

**HelmholtzZentrum münchen**

German Research Center for Environmental Health

# **Computational Phantoms used in Internal Dosimetry for Radiation Protection and Medicine**

**M. Zankl<sup>1</sup>, J. Becker<sup>1</sup>, C. Lee<sup>2</sup>, W.E. Bolch<sup>3</sup>, Y.S. Yeom<sup>4</sup>, C.H. Kim<sup>4</sup>**

**<sup>1</sup> Institute of Radiation Protection, Department of Radiation Sciences, Helmholtz Zentrum München, Neuherberg, Germany**

**<sup>2</sup> Radiation Epidemiology Branch, National Cancer Institute, National Institutes of Health (NIH), Rockville, U.S.A.**

**<sup>3</sup> J. Crayton Pruitt Family Department of Biomedical Engineering, University of Florida, Gainesville, U.S.A.**

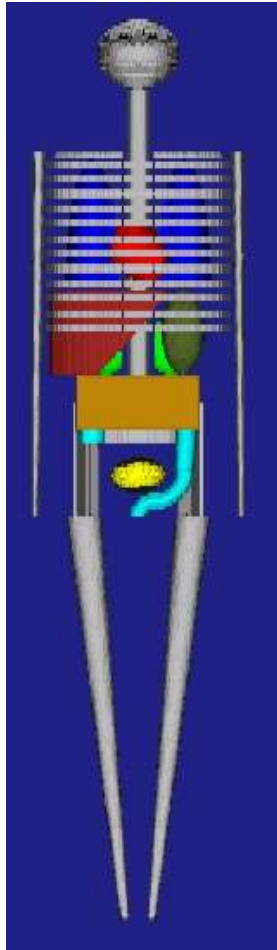
**<sup>4</sup> Department of Nuclear Engineering, Hanyang University, Seoul, Korea**

# Overview

- 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

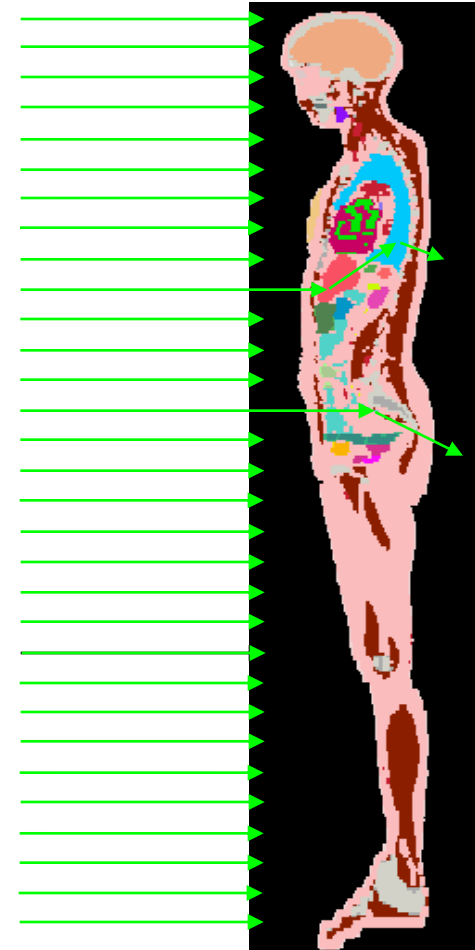
# Calculation of dose coefficients with radiation transport programs

Past

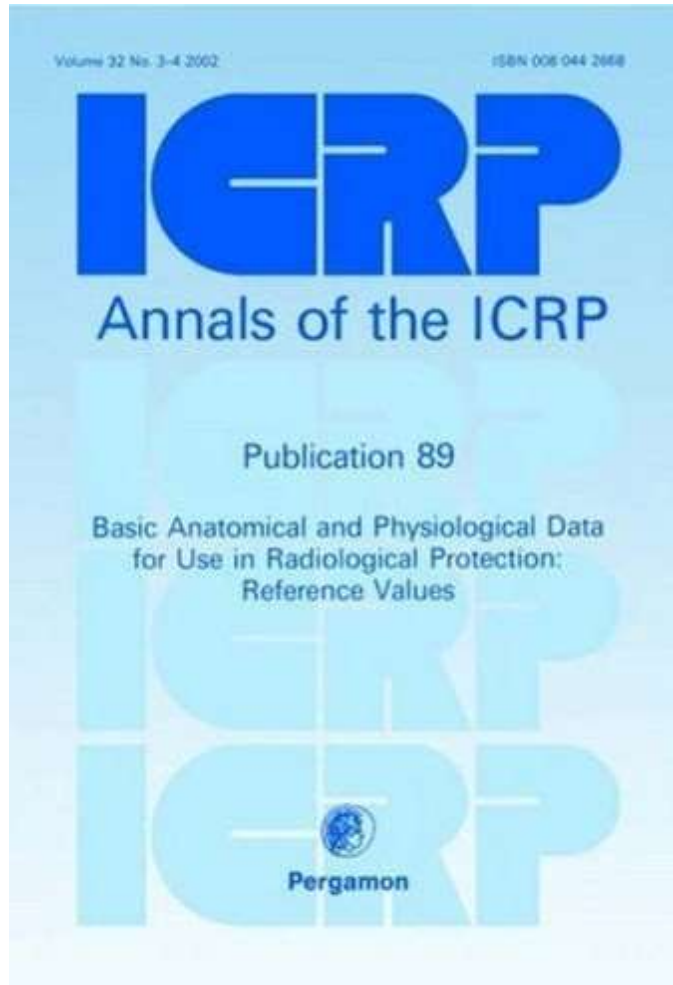


- Model of the radiation source
- Model of the body
- Physical models of
  - radiation interactions
  - energy depositions

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

Age	Height (cm)		Mass (kg)	
	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, movement of arms, adjustment of whole-body mass by adding adipose tissue)
- Sub-segmentation of the skeleton (cortical shell, spongiosa, medullary cavities)

Golem



Laura

# Reference computational phantoms – Characterisation

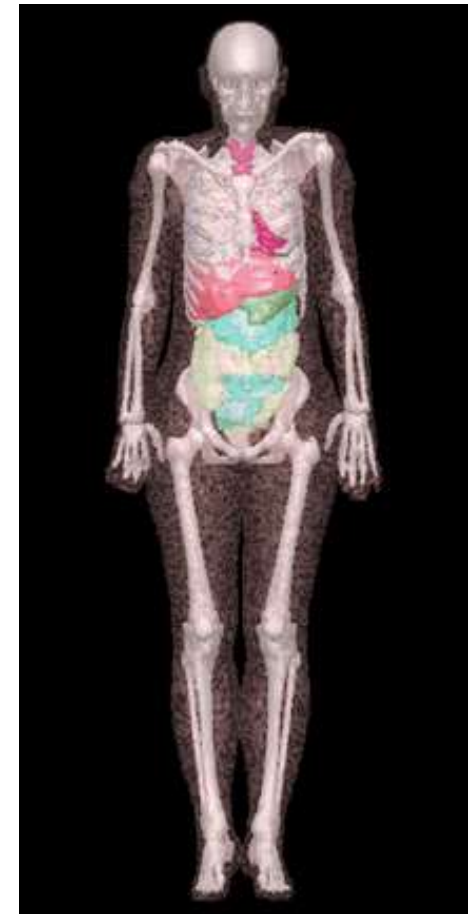


Male  
176 cm, 73 kg  
1.9 million voxels  
Voxel size: 36.5 mm<sup>3</sup>

**140 Organ identification  
numbers**

**Adopted by ICRP and ICRU  
ICRP Publication 110 (2009)**

Female  
163 cm, 60 kg  
3.9 million voxels  
Voxel size: 15.2 mm<sup>3</sup>



# 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.

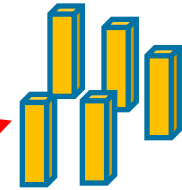
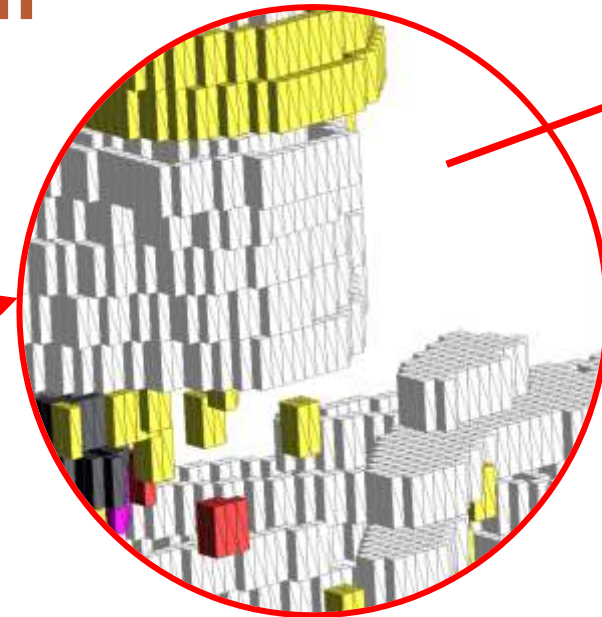
They are defined to enable calculations of the protection quantities organ and tissue equivalent dose and effective dose.

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.

# ICRP 110 Reference Phantoms – limitations due to voxel resolution

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

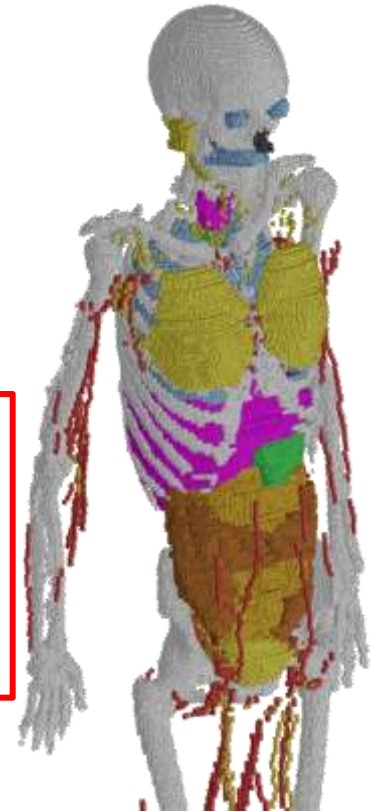


voxels

Small tissues cannot be properly represented:

- Extrathoracic airways, bronchi and bronchioles
- Blood vessels
- Skin
- Eye lenses, ...

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



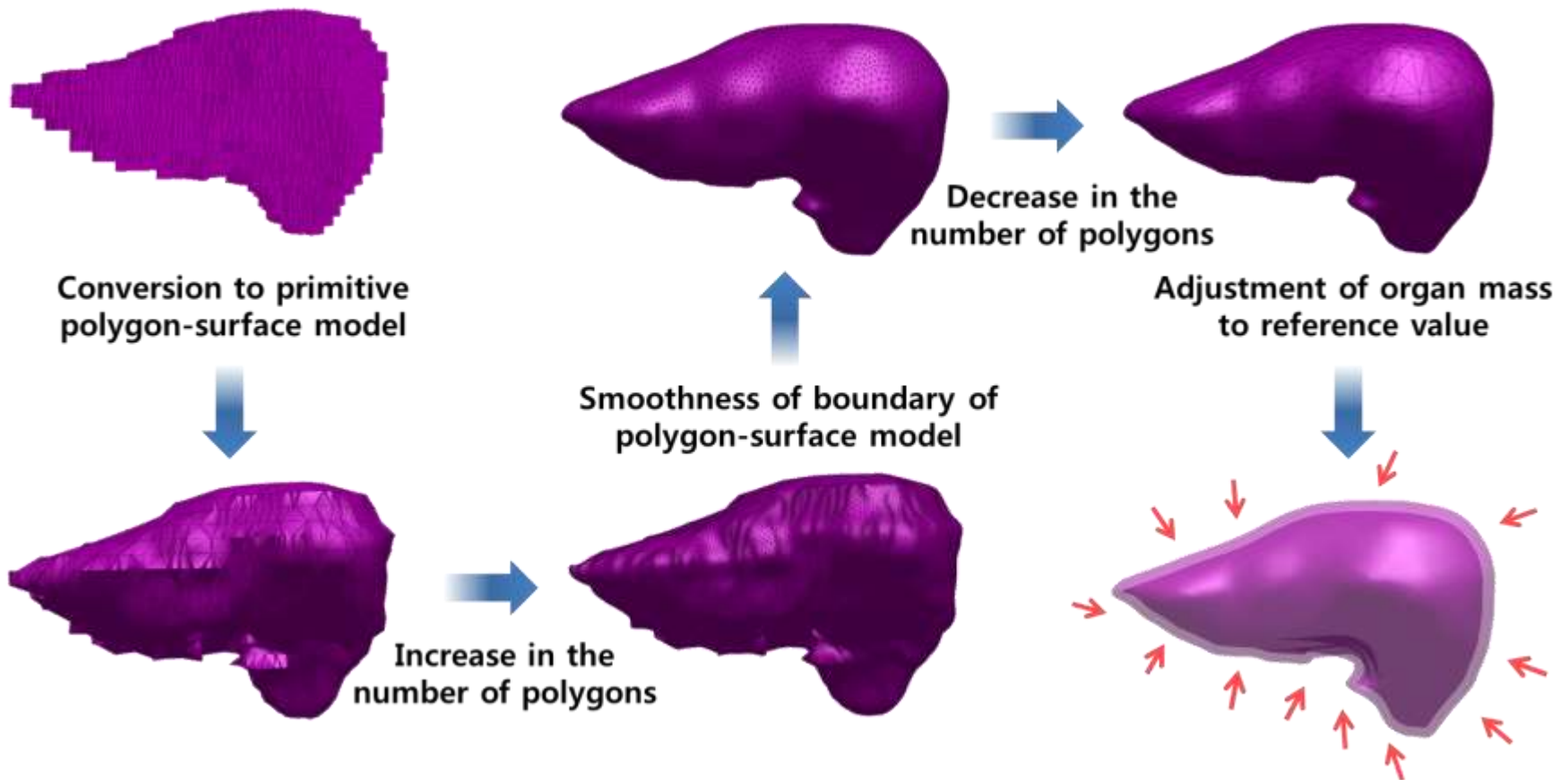


# Research project at Hanyang University, Seoul, for creating BREP phantom versions

- 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“
- The phantoms include
  - Continuous and fully-enclosed walls for skin, stomach, gall bladder, and urinary bladder
  - Thin target layers (10-300  $\mu\text{m}$ ) for the alimentary and respiratory tract organs
  - Detailed and correct models for skeletal systems (including cartilage), eyes, lymphatic nodes, blood vessels, etc.

# Conversion method – simple organs

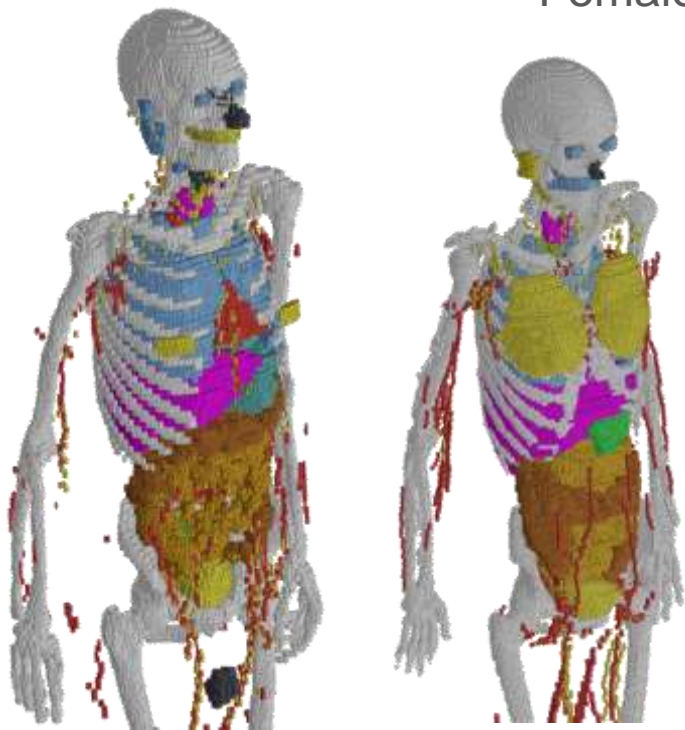
## Method 1



# Developed Phantoms

Male

Female



Male

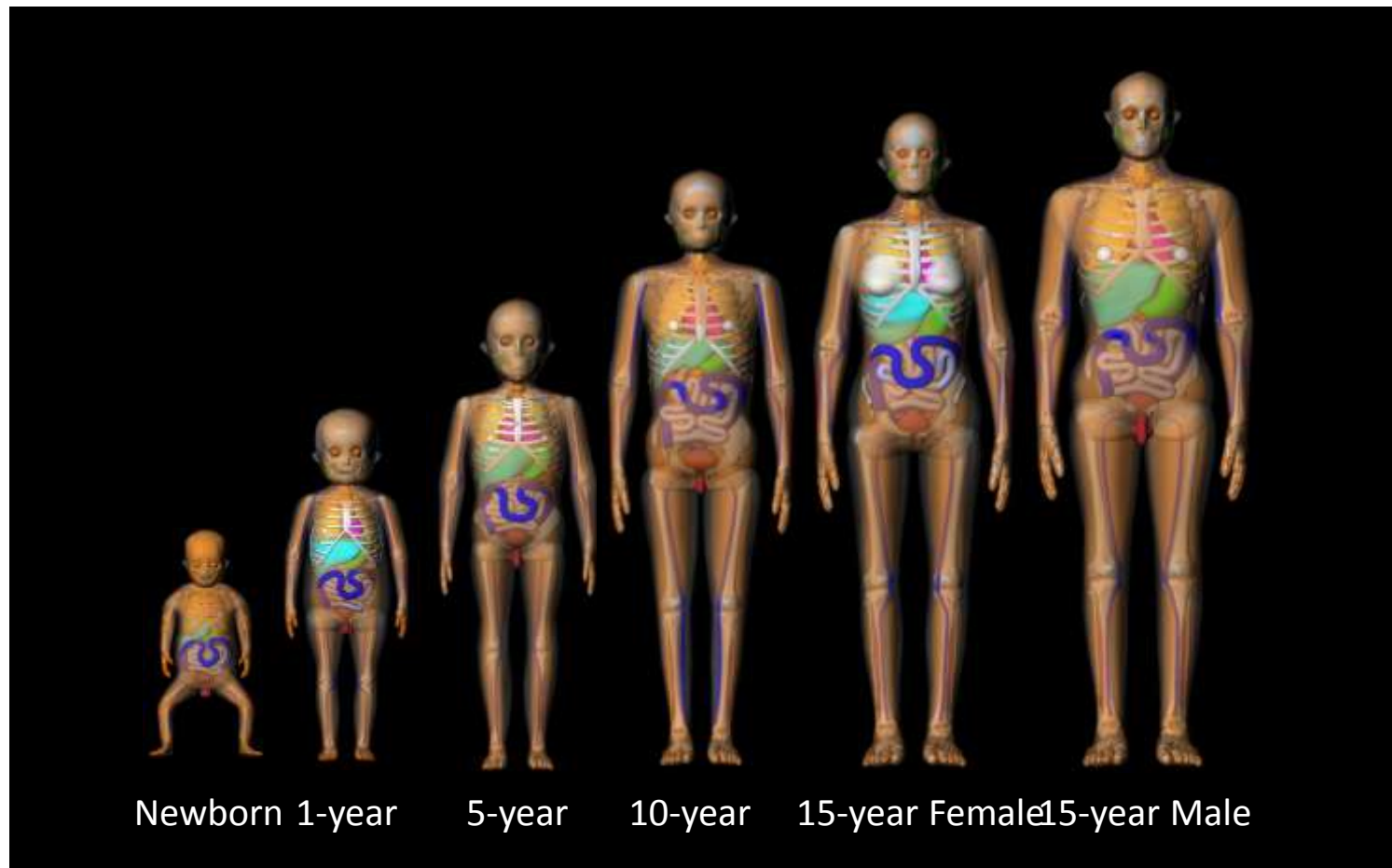
Female



ICRP-110 phantoms  
(voxel geometry)

Polygon-mesh phantom versions  
(preliminary versions)

# ICRP paediatric reference phantoms (developed by University of Florida and National Cancer Institute)



# 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 polygon mesh phantoms are **deformable**, providing also the potential for assuming different postures.
- The ICRP **pediatric reference computational phantoms** have directly been constructed as **boundary representation** phantoms.