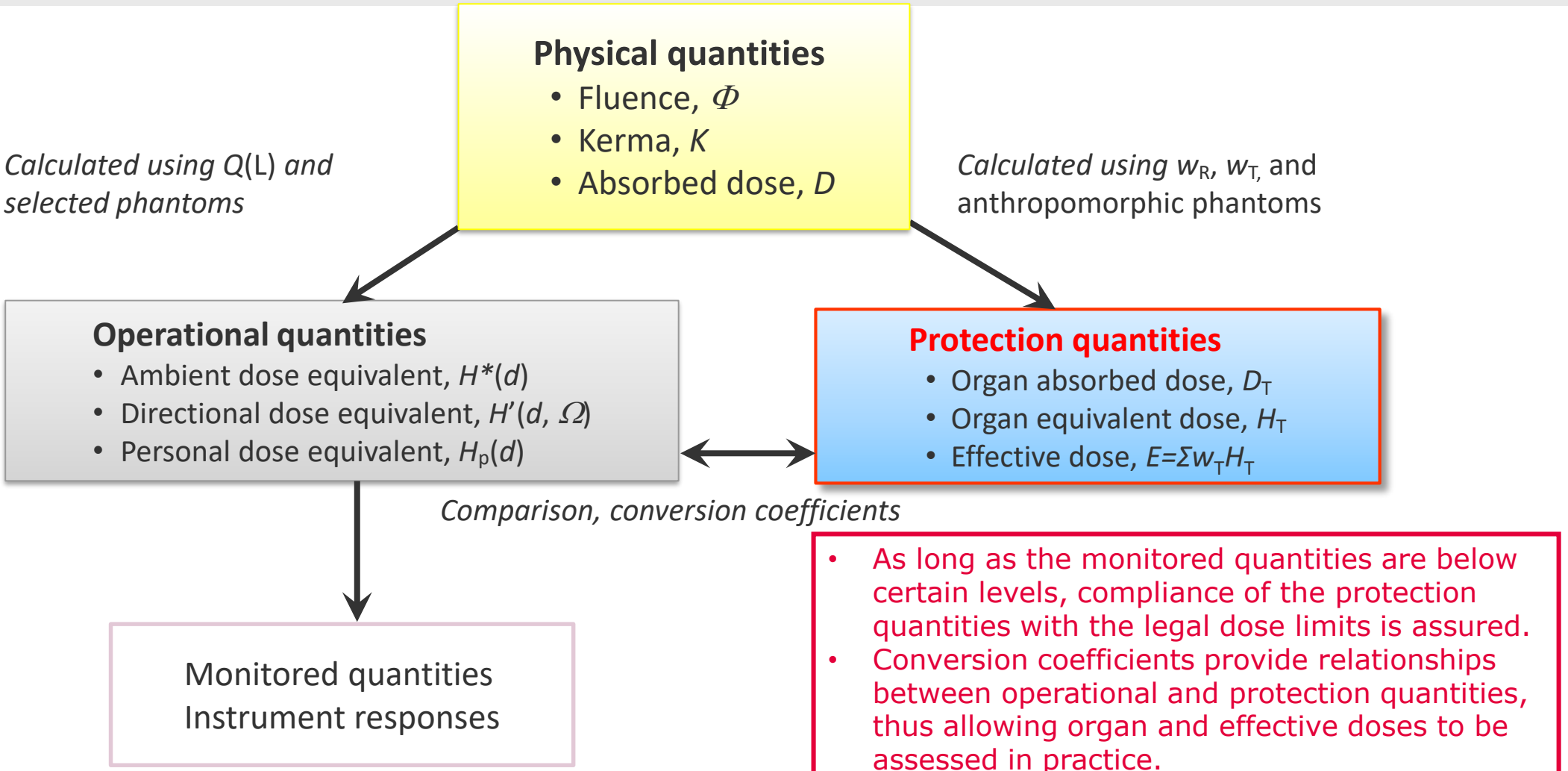
HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt

Evolution of Computational ICRP/ICRU phantoms

M. Zankl

XLII Radiation Protection Days, 08.-11.11.2021

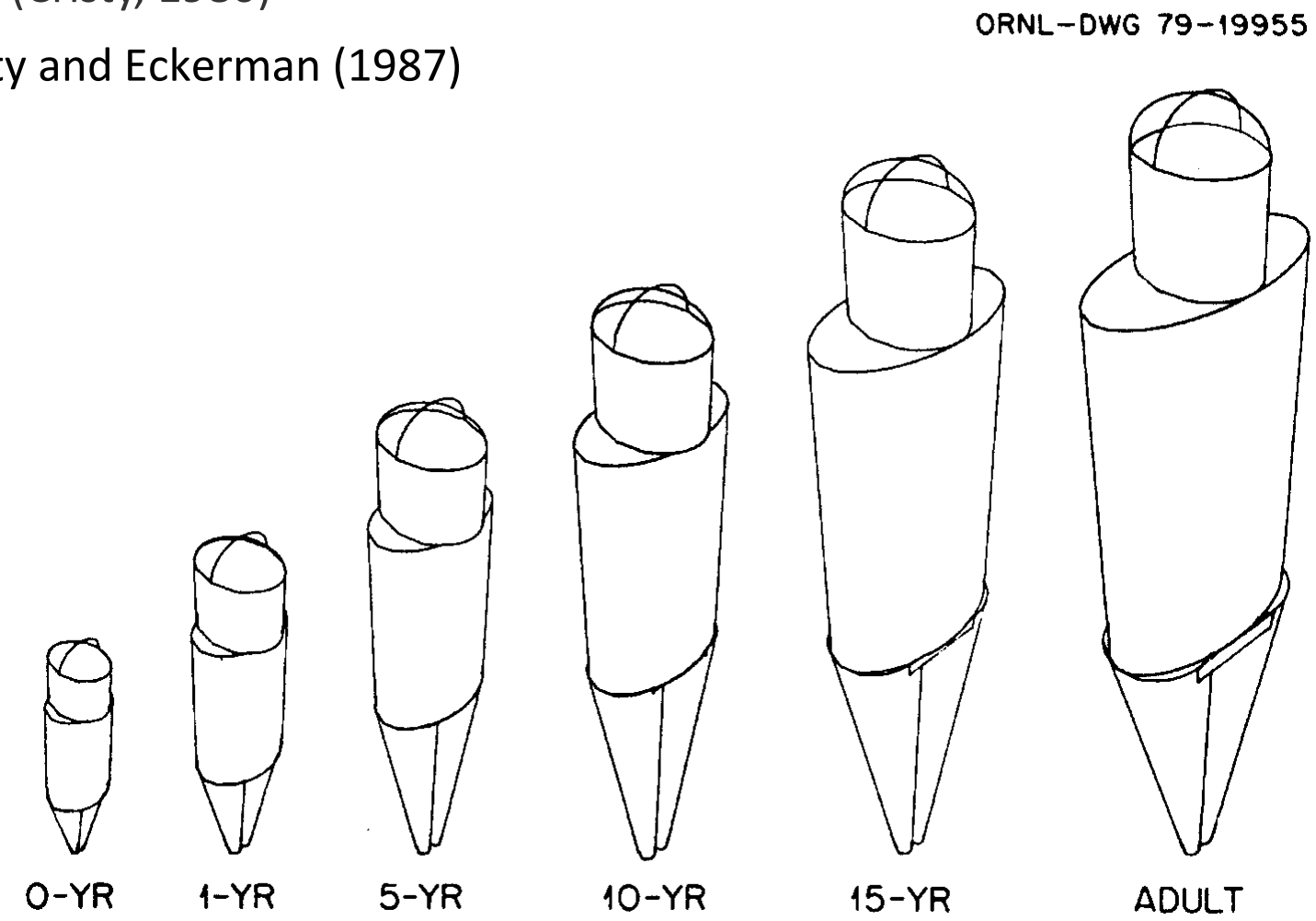
Dose quantities for radiological protection – requirement of computational phantoms



Various types of anthropomorphic phantoms – mathematical phantoms

Oak Ridge phantom family (Cristy, 1980)

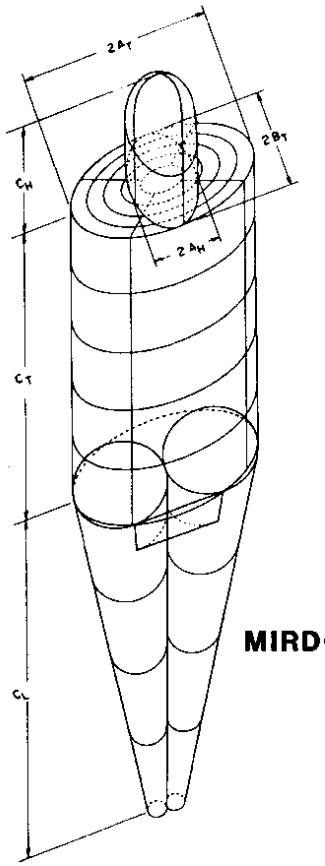
Further developed by Cristy and Eckerman (1987)

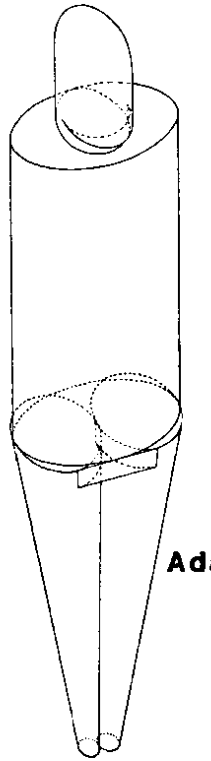


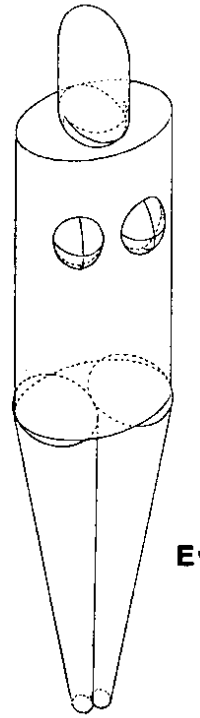
Various types of anthropomorphic phantoms – mathematical phantoms

- Organ masses and volumes according to data on Reference Man (ICRP Publication 23, 1975)
- Organ shapes described by geometrical bodies (spheres, ellipsoids, cylinders, cones ...)

ORNL:
Hermaphrodite phantom
(1969, 1974)



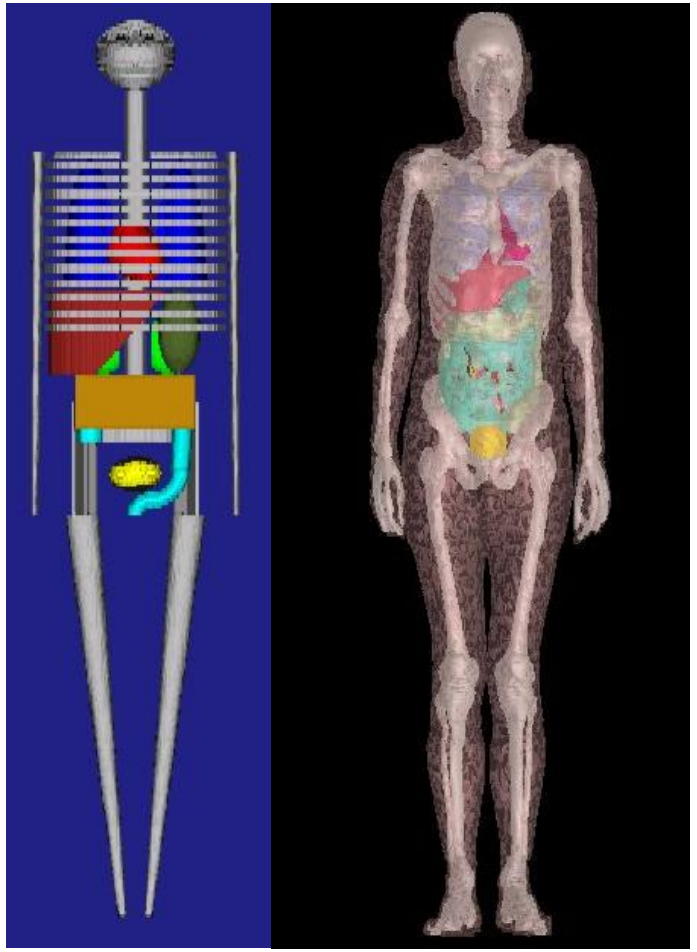




GSF:
Male and female phantoms (1982)

Various types of anthropomorphic phantoms – mathematical phantoms

- Advantages:
  - They are simple.
  - They are flexible.
  - They represent a „standard“ or „reference“ patient.
  - They can easily be used with (Monte Carlo) radiation transport programmes.
- Disadvantage:
  - They are unrealistic.

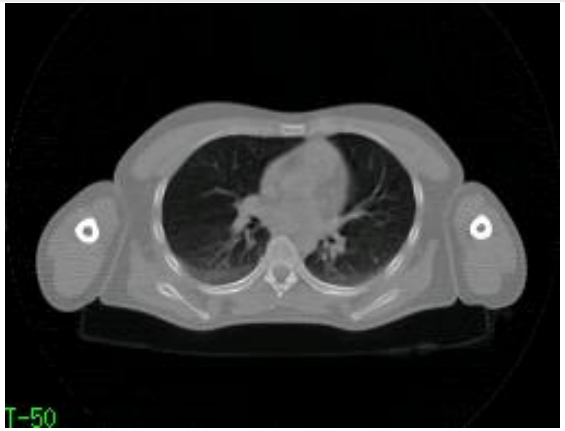


Adam Golem

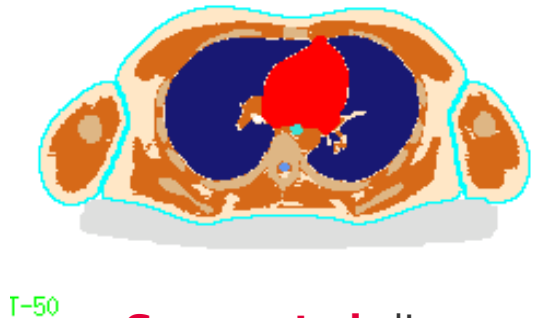
Various types of anthropomorphic phantoms – voxel phantoms

Construction of voxel models from 3D medical image data

- Whole body (or partial body) tomographic data of contiguous slices
- Numbered list of relevant organs (organ identification numbers, OID)
- Identification of relevant organs on the single slice images
- Replacement of the grey values (Hounsfield Units) by organ identification numbers (segmentation) using image processing software



Original CT slice
Grey values: absorption properties

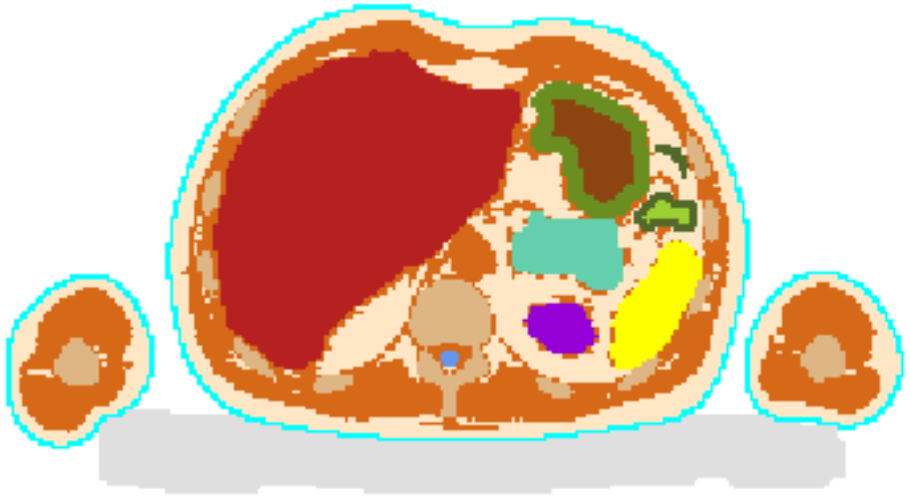


Segmented slice
Colours: identification numbers assigned to individual organs

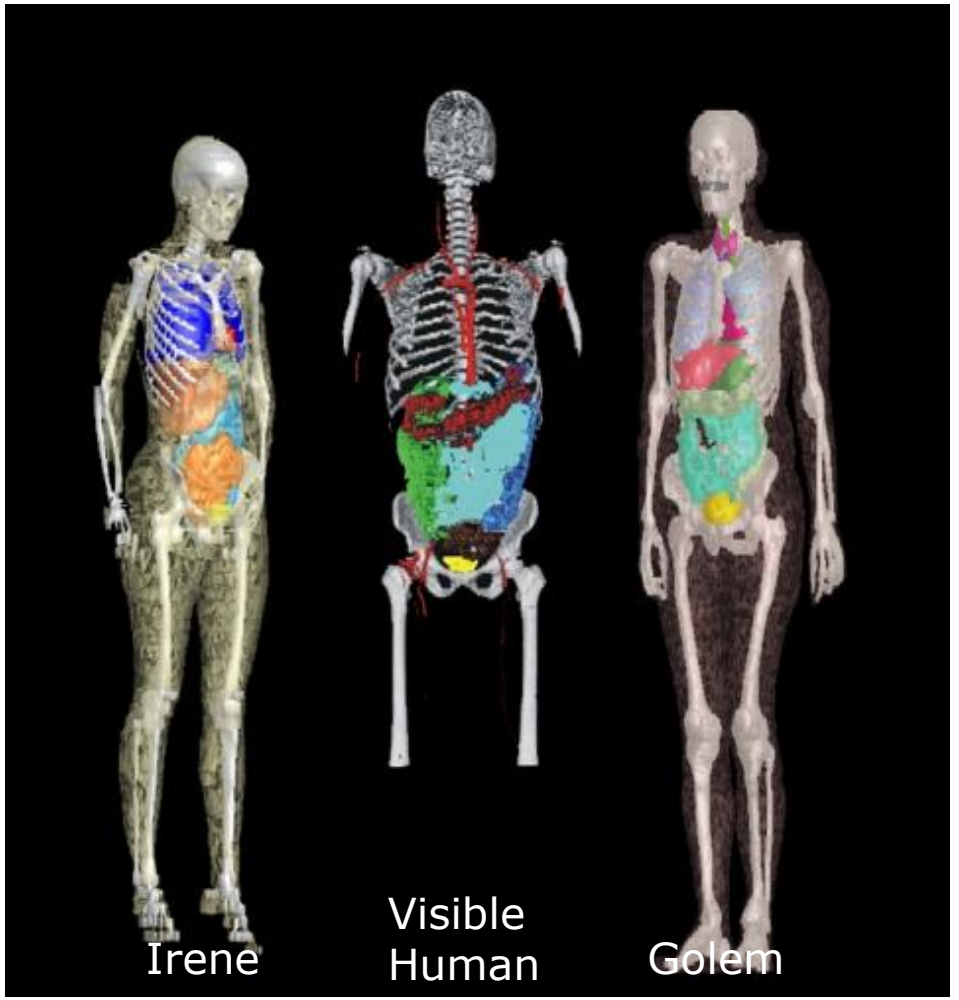
Various types of anthropomorphic phantoms – voxel phantoms

Segmented data

Data per slice arranged in columns and rows of picture elements (pixel)

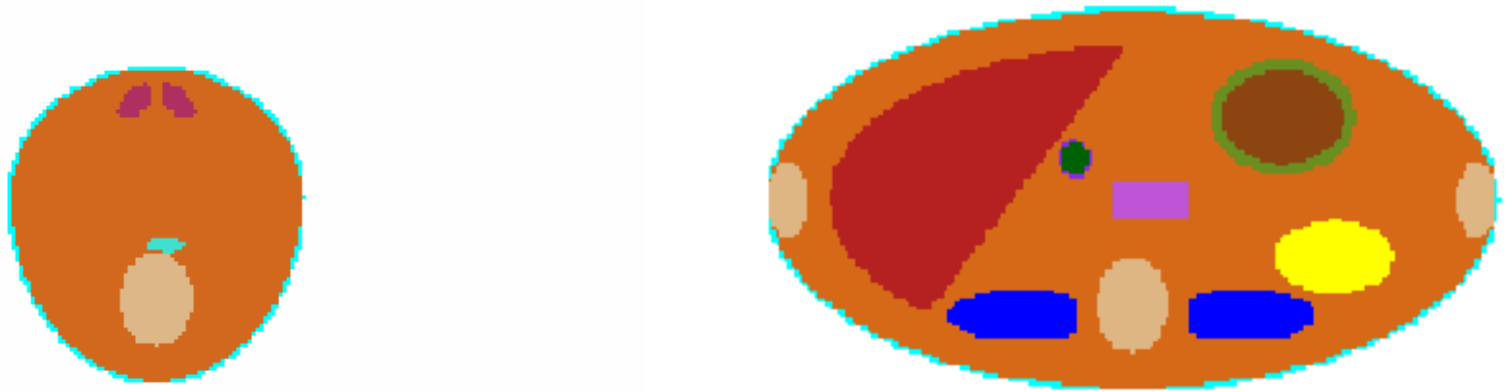


Stack of slices
→ 3D array of volume elements (voxel)

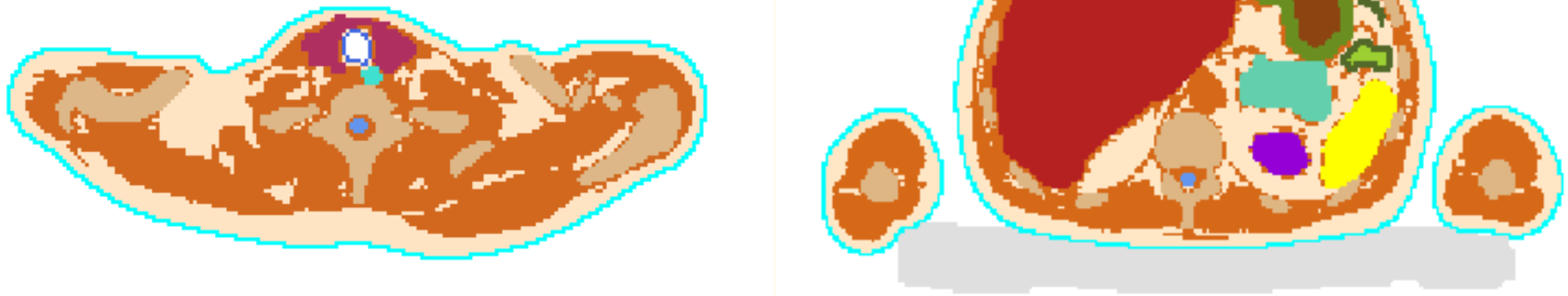


Voxel models have a more realistic anatomy

Adam



Golem



Various types of anthropomorphic phantoms – voxel phantoms

Advantages:

- They are realistic.
- They can easily be used with (Monte Carlo) radiation transport programmes.

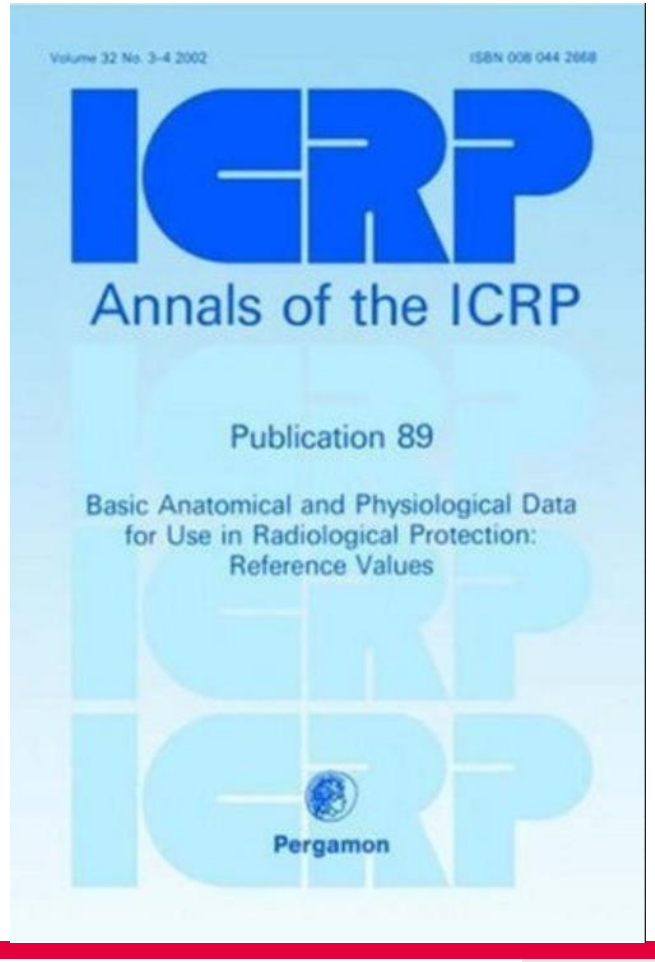
Disadvantages:

- They require a large amount of data storage.
- They are inflexible.
- They represent an individual patient (highly specific).

Helga Irene

Various types of anthropomorphic phantoms – ICRP reference computational phantoms

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 phantoms – methods of construction

Golem

Selection of segmented voxel models of a male and a female, whose body height and mass resembled the reference values of ICRP 89

„Golem“: 176 cm, 69 kg (176 cm, 73 kg)

„Laura“: 167 cm, 59 kg (163 cm, 60 kg)

Modification of these segmented voxel models

Voxel scaling

- Use body height to scale voxel height
- Use skeleton volume to scale voxel in-plane resolution

Adjustment of individual organ volumes

Adjustment of whole-body mass by adjusting amount of adipose tissue

Laura

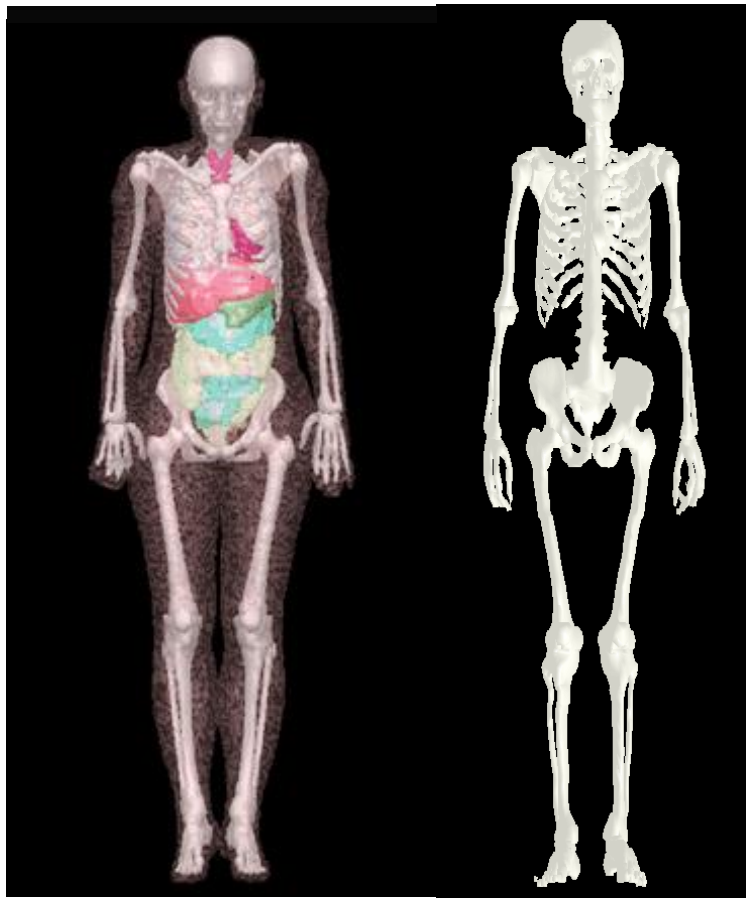
Various types of anthropomorphic phantoms – ICRP reference computational phantoms (ICRP Publ. 110)

Advantages:

- They are (relatively) realistic.
- They can easily be combined with (Monte-Carlo-) radiation transport programs.
- They represent a „standard “ oder „reference“ person.

Disadvantages:

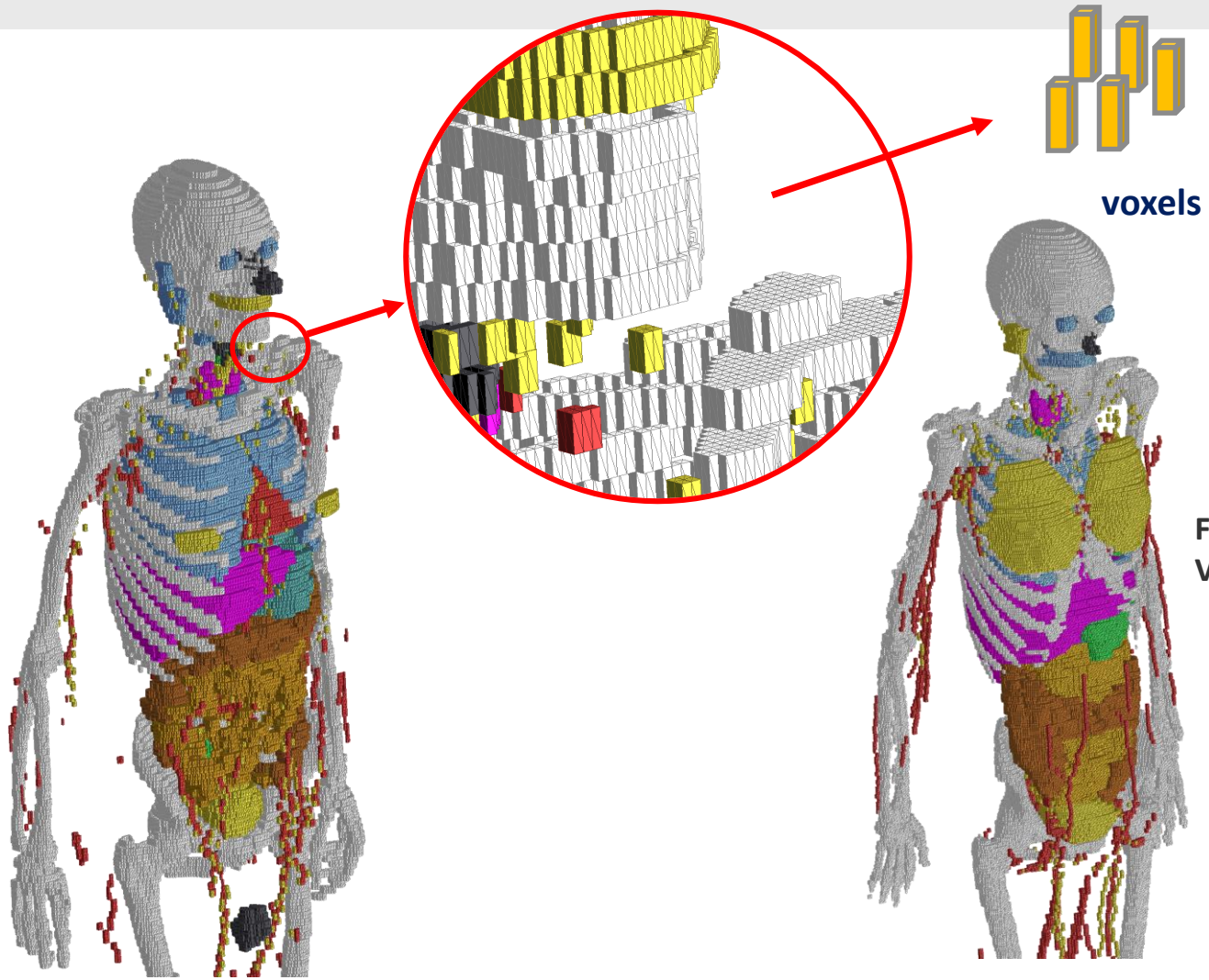
- They are unflexible.
- They have additional limitations due to the voxel geometry and dimensions.



Female Male

Voxel-type reference computational phantoms (ICRP Publication 110)

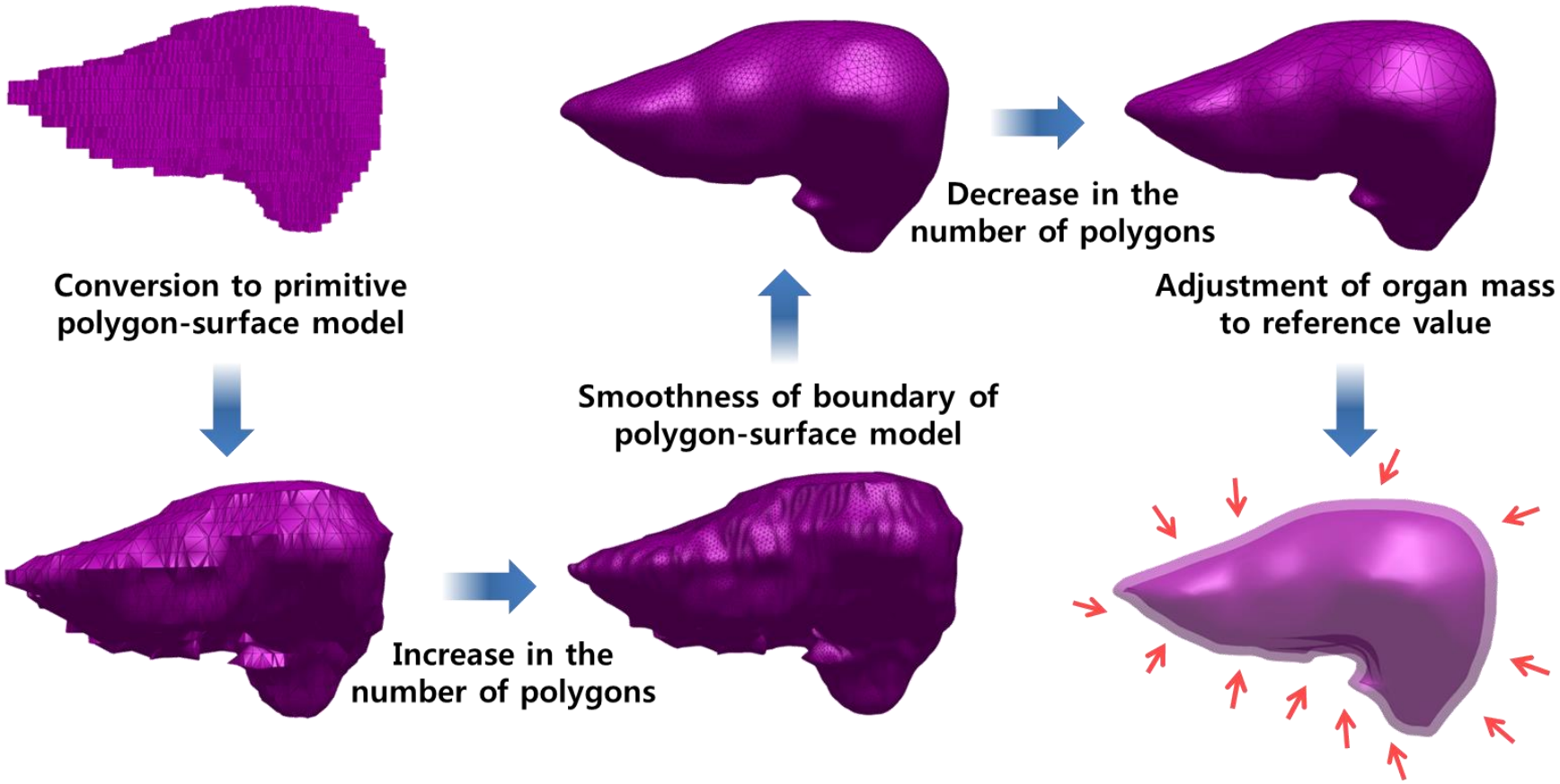
Male phantom
Voxel size: 2.137 × 2.137 × 8 mm³



Female phantom
Voxel size: 1.775 × 1.775 × 4.8 mm³

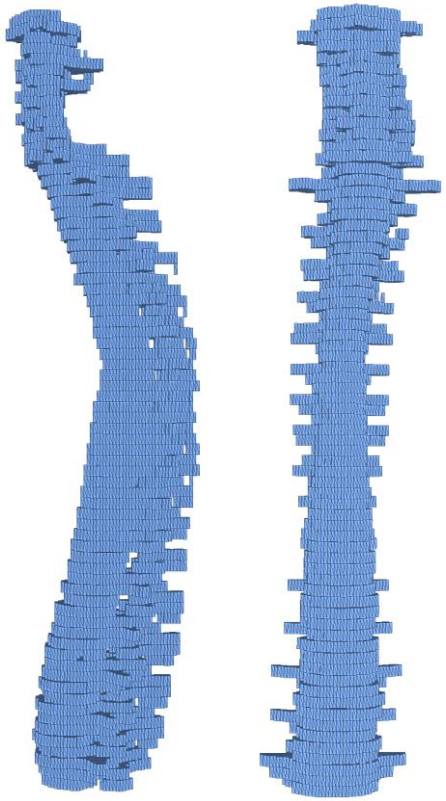
Construction of Mesh-type Reference Computational Phantoms (MRCP) by ICRP Task Group 103

Simple Organs: Direct Conversion

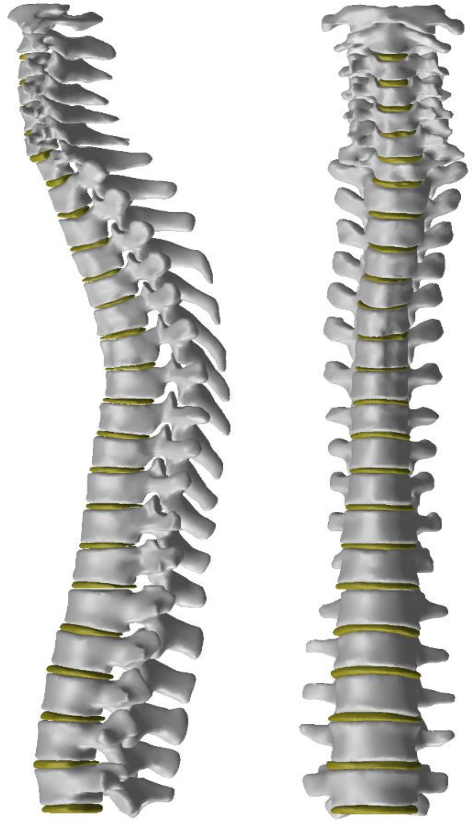


Construction of Mesh-type Reference Computational Phantoms (MRCP) by ICRP Task Group 103

Spine: Fitting



Fitting



Voxel model

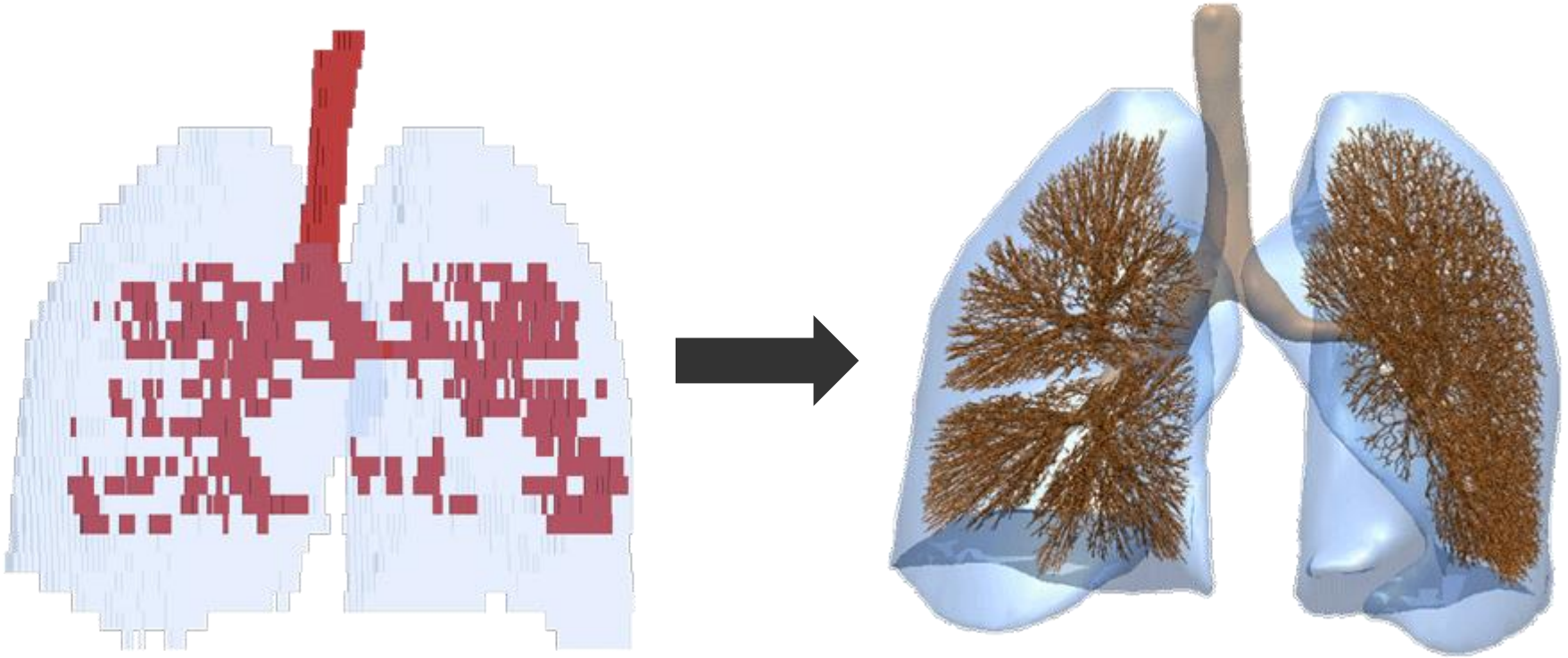
High-quality mesh model

Yeom Y.S., et al. Phys. Med. Biol. (2016)

Construction of Mesh-type Reference Computational Phantoms (MRCP) by ICRP Task Group 103

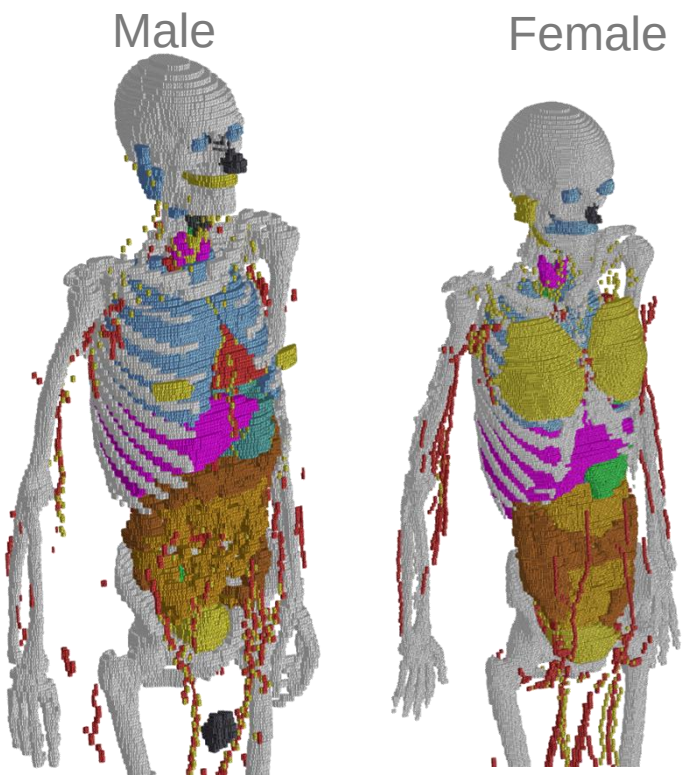
Lung airways: Modelling

Male

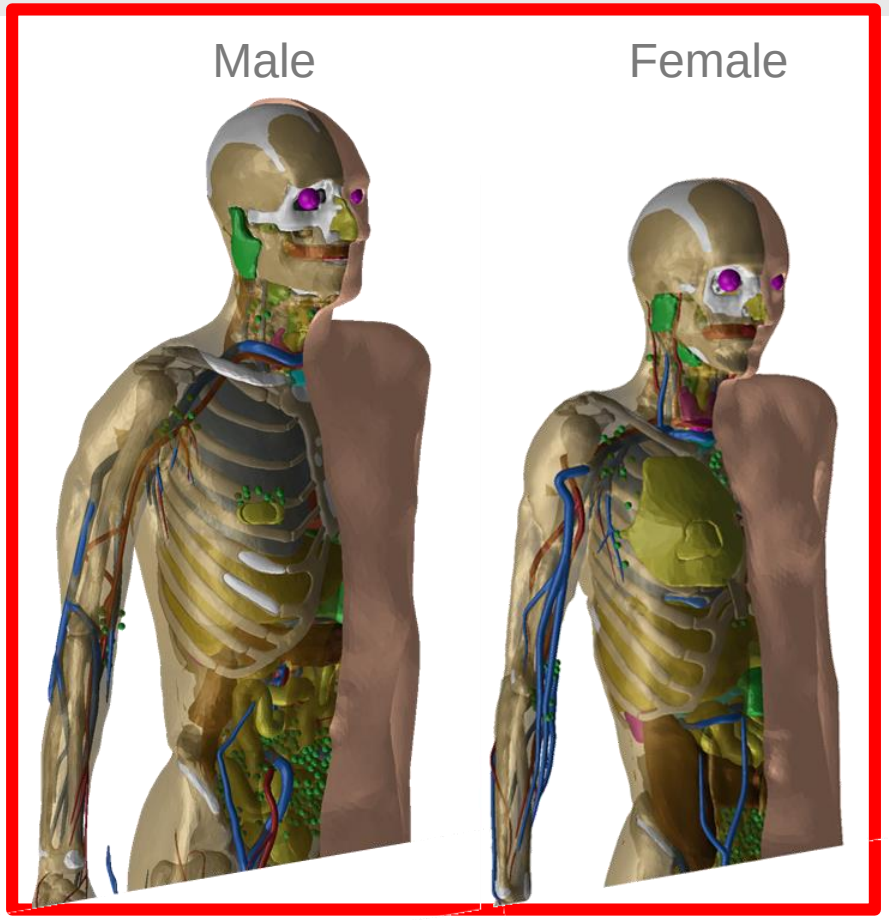


Voxel **Mesh**

ICRP Adult Reference Computational Phantoms – voxel *versus* mesh type



ICRP Reference Computational Phantoms (voxel-type) (ICRP Publication 110, 2009)



ICRP Reference Computational Phantoms (mesh-type) (ICRP Publication 145, 2020)

ICRP Adult Reference Computational Phantoms – voxel *versus* mesh type

- Polygon-mesh (PM) versions of the ICRP 110 phantoms have been published as ICRP Publication 145
- 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
- The PM phantoms can be made to move as necessary
- The PM phantoms can be combined with some Monte Carlo codes (Geant4, MCNP6, PHITS)

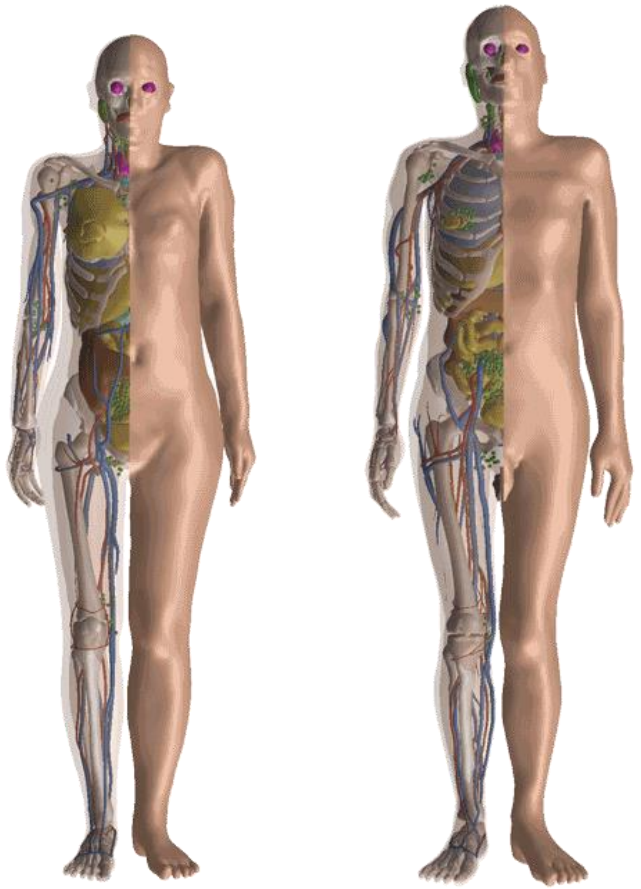
Various types of anthropomorphic phantoms – ICRP mesh-type reference computational phantoms (ICRP Publ. 145)

Advantages:

- They represent a „standard “ oder „reference“ person.
- They are very realistic.
- They have continuous and smooth surfaces and contain finest structures.
- They contain all relevant tissues and make surrogate phantoms unnecessary.
- They are flexible.

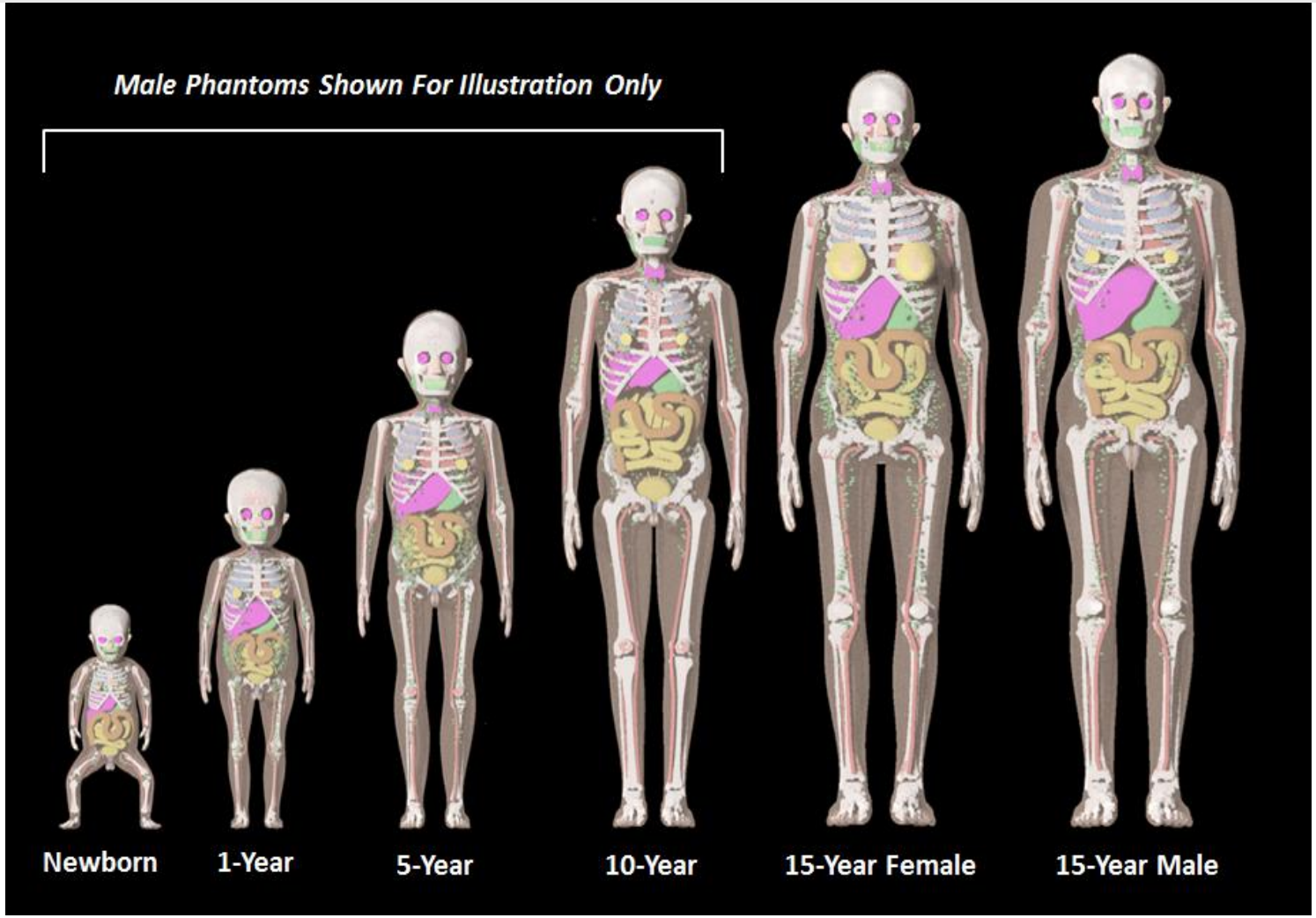
Disadvantage:

- Only few (Monte-Carlo-) radiation transport programs are able to directly deal with them.



Female Male

ICRP Reference phantoms – new developments



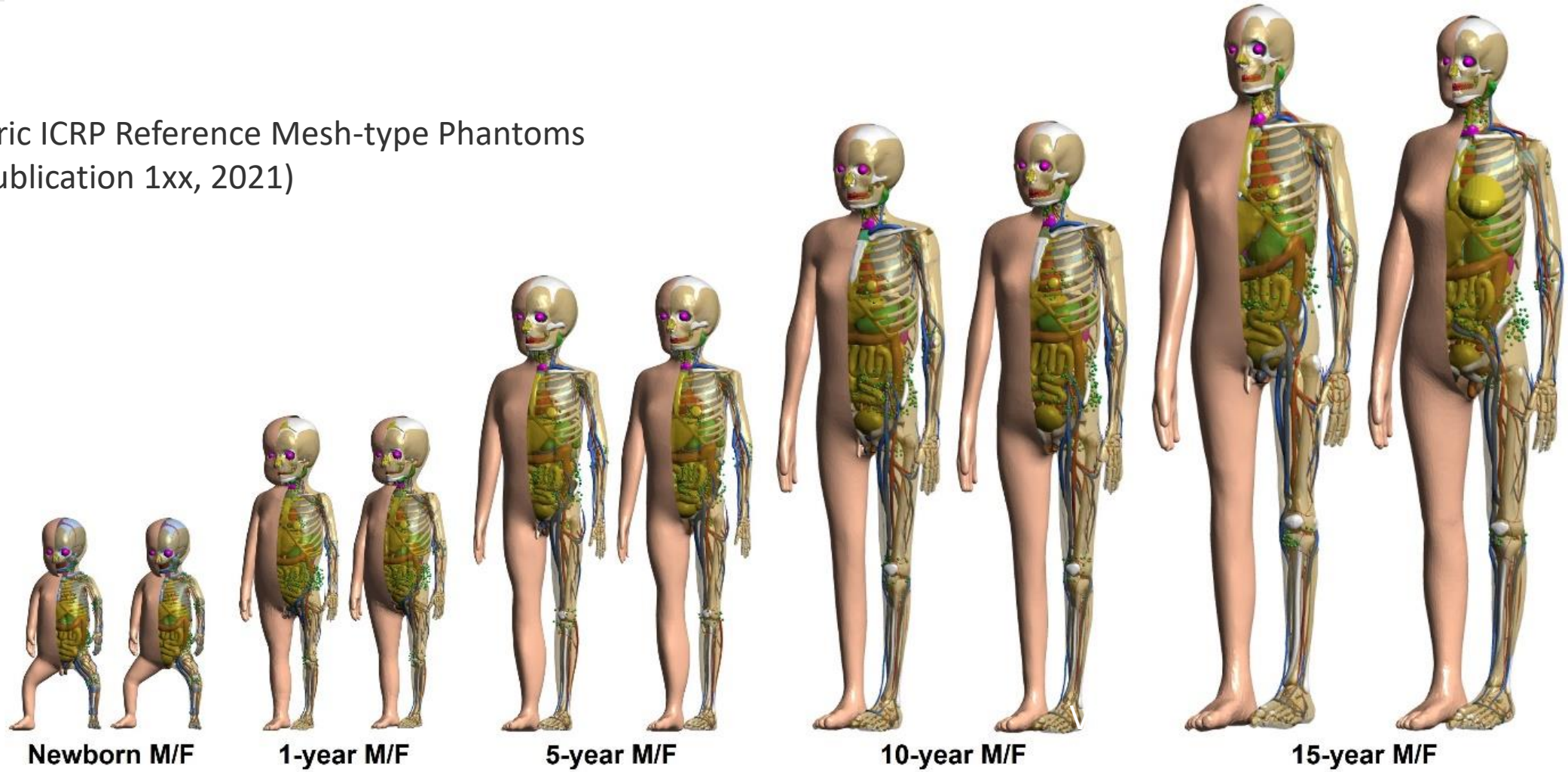
Paediatric ICRP Reference Voxel Phantoms (ICRP Publication 143, 2020)

Resolution and array dimensions of paediatric reference voxel phantoms

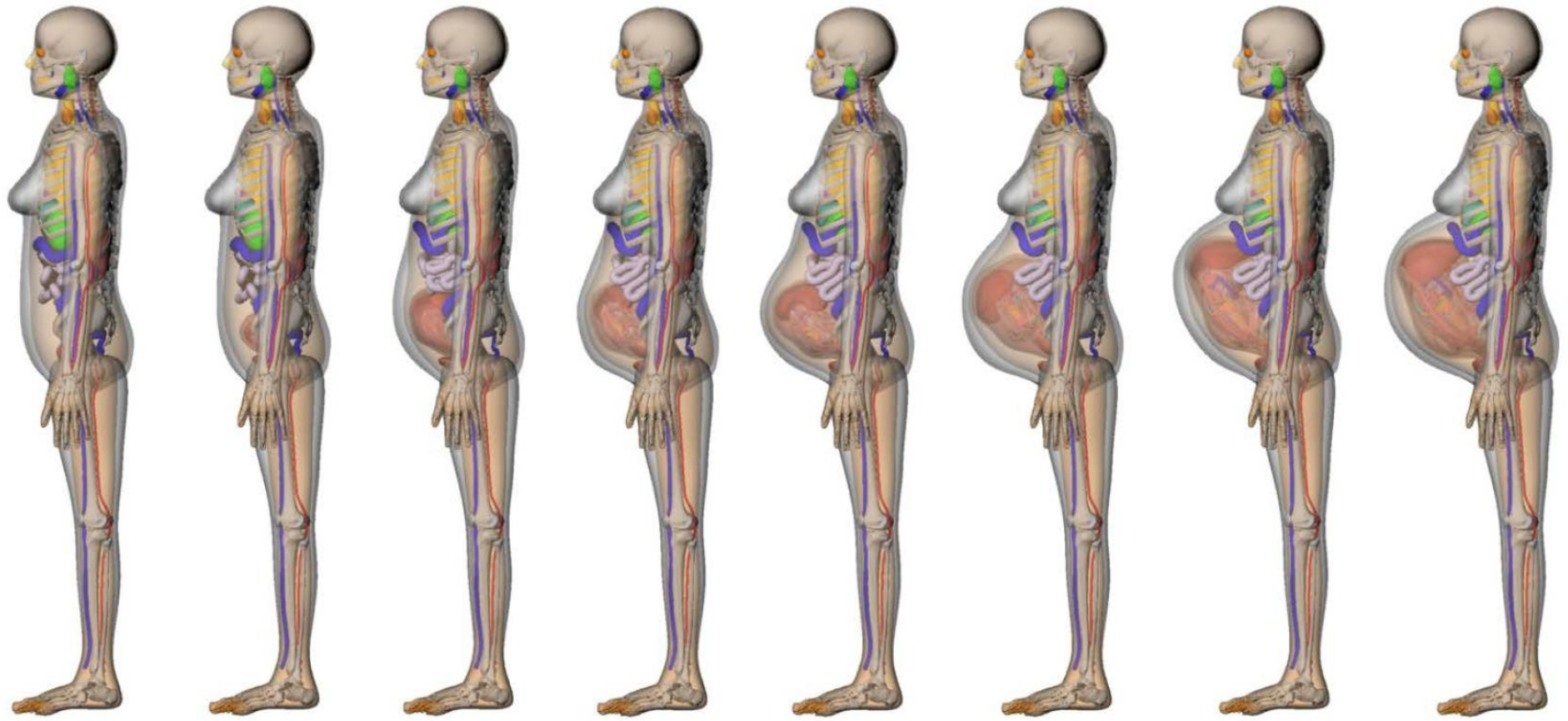
Phantom	Resolution (cm)			Array size			Matrix size
	X	Y	Z	X	Y	Z	(million)
00MF	0.0663	0.0663	0.0663	345	211	716	52.1
01MF	0.0663	0.0663	0.1400	393	248	546	53.2
05MF	0.0850	0.0850	0.1928	419	230	572	55.1
10MF	0.0990	0.0990	0.2425	419	226	576	54.5
15F	0.1200	0.1200	0.2828	401	236	571	54.0
15M	0.1250	0.1250	0.2832	407	225	586	53.7
AF	0.1775	0.1775	0.4840	299	137	348	14.3
AM	0.2137	0.2137	0.8000	254	127	222	7.2

ICRP Reference phantoms – new developments

Paediatric ICRP Reference Mesh-type Phantoms
(ICRP Publication 1xx, 2021)



ICRP Reference phantoms – new developments: 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 presently 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 have been addressed by the phantom conversion project.
- The resulting mesh-type phantoms have been published as ICRP Publication 145.
- They are deformable, providing also the potential for assuming different postures.
- The ICRP paediatric reference computational phantoms have been published in a voxelised version as ICRP Publication 143.
- Polygon mesh versions of the paediatric reference computational phantoms will be published later this year.
- Pregnant phantoms at 8 to 38 weeks post-conception complete the family of phantoms available for radiological protection computations.