HelmholtzZentrum münchen
German Research Center for Environmental Health

Computational Phantoms, ICRP/ICRU and further developments

M. Zankl[1], J. Becker[1], C. Lee[2], W.E. Bolch[3], Y.S. Yeom[4], C.H. Kim[4]

[1] Research Unit Medical Radiation Physics and Diagnostics, Department of Radiation Sciences, Helmholtz Zentrum München, Neuherberg, Germany
[2] Radiation Epidemiology Branch, National Cancer Institute, National Institutes of Health (NIH), Rockville, U.S.A.
[3] J. Crayton Pruitt Family Department of Biomedical Engineering, University of Florida, Gainesville, U.S.A.
[4] Department of Nuclear Engineering, Hanyang University, Seoul, Korea

HELMHOLTZ ASSOCIATION

Overview

- Background (radiological protection)
- ICRP adult male and female reference computational phantoms
  - Specification
  - Method of construction
  - Limitations
- ICRP 110 reference phantoms conversion project at Hanyang University, Seoul, Korea
- ICRP pediatric reference computational phantoms developed at UF/NCI, USA
- Fetus and pregnant computational phantoms developed at UF, USA

Protection against ionising radiation

Risk from ionising radiation:

- Potential detrimental effects on human health at higher exposure levels
- Needs to be limited

Radiation protection legislation and infrastructure that limits annual doses to

- whole body
- individual radiation-sensitive organs

at workplaces and from the environment

Dose quantities for radiological protection

Physical quantities
- Fluence, Φ
- Kerma, K
- Absorbed dose, D

Calculated using Q(L) and selected phantoms (sphere, slab, rod, …)

Calculated using w_R, w_T, and anthropomorphic phantoms

Operational quantities
- Ambient dose equivalent, $H^*(d)$
- Directional dose equivalent, $H'(d, \Omega)$
- Personal dose equivalent, $H_p(d)$

Protection quantities
- Organ absorbed dose, D_T
- Organ equivalent dose, H_T
- Effective dose, E

Related by calibration and calculation

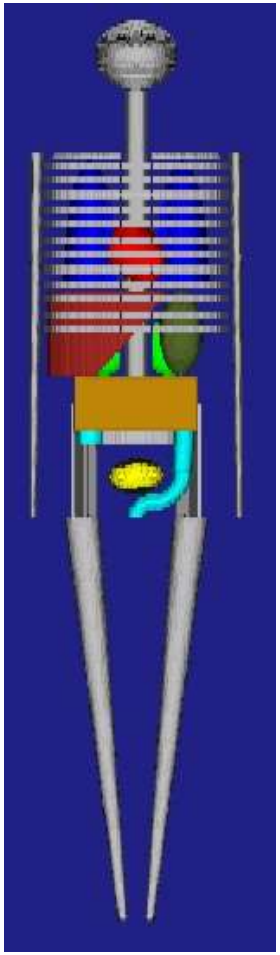
Monitored quantities
Instrument responses

Comparison

- As long as the monitored quantities are below certain levels, compliance of the protection quantities with the legal dose limits is assured.
- Conversion coefficients provide relationships between operational and protection quantities, thus allowing organ and effective doses to be assessed in practice.

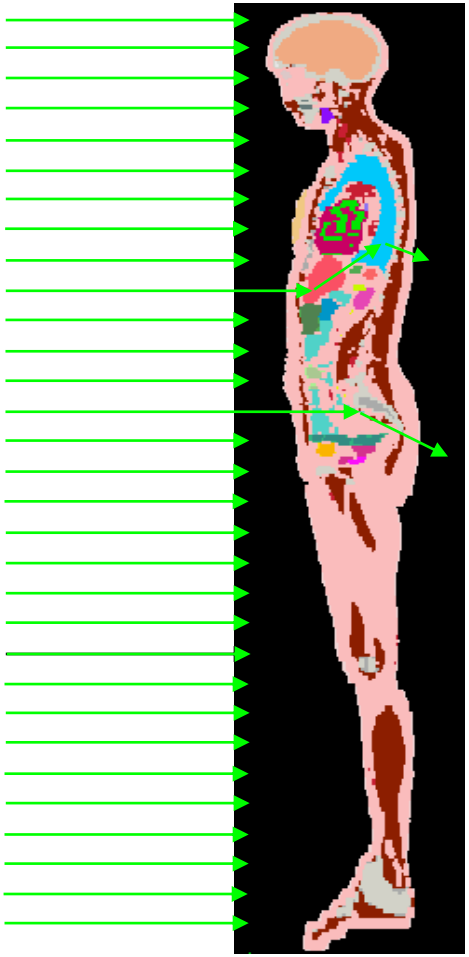
Calculation of conversion coefficients with radiation transport programs

Past

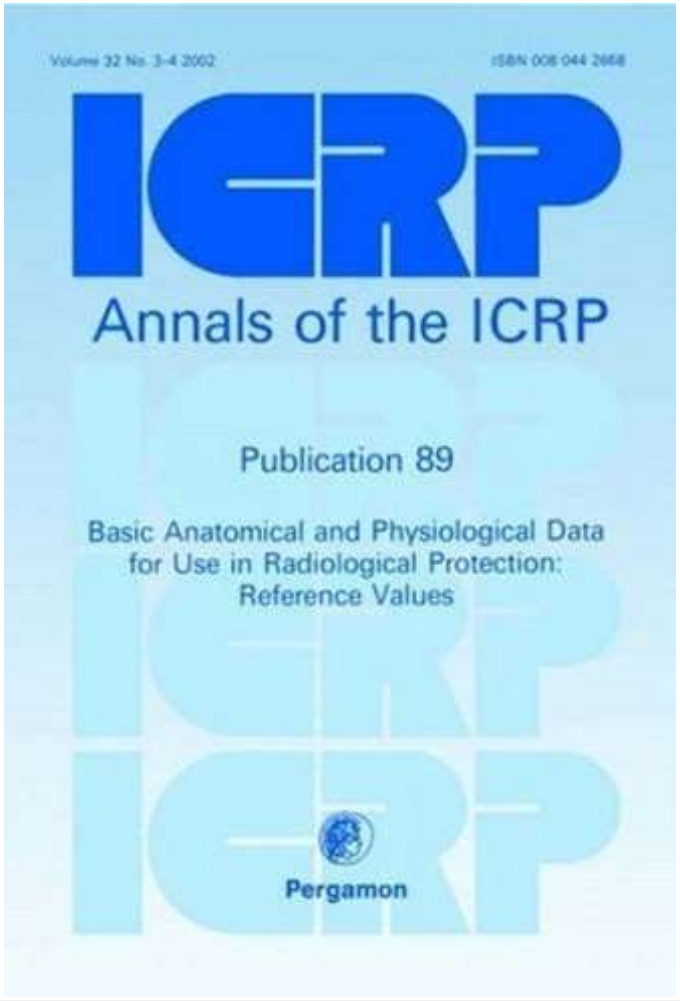


- Model of the radiation source
- Model of the body
- Physical models of
  - radiation interactions
  - energy depositions

Present



For legislation, „standard“ (or „reference“) persons are needed



ICRP has specified their main characteristics:

Table 2.9. Reference values for height, mass, and surface area of the total body

	Height (cm)		Mass (kg)	
Age	Male	Female	Male	Female
Newborn	51	51	3.5	3.5
1 year	76	76	10	10
5 years	109	109	19	19
10 years	138	138	32	32
15 years	167	161	56	53
Adult	176	163	73	60

Reference masses for 56 organs, organ groups, and tissues

Reference computational phantoms – Method of construction

Select segmented voxel models of male and female individual whose body height and mass closely resemble the ICRP 89 reference values

„Golem“:	176 cm,	69 kg	(176 cm,	73 kg)
„Laura“:	167 cm,	59 kg	(163 cm,	60 kg)

Modify these segmented voxel models in several steps

- Voxel scaling
- Individual organ volume modifications
- Additional modifications (blood, lymphatic nodes, …)
- Sub-segmentation of bones (cortical bone, spongiosa, medullary cavity)

Golem

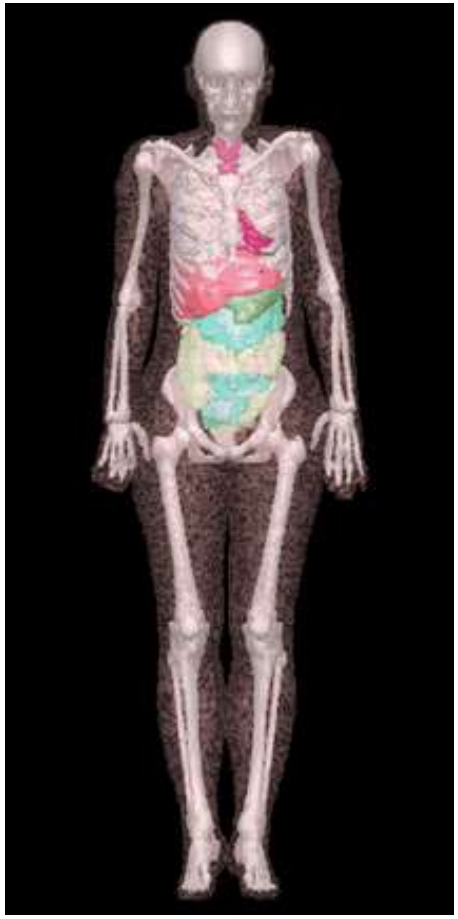
Laura

Reference computational phantoms – Characterisation

Male
176 cm, 73 kg
1.9 million voxels
Voxel size: 36.5 mm^3

140 Organ identification numbers

Female
163 cm, 60 kg
3.9 million voxels
Voxel size: 15.2 mm^3



Applications and conceptual limitations of the reference computational phantoms

These phantoms are the official computational models representing the ICRP Reference Male and Reference Female.

They are based on computed tomographic data of real persons.

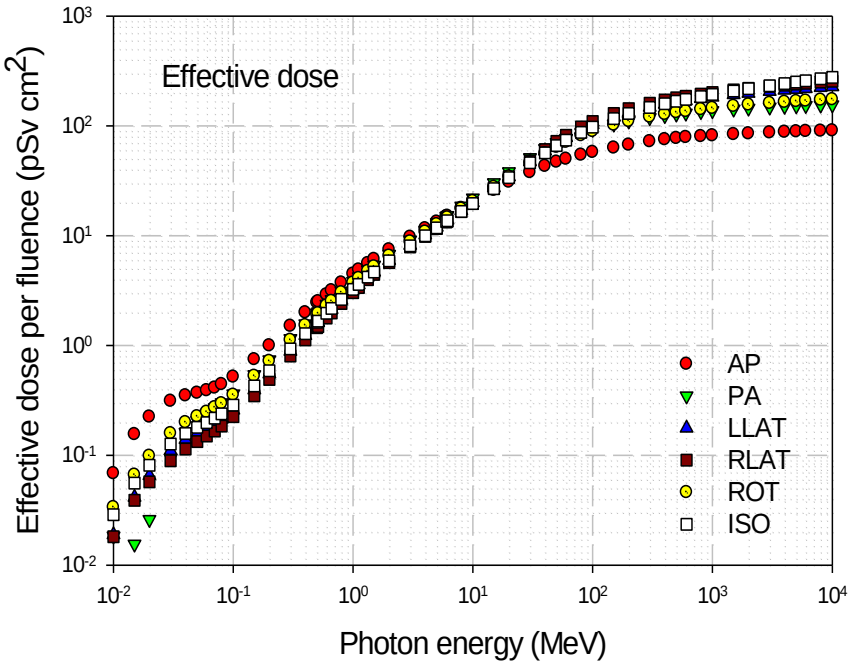
They are defined to enable calculations of the protection quantities organ and tissue equivalent dose and effective dose.

They have organ masses of reference values, but they have still individual organ topology reflecting the tomographic data used in their construction.

Both models cannot represent any real individual.

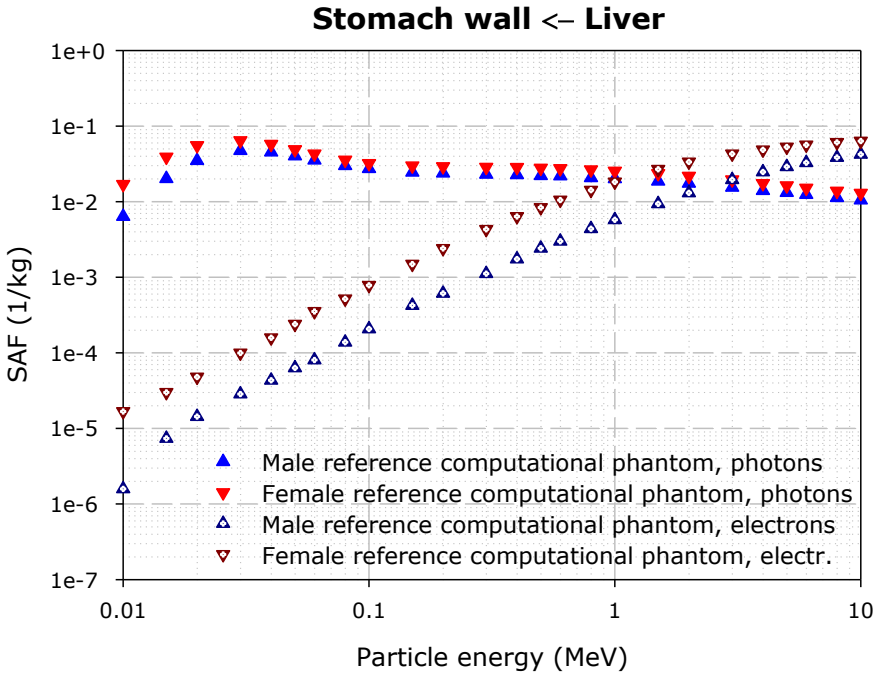
Current applications by the ICRP of the reference computational phantoms

Dose conversion coefficients (external exposures)



- ICRP Publication 116 (2010) „Conversion coefficients for radiological protection quantities for external radiation exposures ":
  Idealised exposure geometries
  Many different particles / radiation types
  Extensive energy ranges
- Forthcoming: Environmental exposures (age-dependent)

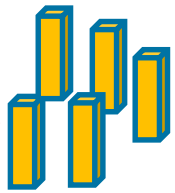
Specific absorbed fractions and dose coefficients (internal exposures)



- ICRP Publication 133 (2016) „The ICRP computational framework for internal dose assessment for reference adults: Specific absorbed fractions":
  SAFs for 60–70 source and target regions
  Alpha, beta, gamma radiation, neutron spectra
- ICRP Publication series on „Occupational intakes of radionuclides"

ICRP 110 Reference Phantoms – limitations due to voxel resolution

Male phantom
(Voxel size:
2.137×2.137×8 mm³)



voxels

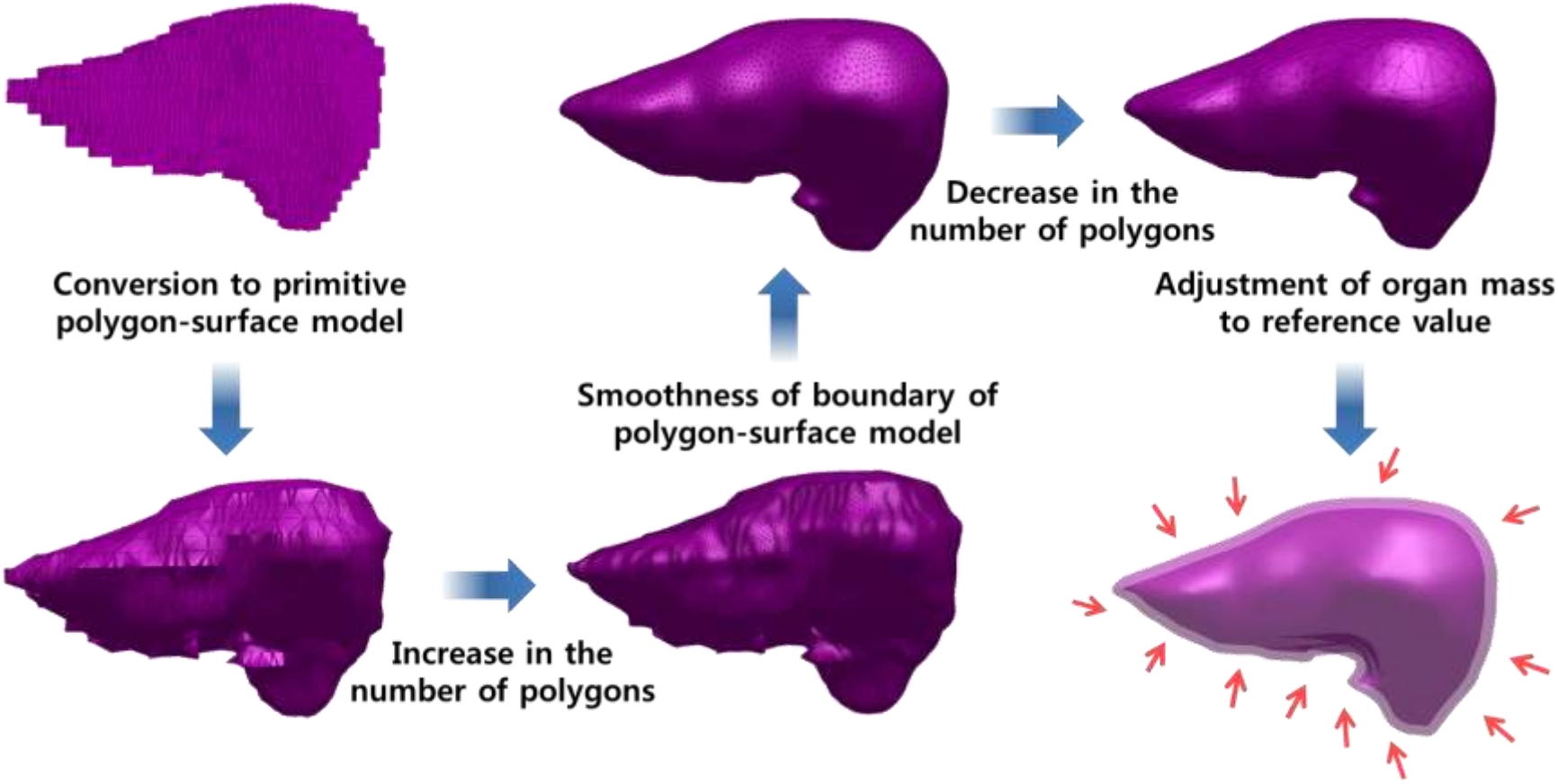
Stepped surfaces, not closed
Thin/tiny objects cannot be represented (e.g. stem cell layers)
=> Necessity to use 12 additional stylised phantoms for dose calculations

Female phantom
(Voxel size:
1.775×1.775×4.8 mm³)

Research project for creating BREP phantom versions

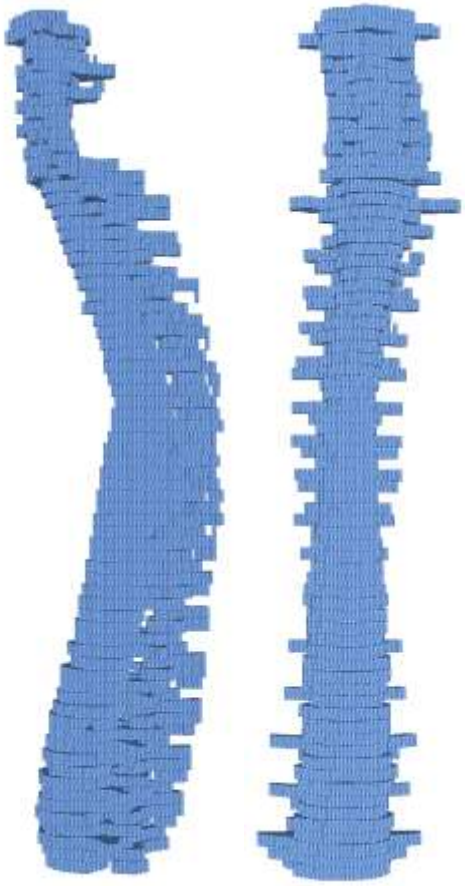
- Issue raised at ICRP Committee 2 meeting in Abu Dhabi, October 2013
- Decision „to produce exact replica of ICRP 110 reference phantoms in a high-quality polygon-mesh (PM) format"
- Task Group 103 „Mesh-type reference computational phantoms" created with this aim (Chair: Prof. Chan Kim, Hanyang University, Seoul, Korea)
- The phantoms include
  - Continuous and fully-enclosed walls for skin, stomach, gall bladder, and urinary bladder
  - Thin target layers (10-300 μm) for the alimentary and respiratory tract organs
  - Detailed and correct models for skeletal systems (including cartilage), eyes, lymphatic nodes, blood vessels, etc.

Conversion methods – simple organs: direct conversion



Method applicable for many organs and simple bones

Construction of spine

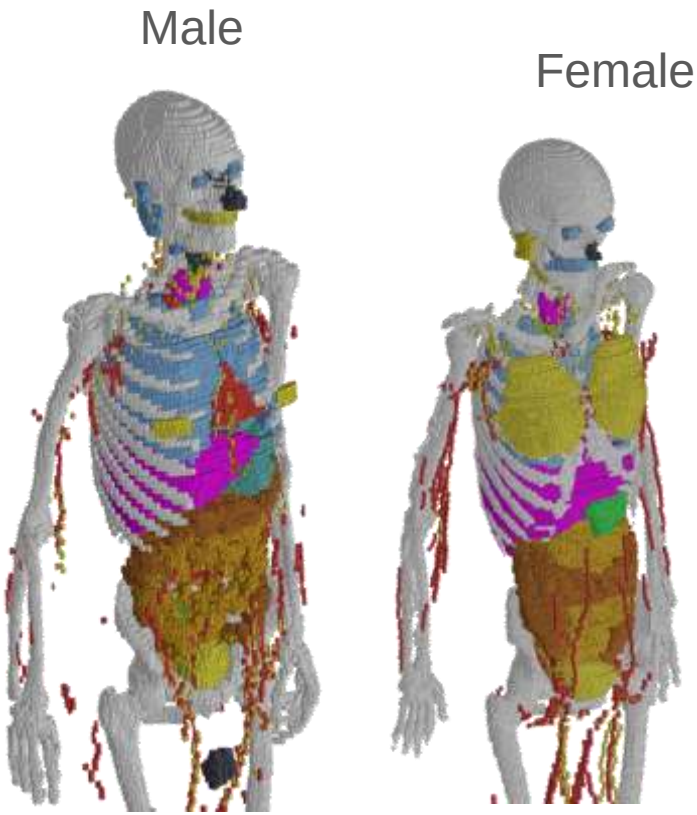


Fitting

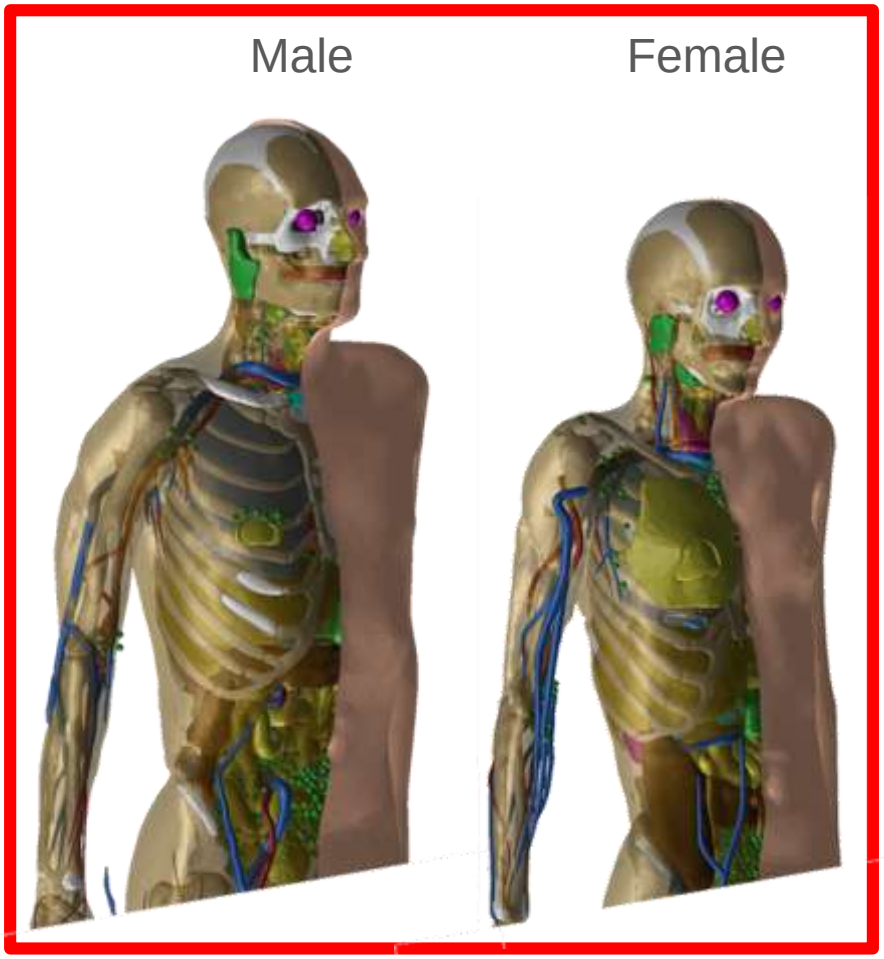
Voxel model

High-quality polygon model

Developed Phantoms

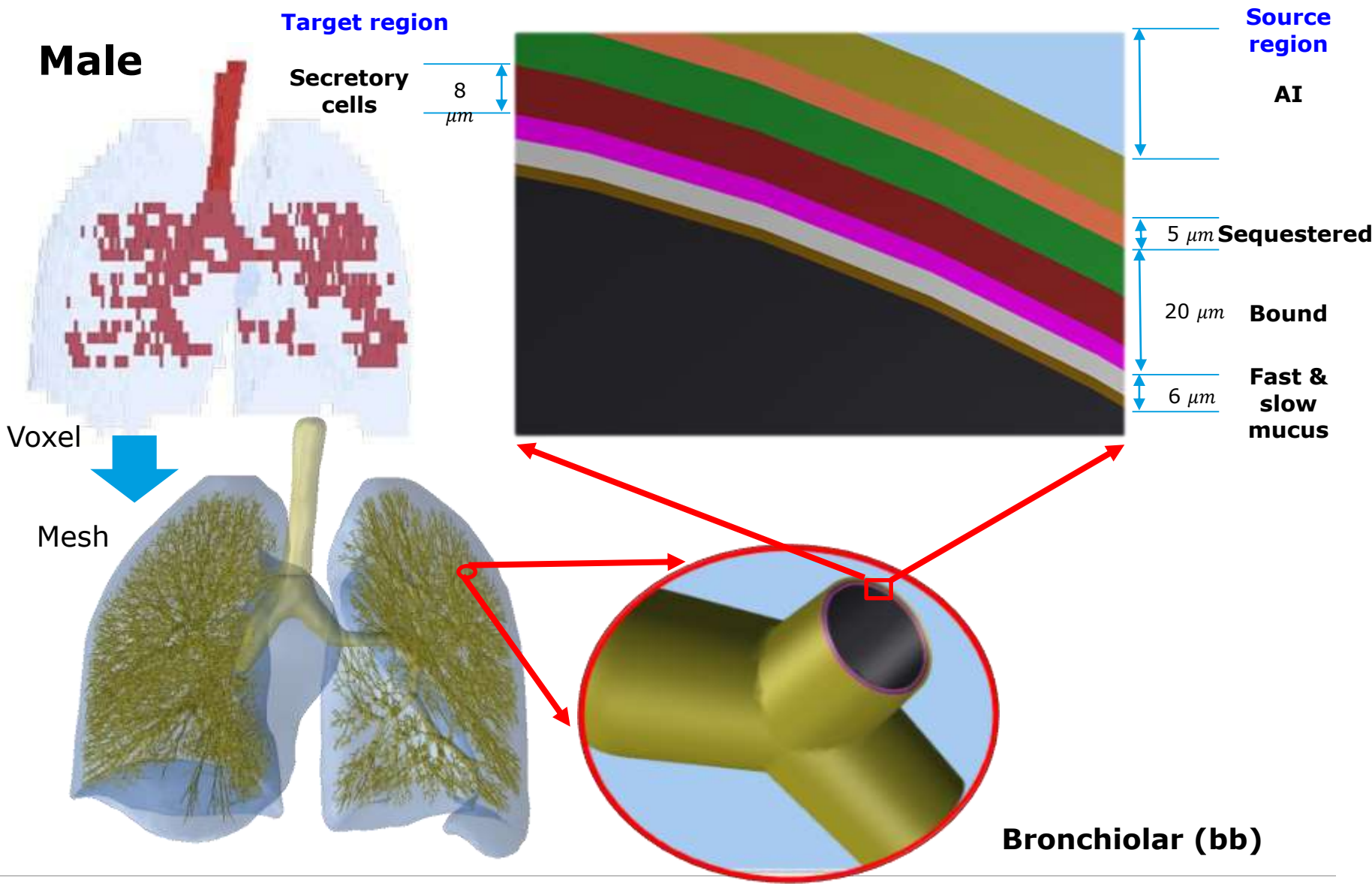


ICRP-110 phantoms
(voxel geometry)



Mesh-type reference computational phantoms

BB / bb – Source & Target Layers

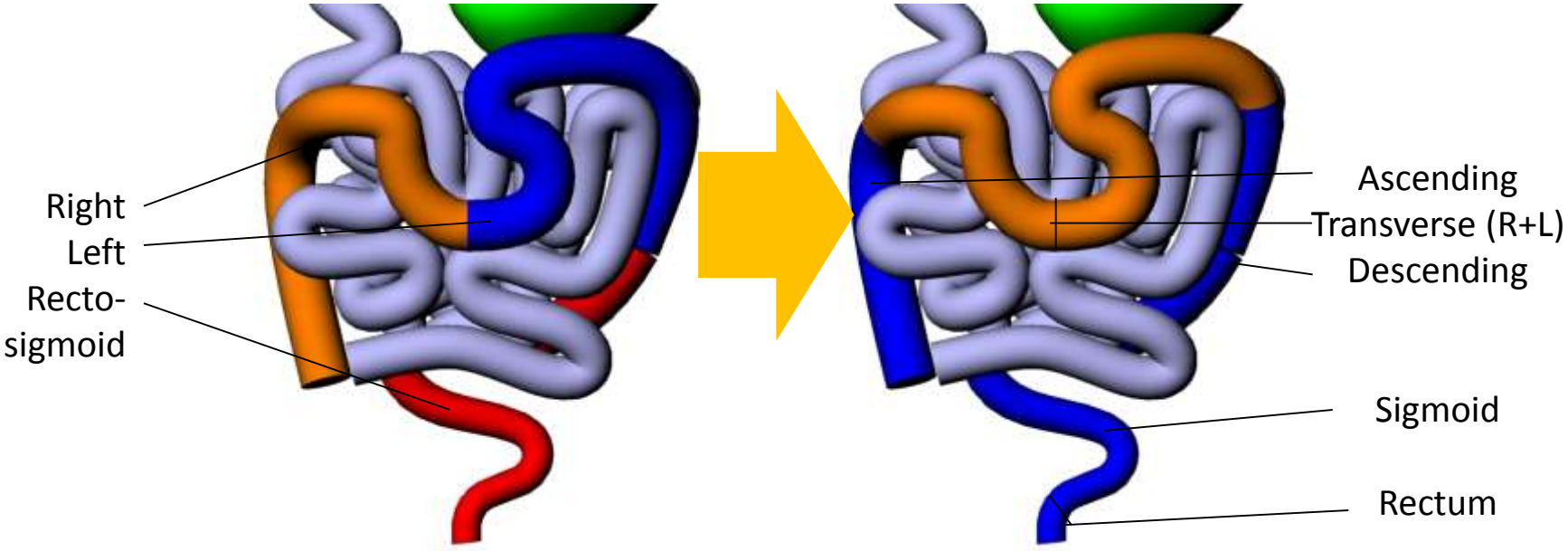


Polygon-mesh versions of ICRP 110 phantoms – Summary

- Polygon-mesh versions of the ICRP 110 phantoms are currently being finalized
- The final versions of the PM phantoms include
  - continuous and fully-enclosed hollow organs
  - thin target layers (10-300 μm) for the respiratory and alimentary tract organs
  - detailed models for skeletal systems, eye lens, lymphatic nodes, blood vessels, etc.
- The PM phantoms provide
  - similar dose values with the ICRP 110 phantoms for highly penetrating radiations
  - „correct" dose values for weakly penetrating radiations
- The PM phantoms are deformable, providing different postures (walking, sitting) to enable dose calculations for emergency exposure scenarios (planned for current term of ICRP)
- The PM phantoms can be made to move as necessary

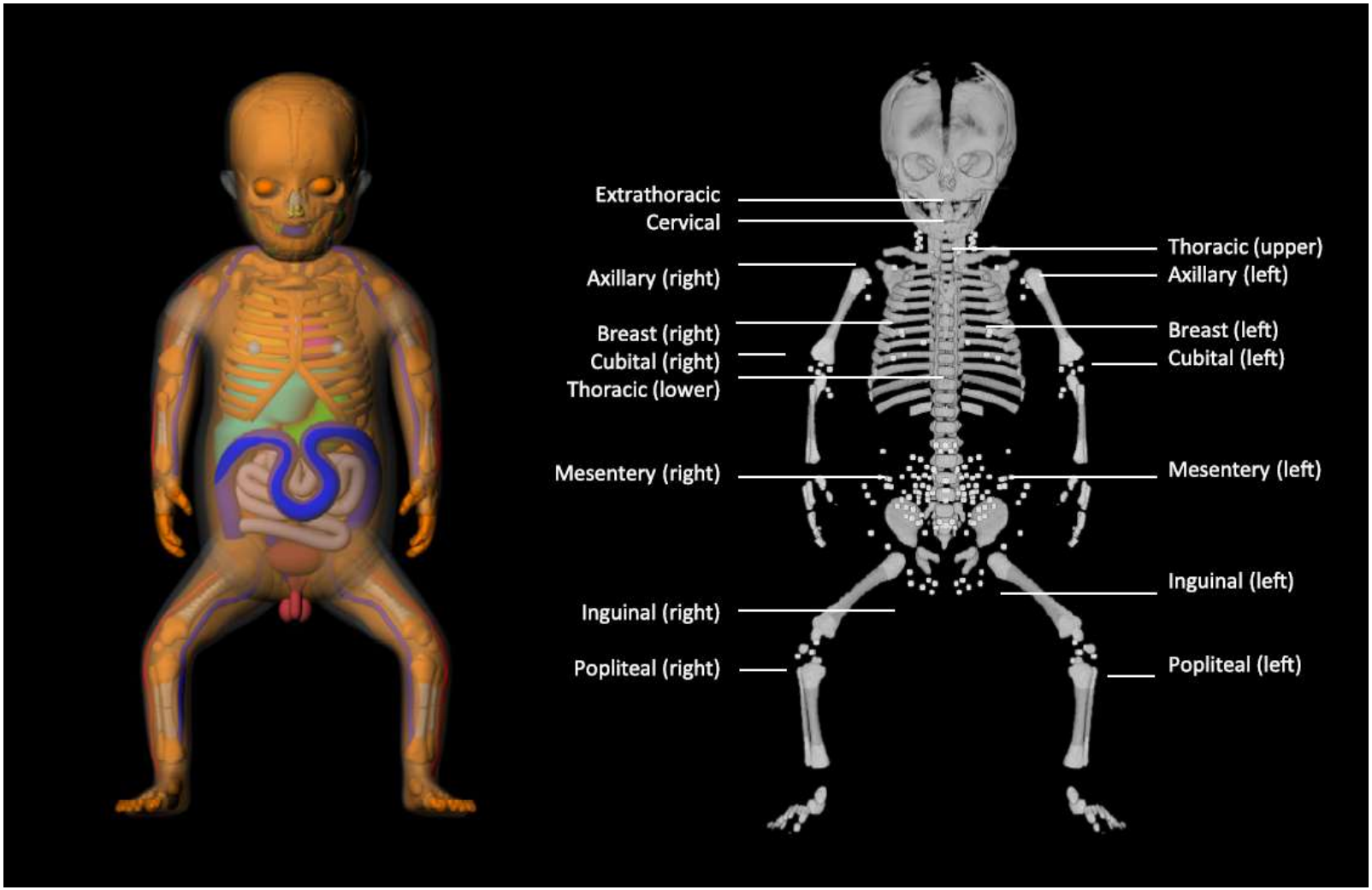
ICRP pediatric reference phantoms

- ICRP Committee 2 Task Group CPRT (Computational Phantoms and Radiation Transport)
- Adopt UF/NCI pediatric phantoms as starting points
  - Retagging

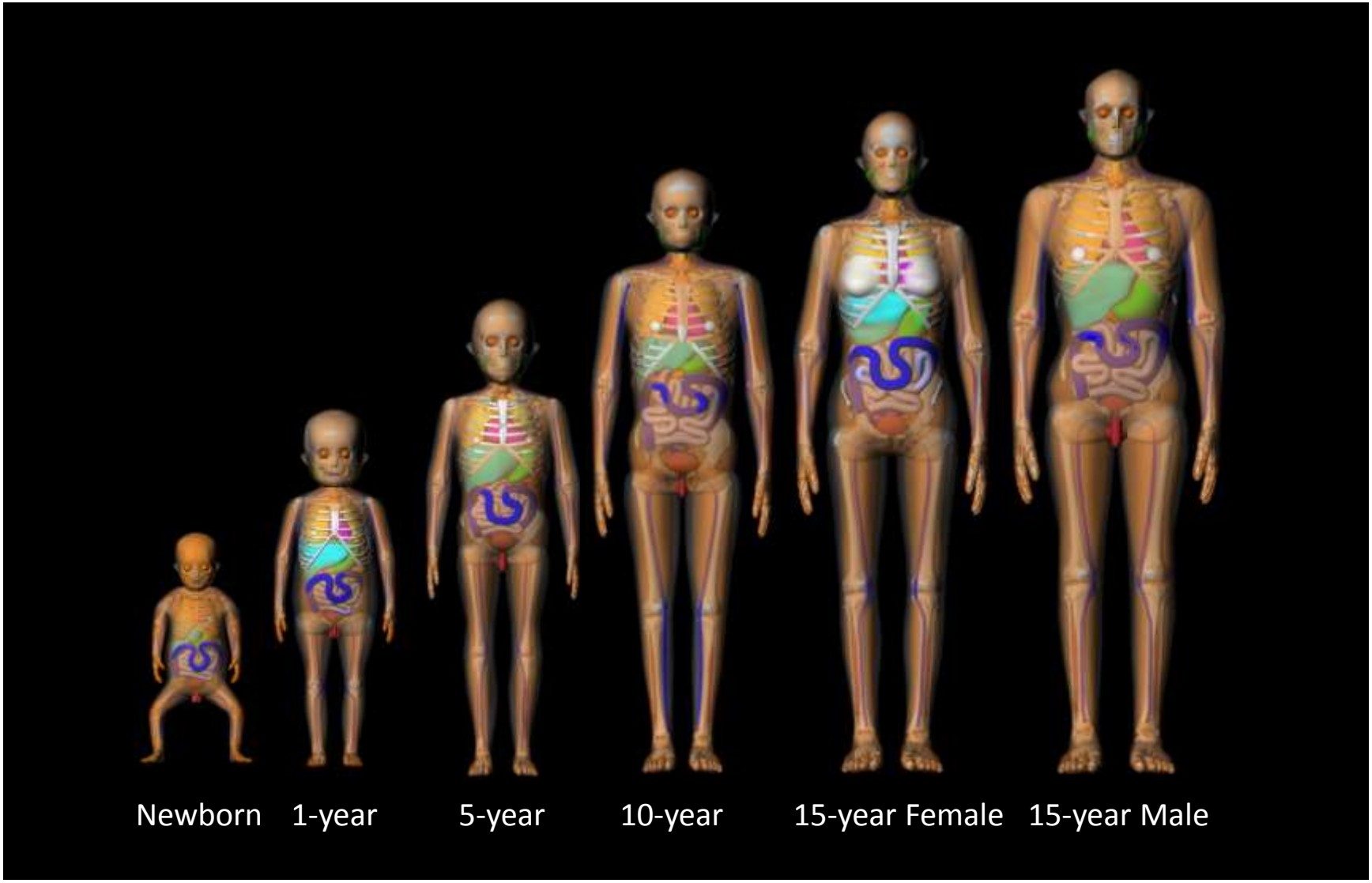


  - Additional modelling

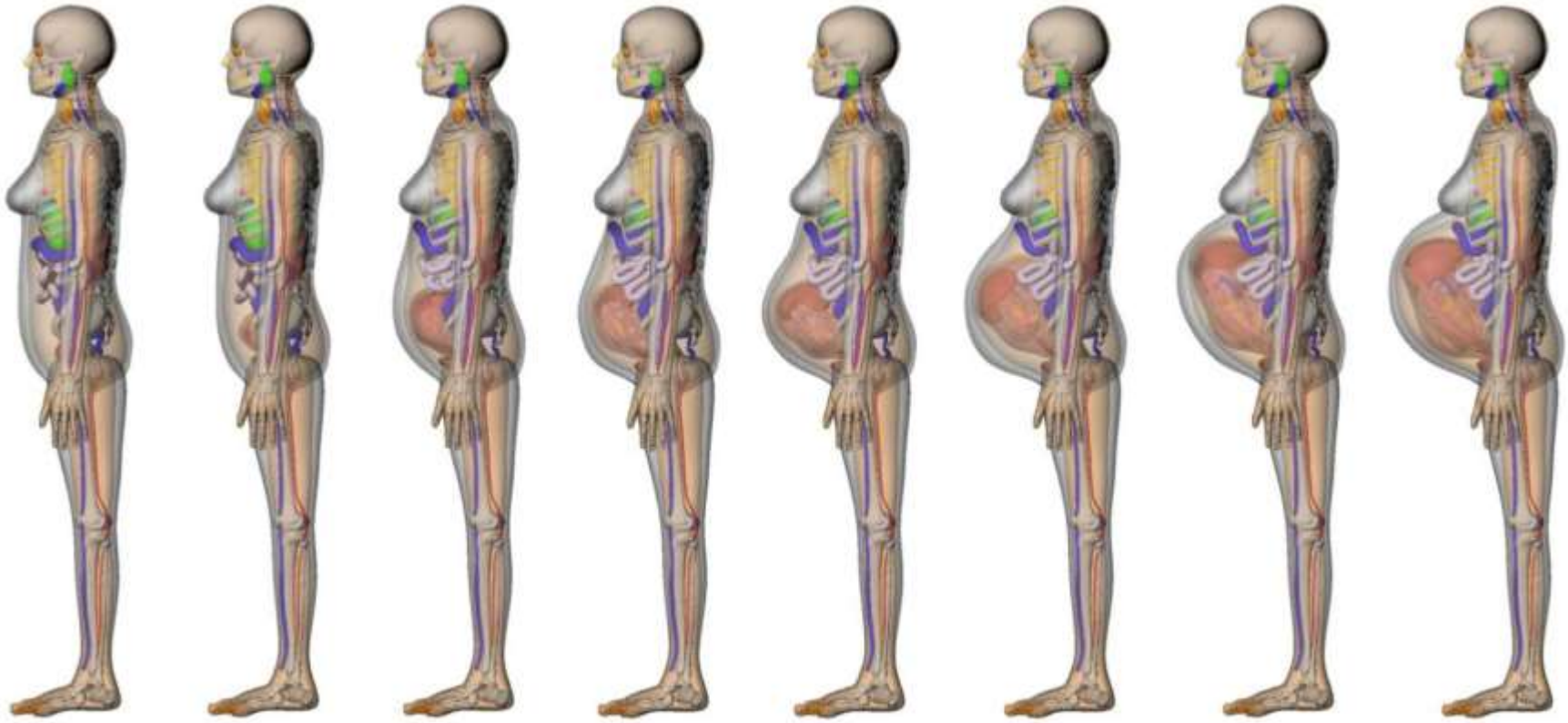
ICRP pediatric reference phantoms – lymph node model



ICRP pediatric reference phantoms



Pregnant phantoms



Models at 8 weeks to 38 weeks post-conception
developed at University of Florida

Summary

- The ICRP 110 adult male and female voxel phantoms are the official computational models representing the ICRP Reference Male and Reference Female.
- They have limitations concerning the representation of small objects due to the voxel resolution of the underlying image data.
- These limitations are being addressed by the current phantom conversion project.
- The resulting mesh-type phantoms are deformable, providing also the potential for assuming different postures.
- The ICRP pediatric reference computational phantoms have been constructed as boundary representation phantoms.
- The primary UF pediatric phantoms are being adjusted to ICRP reference specifications.
- Pregnant phantoms at 8 to 38 weeks post-conception complete the family of phantoms available for radiological protection computations.