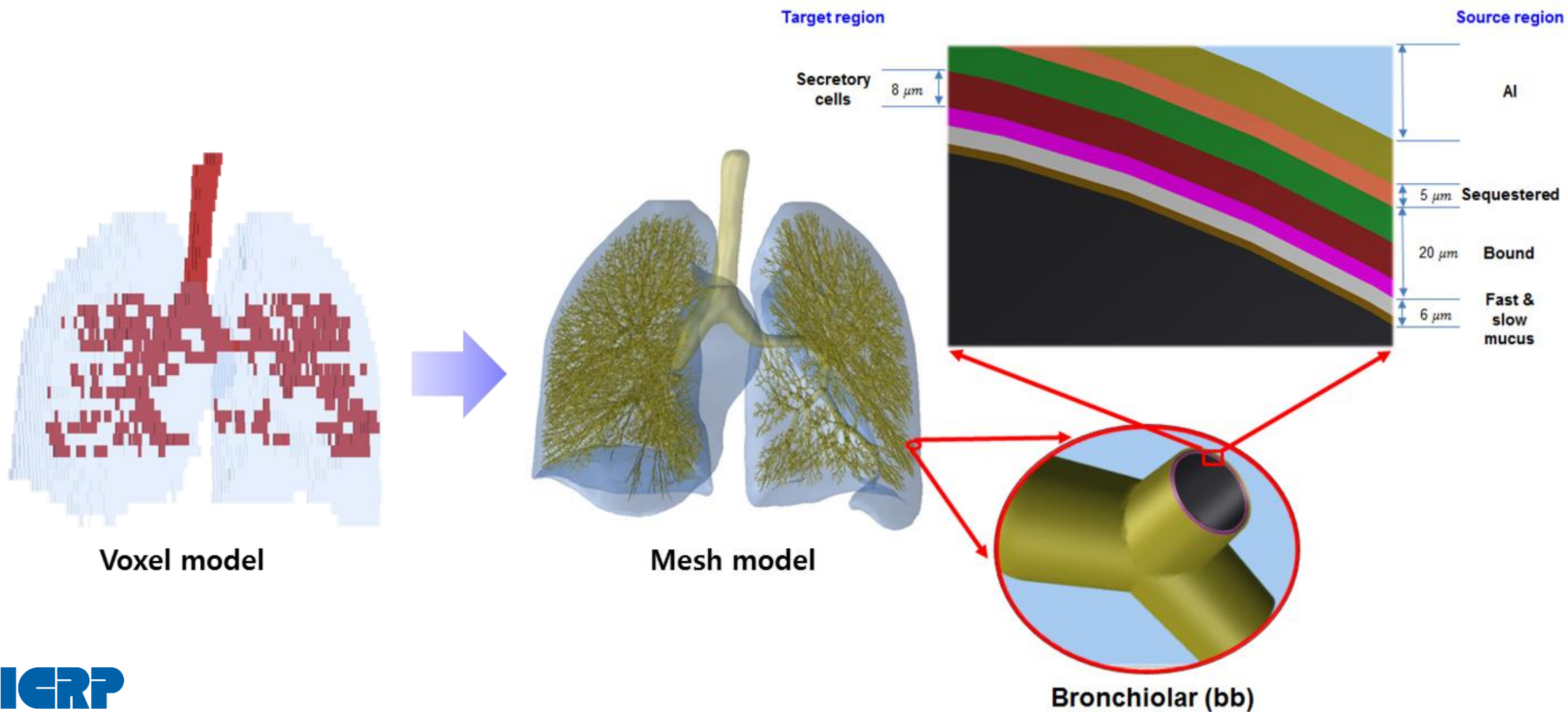
Female



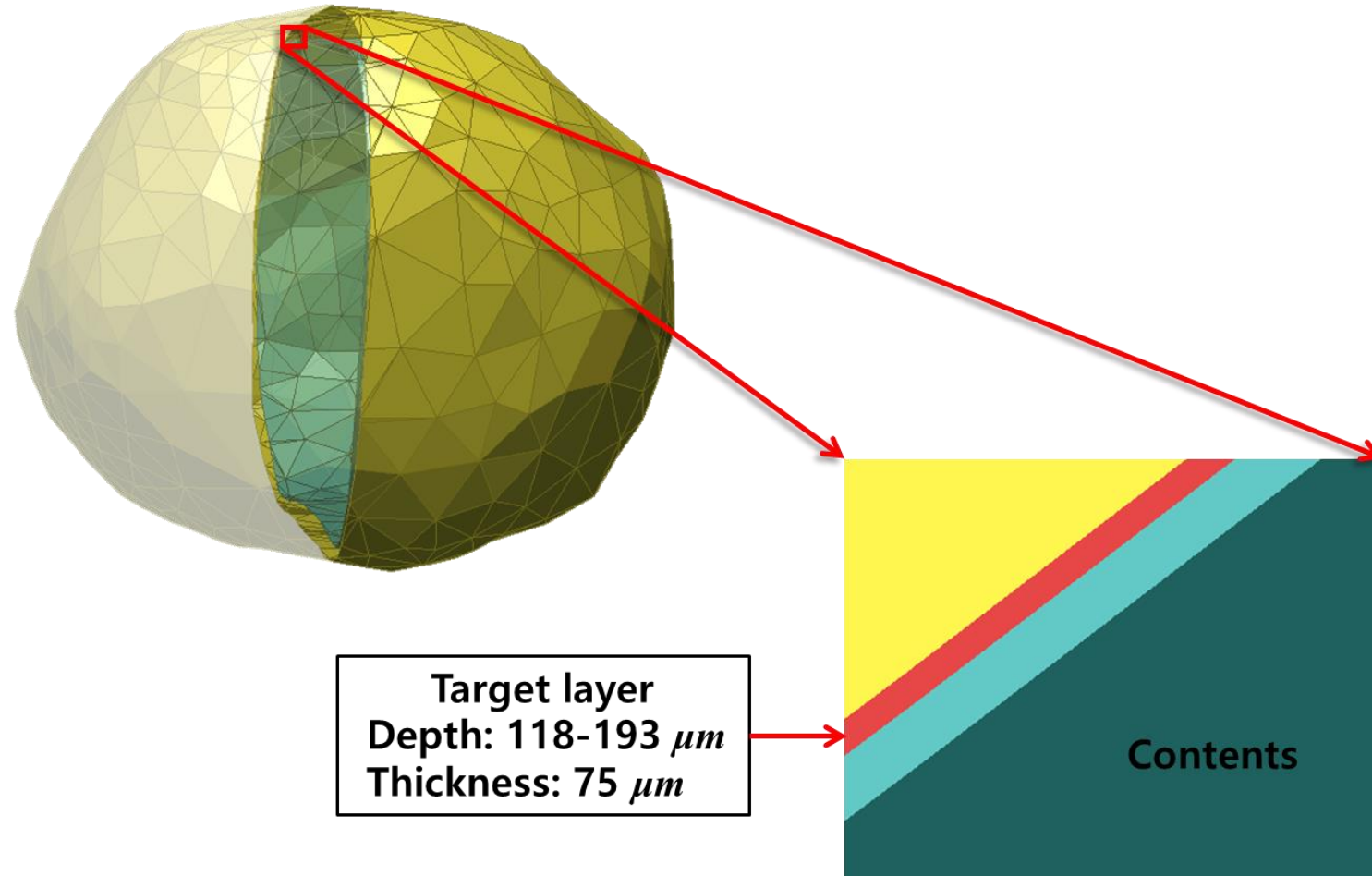
Respiratory Tract Organs



Airway Model of Lungs

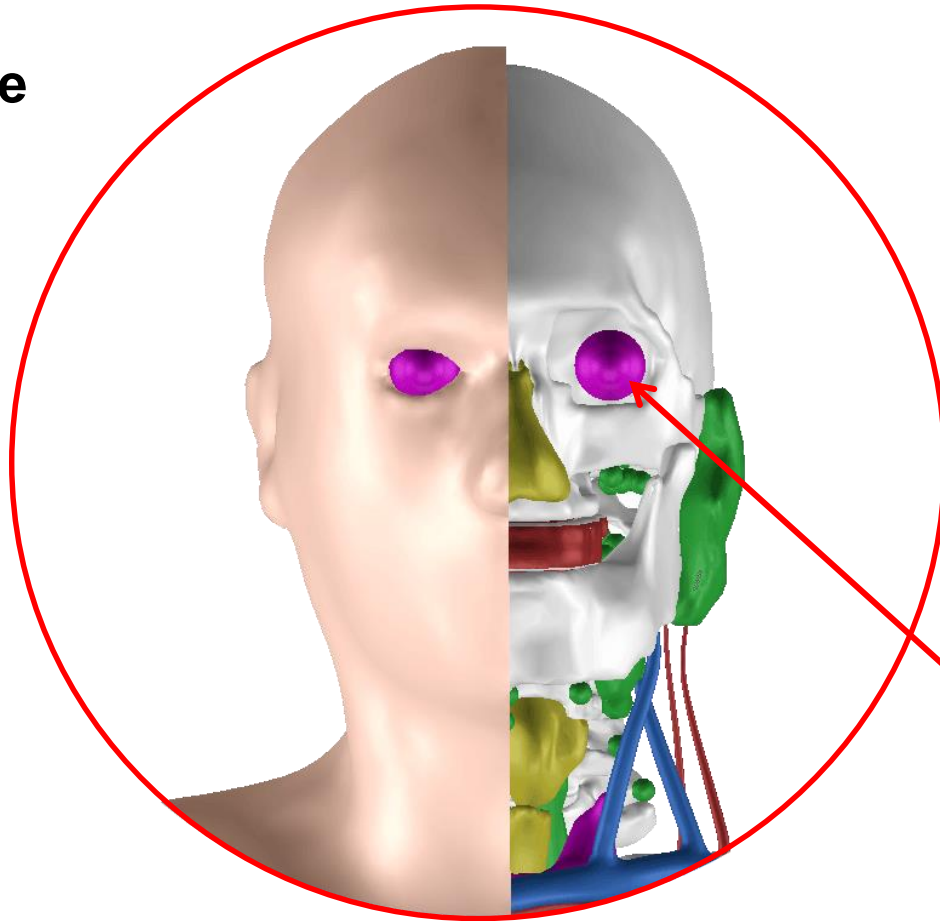


Urinary Bladder

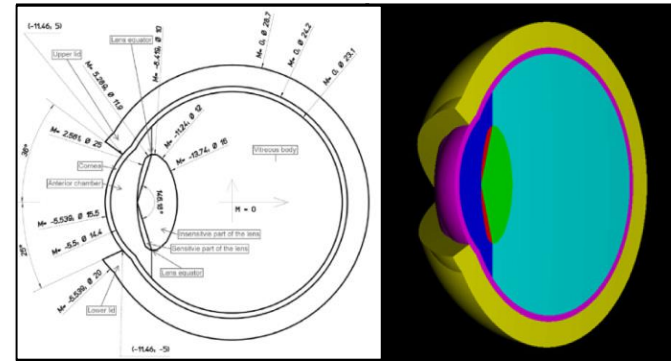


Eyeballs

Male

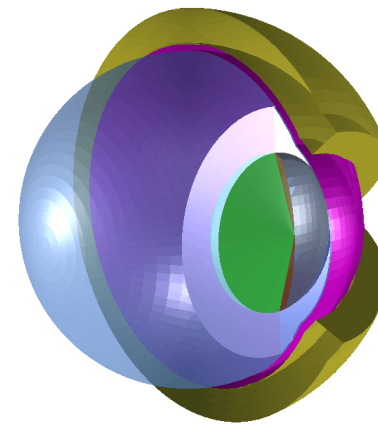


Behrens' eye model (2009)



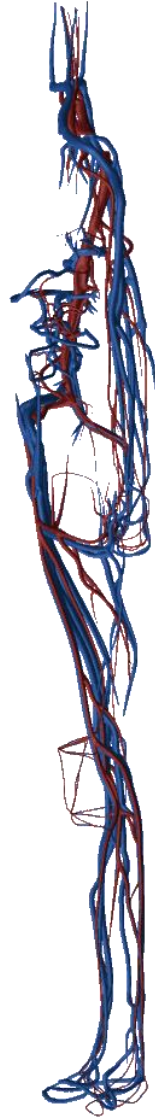
Converted to
mesh format

Installed



Blood in large arteries and veins

Male



Female



Muscle

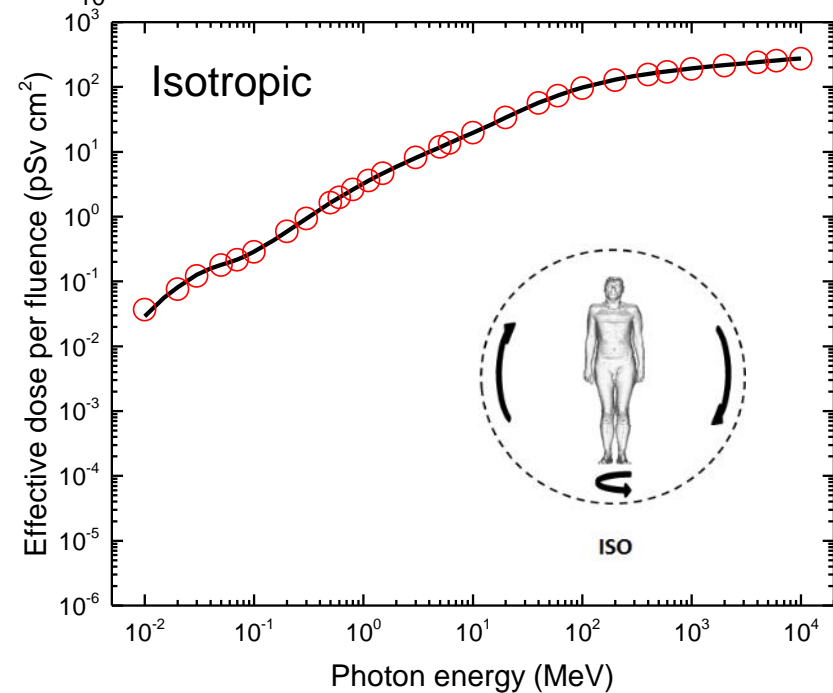
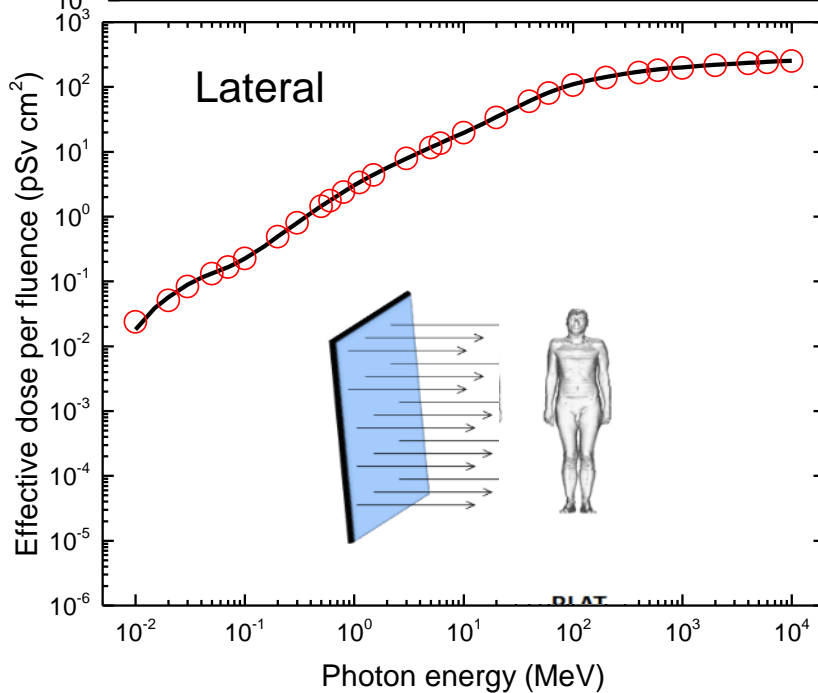
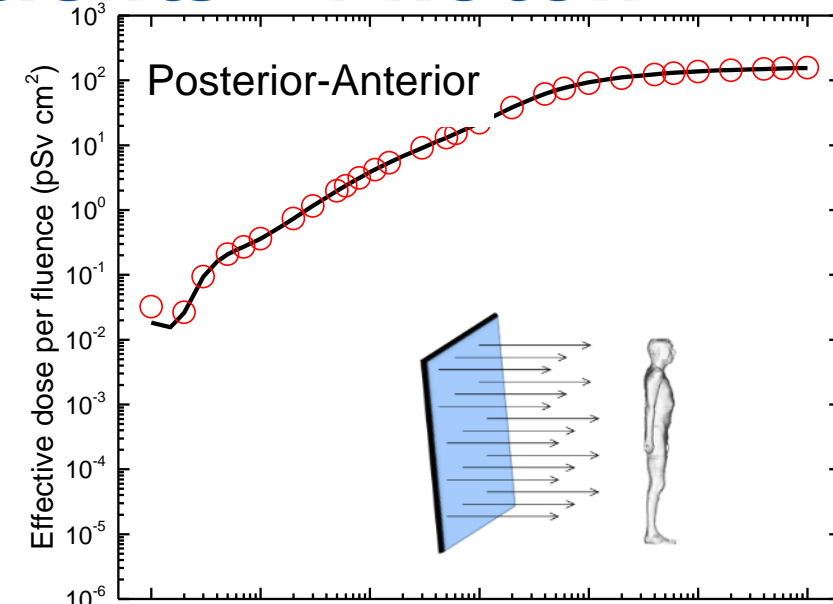
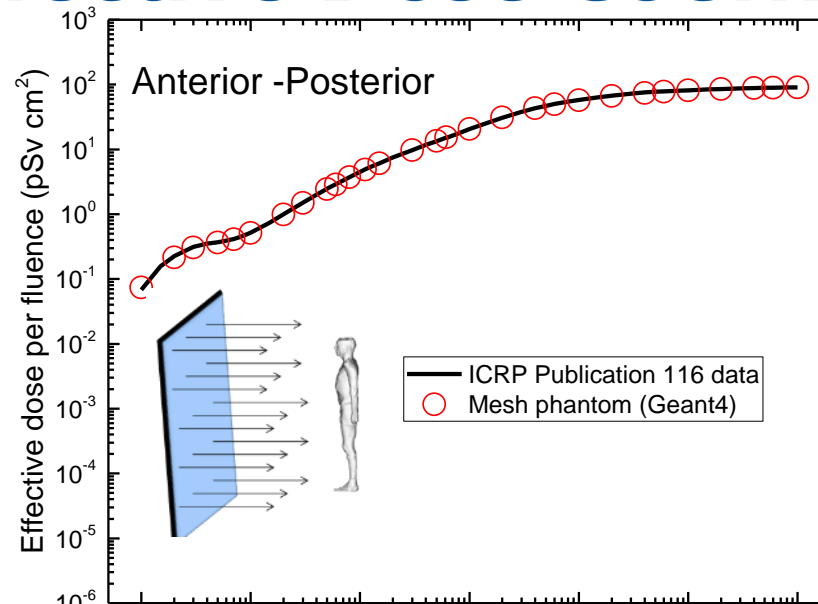
Male



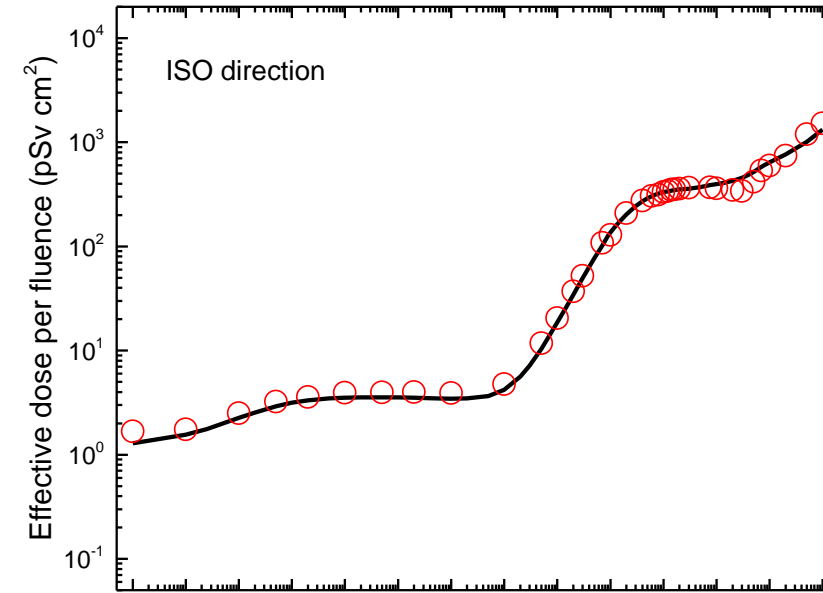
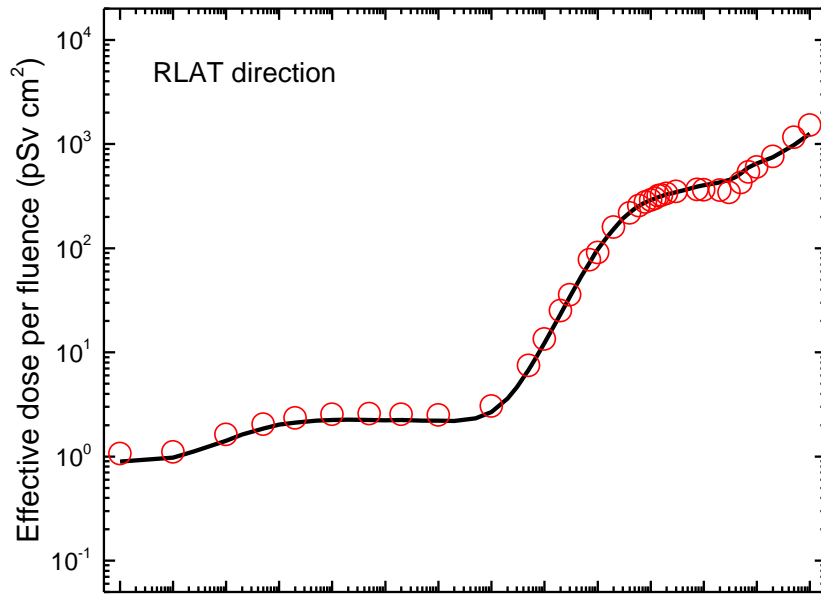
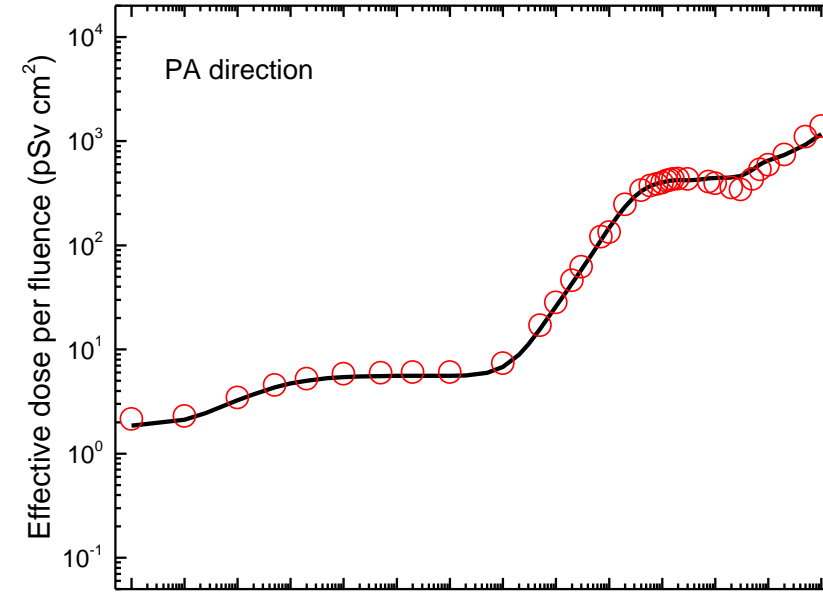
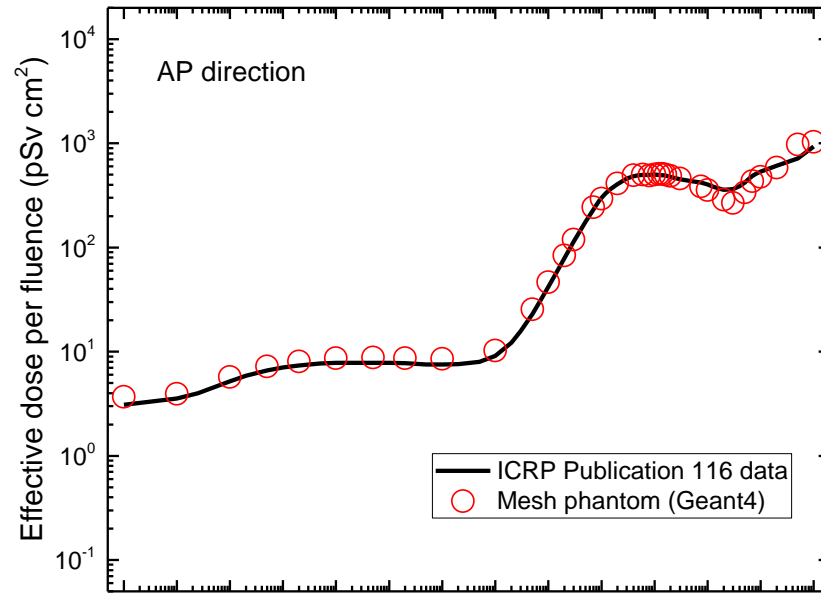
Female



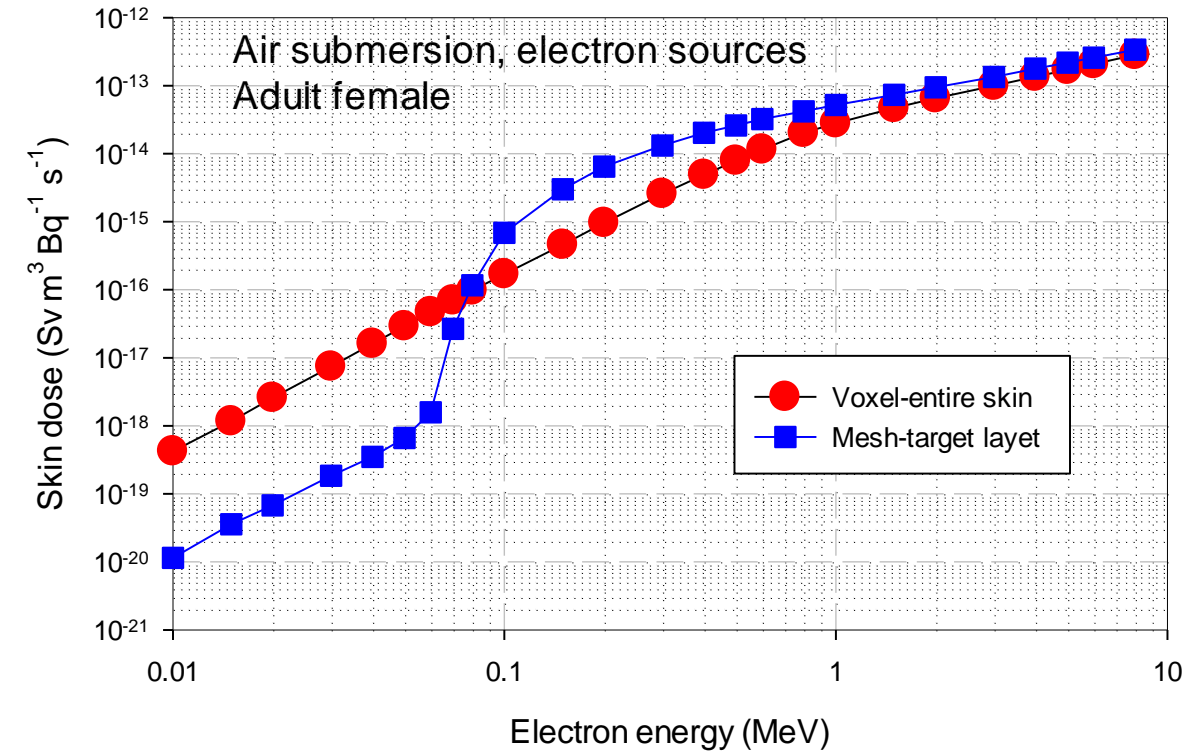
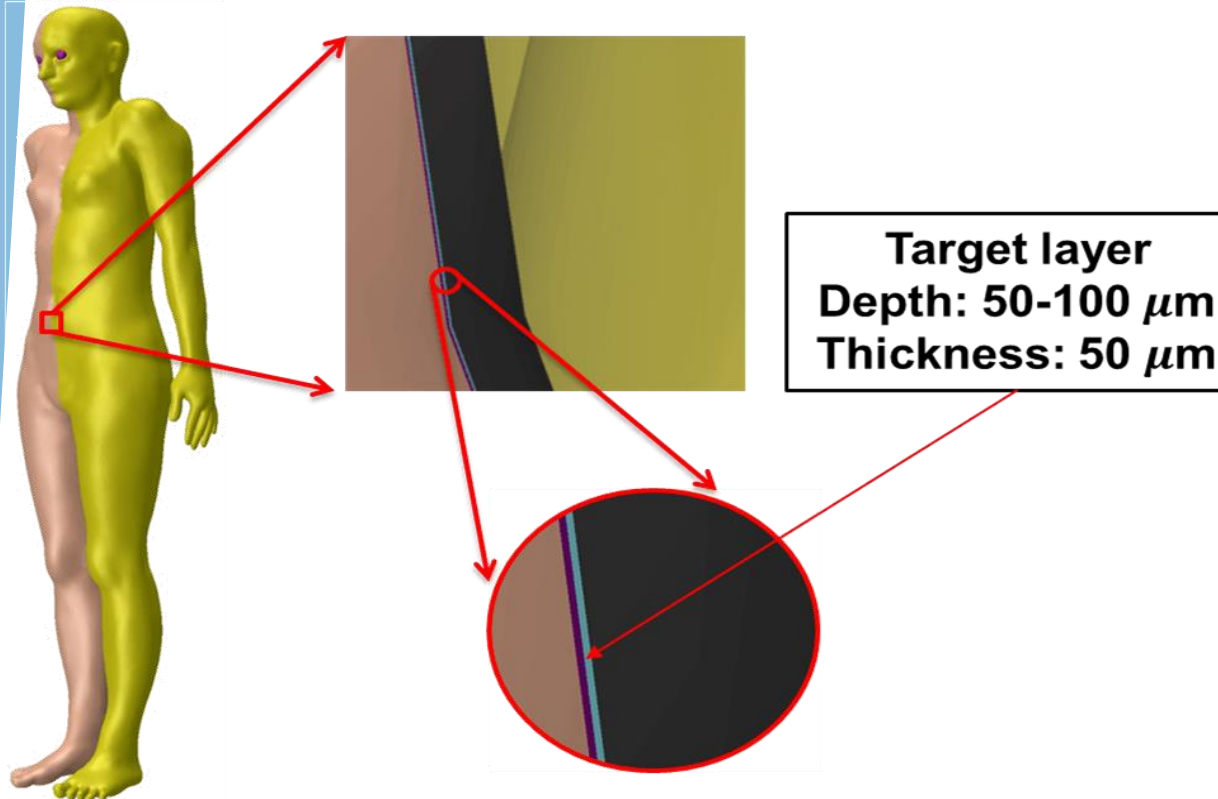
Effective Dose Coefficients – Photon



Effective Dose Coefficient – Neutron



Skin dosimetry - electrons



Mesh phantoms (1)

- The polygon-mesh (PM) versions of the ICRP-110 reference adult phantoms include
 - **continuous and fully-enclosed** surfaces for the skin, stomach, gall bladder, and urinary bladder
 - **thin target layers (8-50 μm)** in the respiratory and alimentary tract organs, and skin; and
 - **detailed and more accurate models** for skeletal system, eye lens, lymphatic nodes, blood vessels, hands, and feet

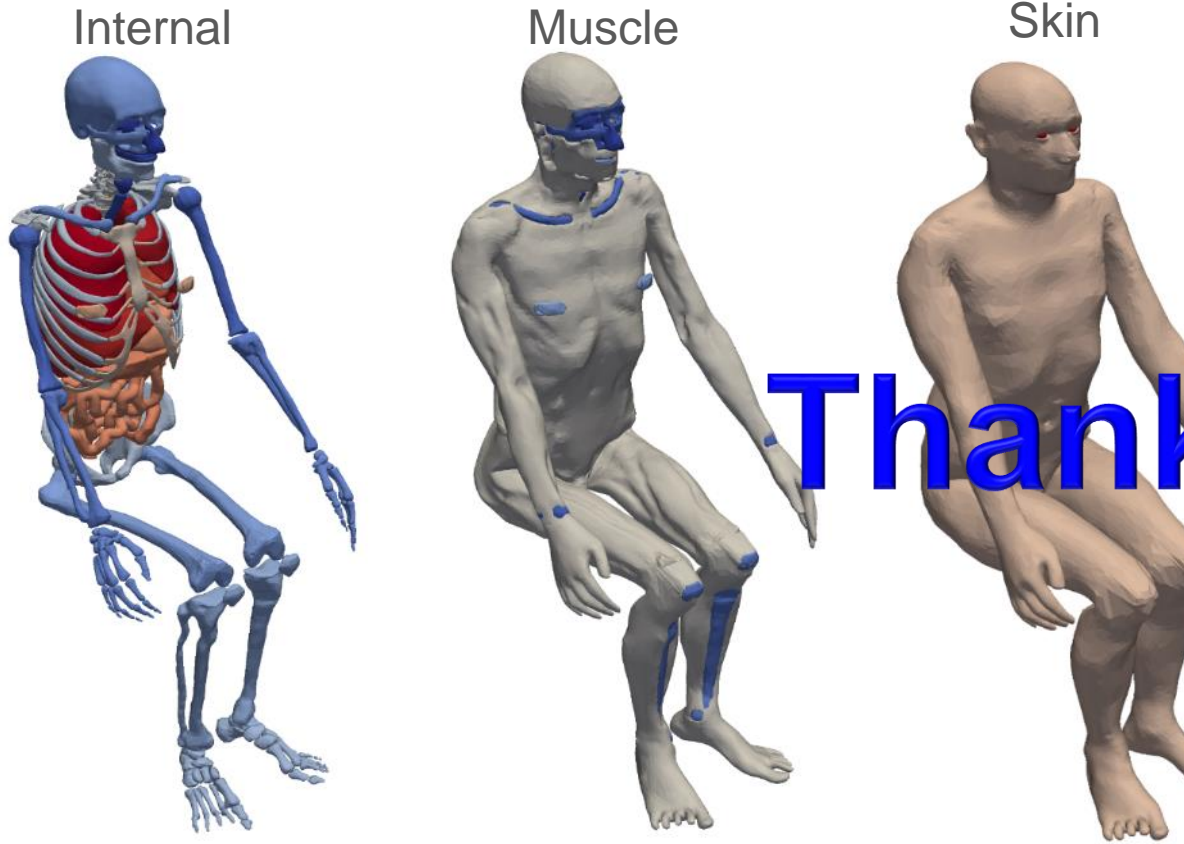
Mesh phantoms - Conclusions (2)

- The developed phantoms lead to
 - **very similar dose values** to those obtained with the ICRP-110 voxel reference phantoms for highly-penetrating radiations (photons ≥ 0.03 MeV, neutrons), and
 - **more accurate dose values** for weakly-penetrating radiation (electrons, ions)
- The mesh phantoms are “**all-in-one**” **detailed** phantoms
- They can be used in Monte Carlo simulation codes **without voxelization**
- They are **deformable**, could be adjusted **to individual anatomy** and **different postures**

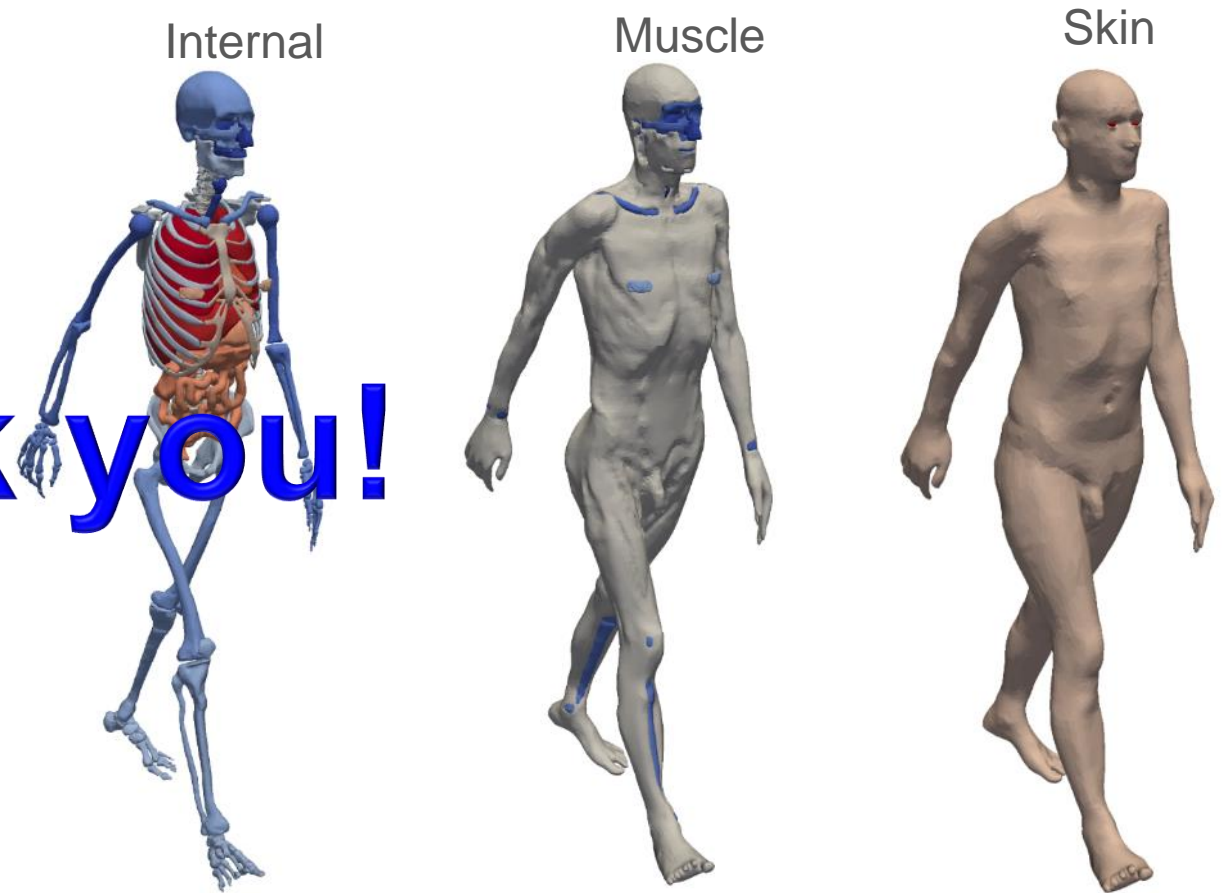
Computational speed

- Geant4
 - The MRCPs are **roughly comparable** to a 0.6 mm resolution voxel phantom
- MCNP6
 - The MRPCs are **slower** than a 0.6 mm resolution voxel phantom by 3-20 times
 - “unstructured mesh geometry format”
- PHITS
 - The MRCPs are **faster** than ICRP 110 reference phantoms

Sitting Posture



Walking Posture



Thank you!