Computational Phantoms of the Reference Adults – Stylized and Voxel

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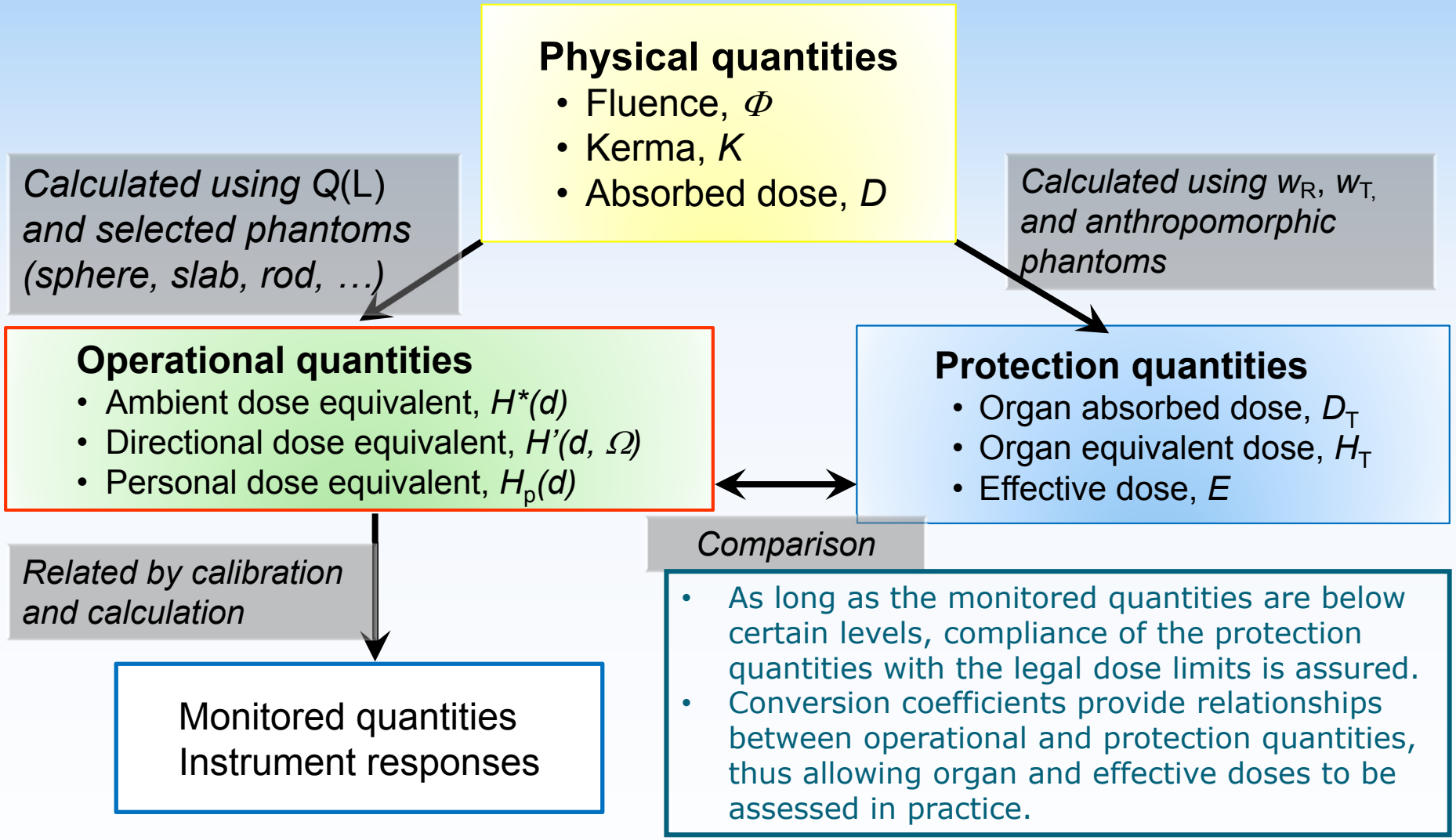
Overview

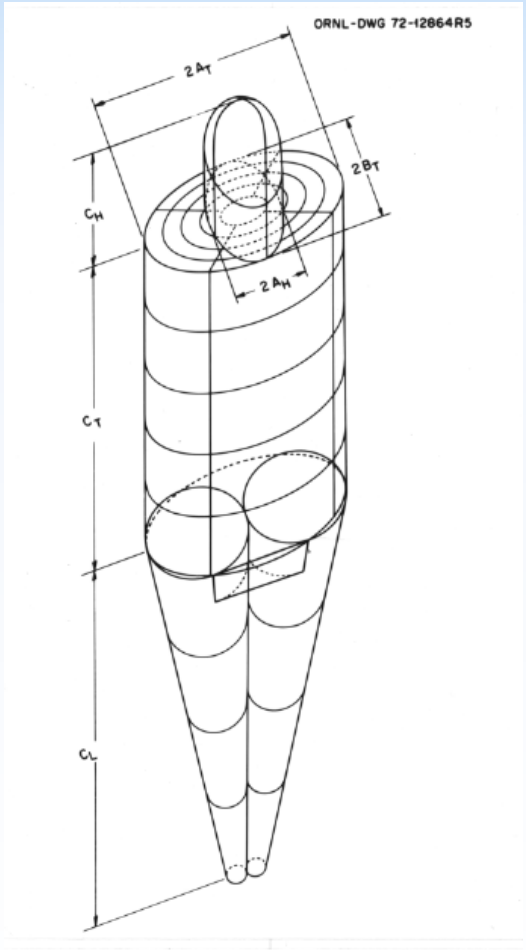
- Dose quantities for radiological protection
- Calculation of conversion coefficients
- Construction of voxel phantoms
- Comparison of stylized and voxel phantoms
- ICRP Reference Computational Phantoms (voxel-type)
- Limitations due to voxel resolution
- Detailed eye model (stylized)
- Applications and conceptual limitations of the reference computational phantoms

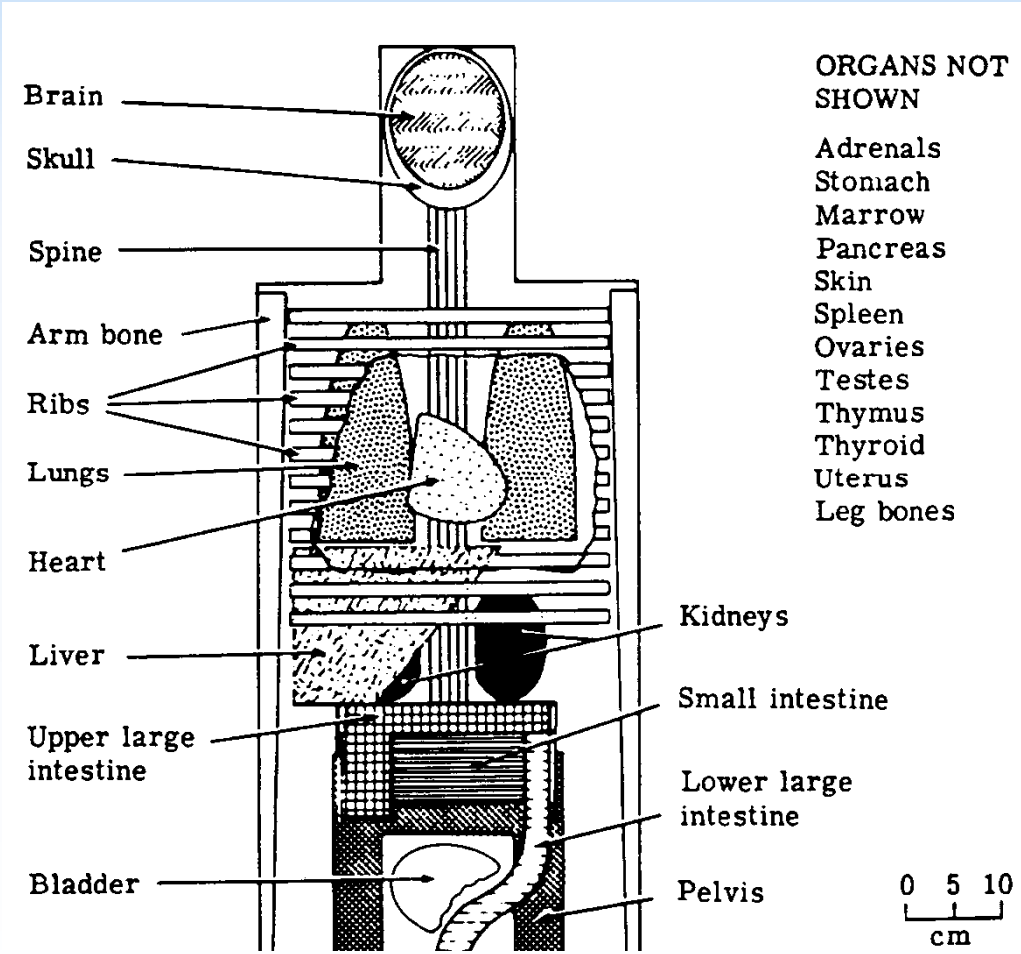
Dose quantities for radiological protection



Calculation of conversion coefficients with radiation transport programs and computational human phantoms

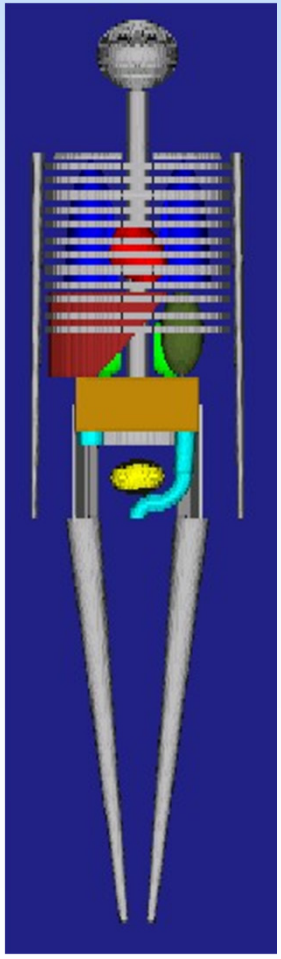
Stylized models of the human body have been used for decades





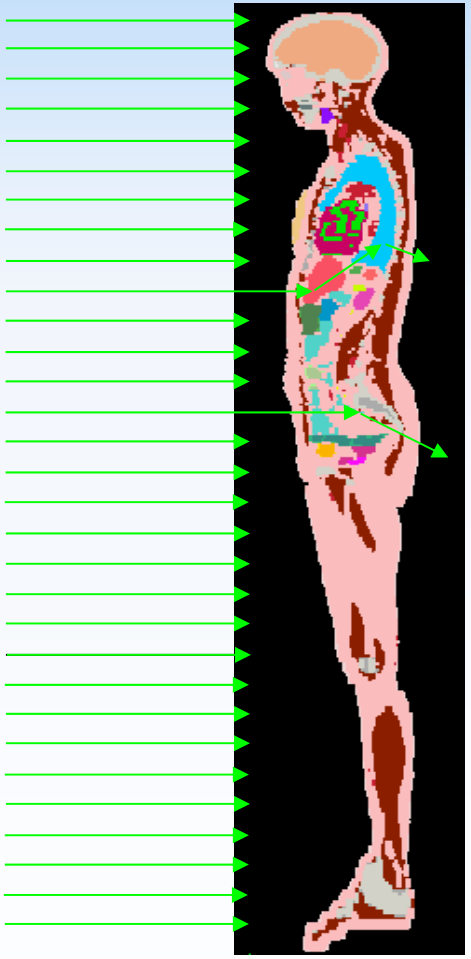
Calculation of conversion coefficients with radiation transport programs and computational human phantoms

Past



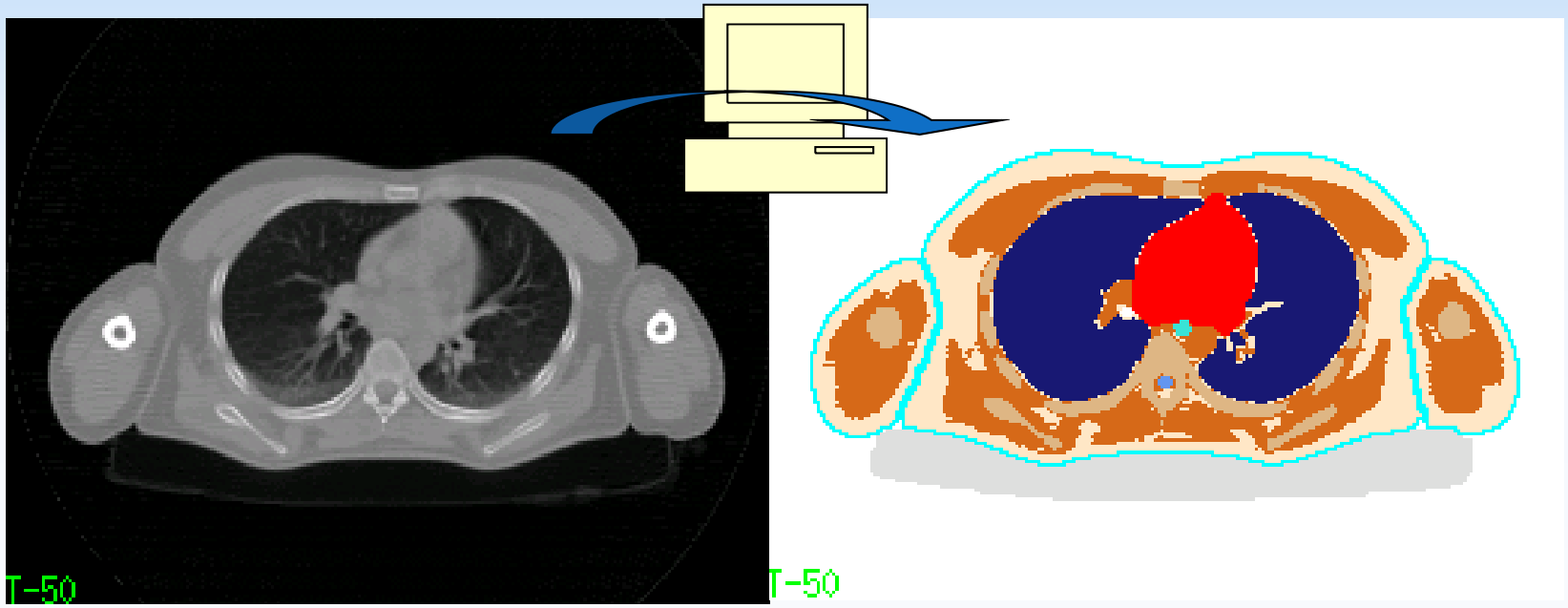
- Model of the radiation source
- Model of the body
- Physical models of
  - radiation interactions
  - energy depositions

Recently



Construction of computational voxel models from medical image data of real persons

Image processing software

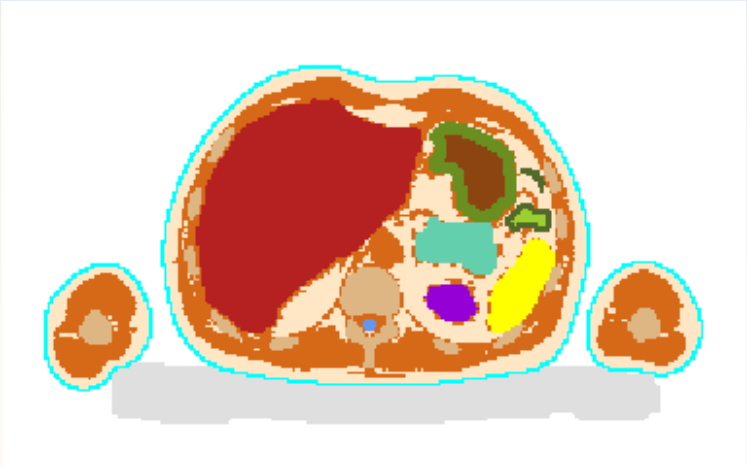


Original CT slice
Grey values: absorption properties

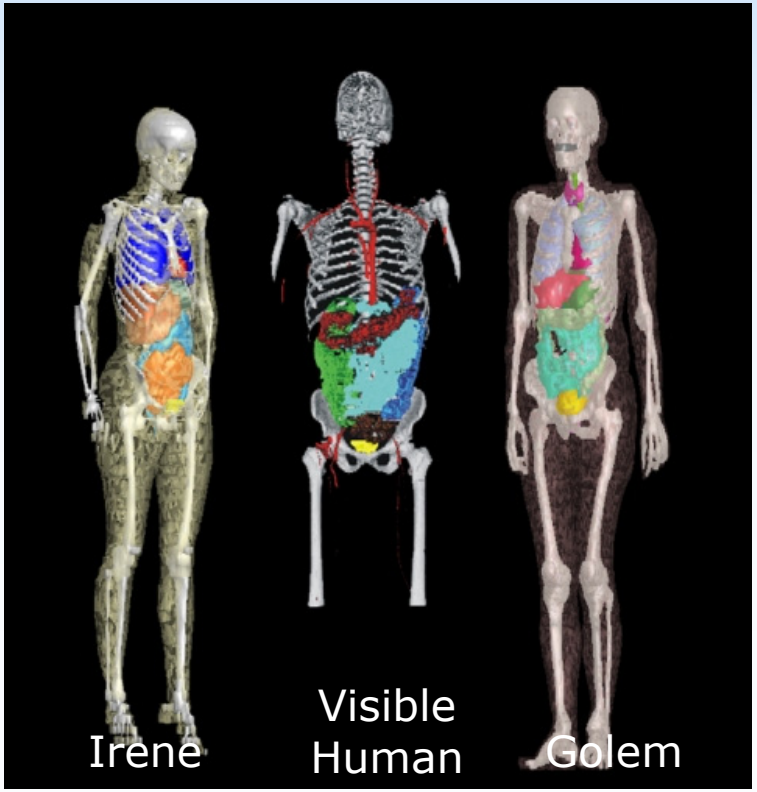
Segmented slice
Colours: identification numbers assigned to individual organs

Examples of voxel models

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



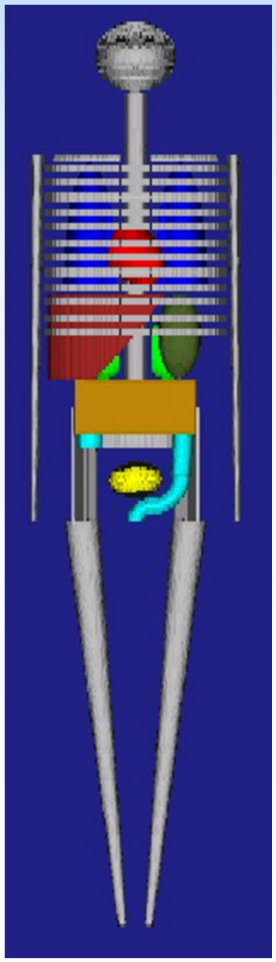
Stack of slices → 3D array of volume elements (voxel)



Irene	Visible Human	Golem
163 cm	180 cm	176 cm
51 kg	102 kg	69 kg

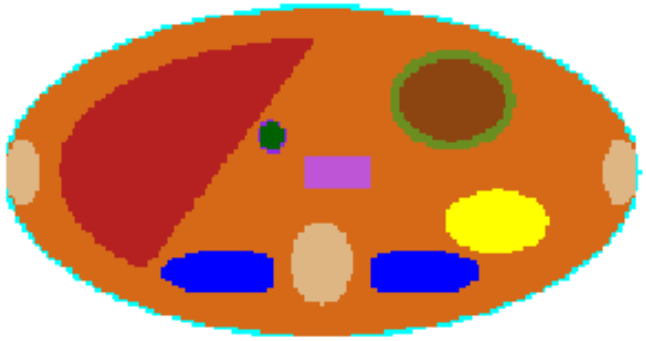
Voxel models are more realistic than stylized models

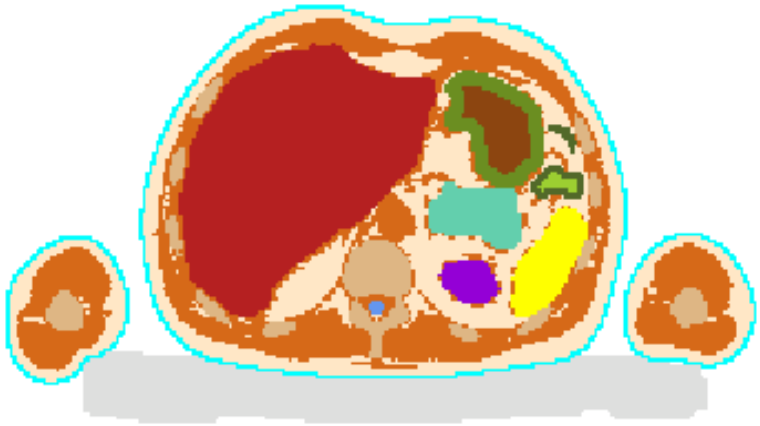
- Made of image data of real patients (millions of voxels) by applying segmentation techniques
- 60-140 different organs and tissues, even small ones
- Realistic anatomy (improvement compared to the stylized phantoms)



Voxel models have a more realistic anatomy

Adam





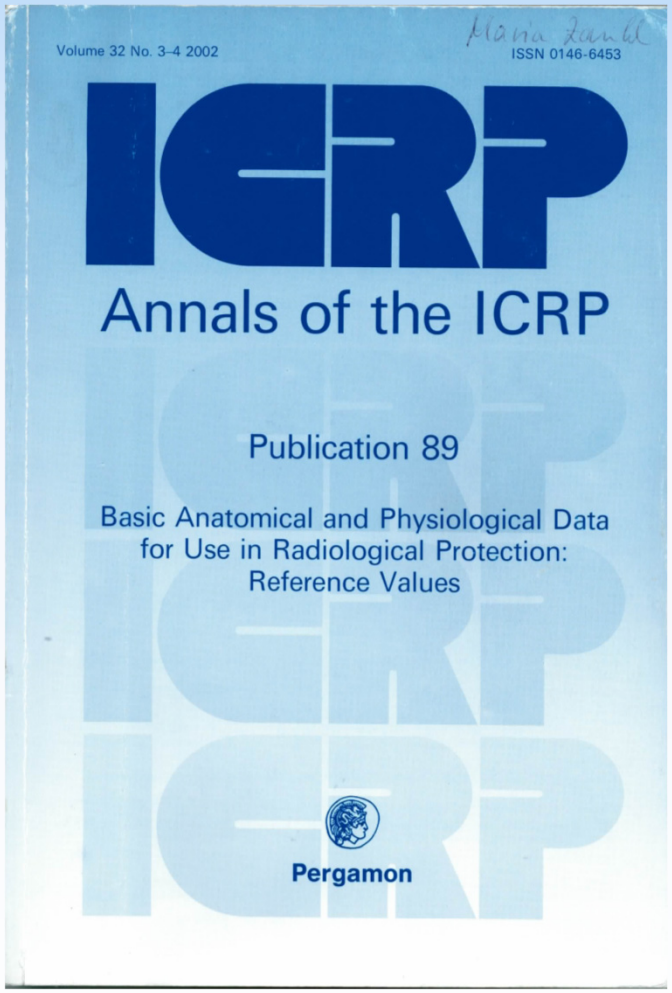
Golem

… and this has a dosimetric impact

Comparison of voxel-type and stylized phantoms – Dosimetry (external photons)

- Dose differences between seven individual voxel models mostly < 30% (60-200 keV); in single cases up to 100% and more
- Dose values for stylized phantoms partly outside these ranges
- Reason: unrealistic geometry
  - Organs located too shallowly beneath the skin: stomach, spleen, kidneys
  - Circumference of trunk too flat (elliptical)
  - Constant trunk diameter from neck down to bottom of trunk

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

Golem

For the first time, the ICRP and ICRU have adopted reference computational phantoms as representations of the Reference Male and Reference Female.

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)

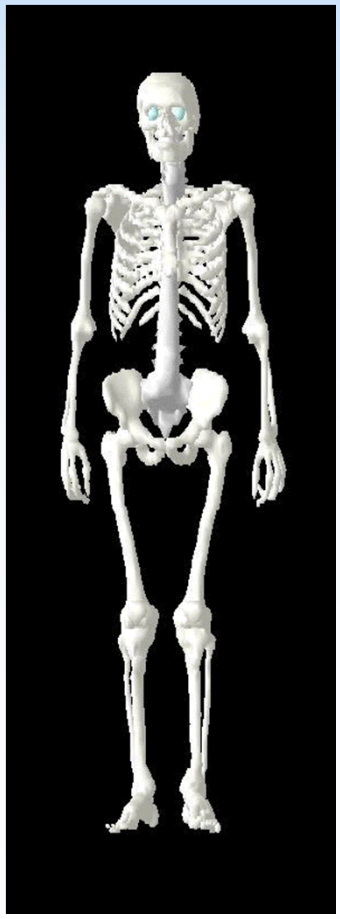
Modify these segmented voxel models in several steps

Laura

Modifications of segmented images to create reference computational phantoms

1. Voxel scaling
   - Use body height to scale voxel height
   - Use skeleton volume to scale voxel in-plane resolution
2. Individual organ volume modifications
   - Dedicated software tool „VolumeChange“
3. Additional modifications (blood, lymphatic nodes, movement of arms, adjustment of whole-body mass by adding adipose tissue, inclusion of skin at top and bottom)
4. Sub-segmentation of the skeleton
   - 19 bones (bone groups)
   - Subdivision in
     - cortical shell
     - spongiosa
     - medullary cavity (long bones)

Reference computational phantoms – Characteristics



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

140 Organ identification numbers

53 different tissue types

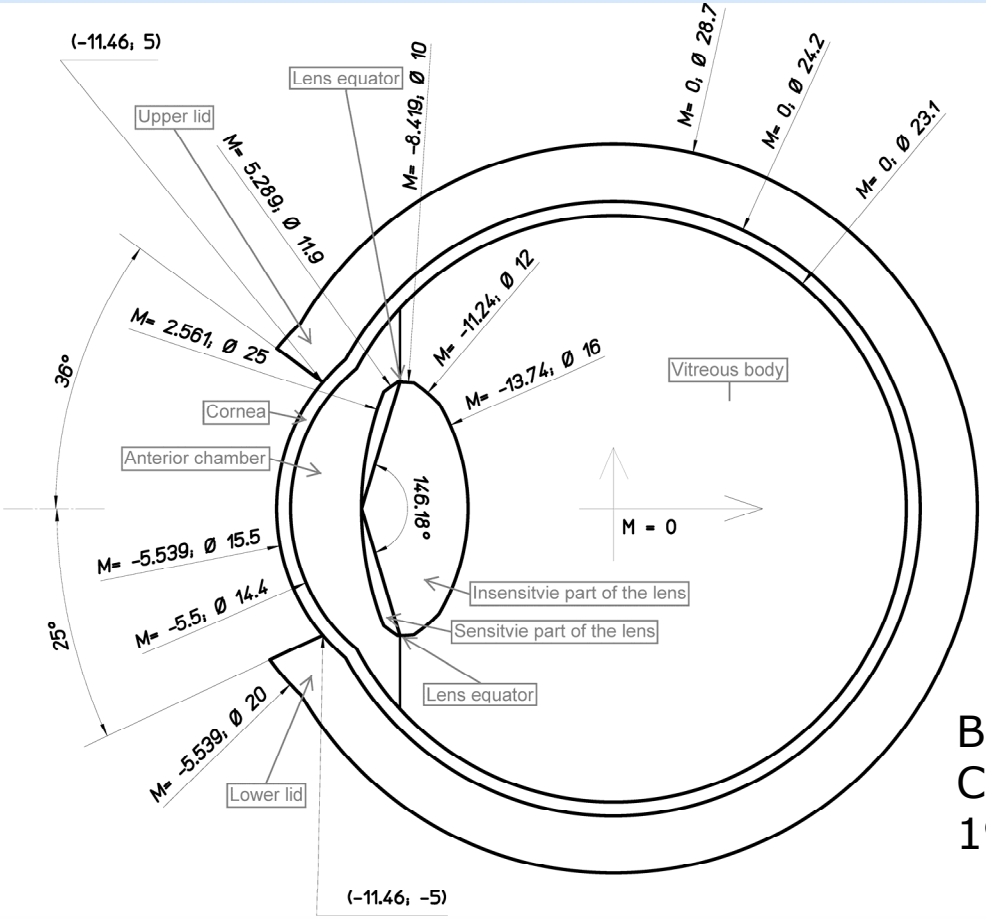
Female
163 cm, 60 kg
3.9 million voxels
Voxel size: 15.2 mm^3

Limitations due to image resolution

- Extrathoracic airways, trachea: one voxel layer
  - does not mirror their small dimensions (thickness in the range of micrometres)
  - but: locates them at correct anatomical position
- Bronchi
  - only larger diameters
  - no proper tree structure
- Bronchioles: homogeneous lung tissue
- Skin: one voxel layer
- Cartilage: only small amount segmented
- Gall bladder: not enough wall voxels to enwind the contents
- Eye lenses: not properly covered by correct amount of overlying tissue
- Adipose tissue
  - used to fill up the whole body mass
  - meets the reference values of ICRP Publication 89 only approximately

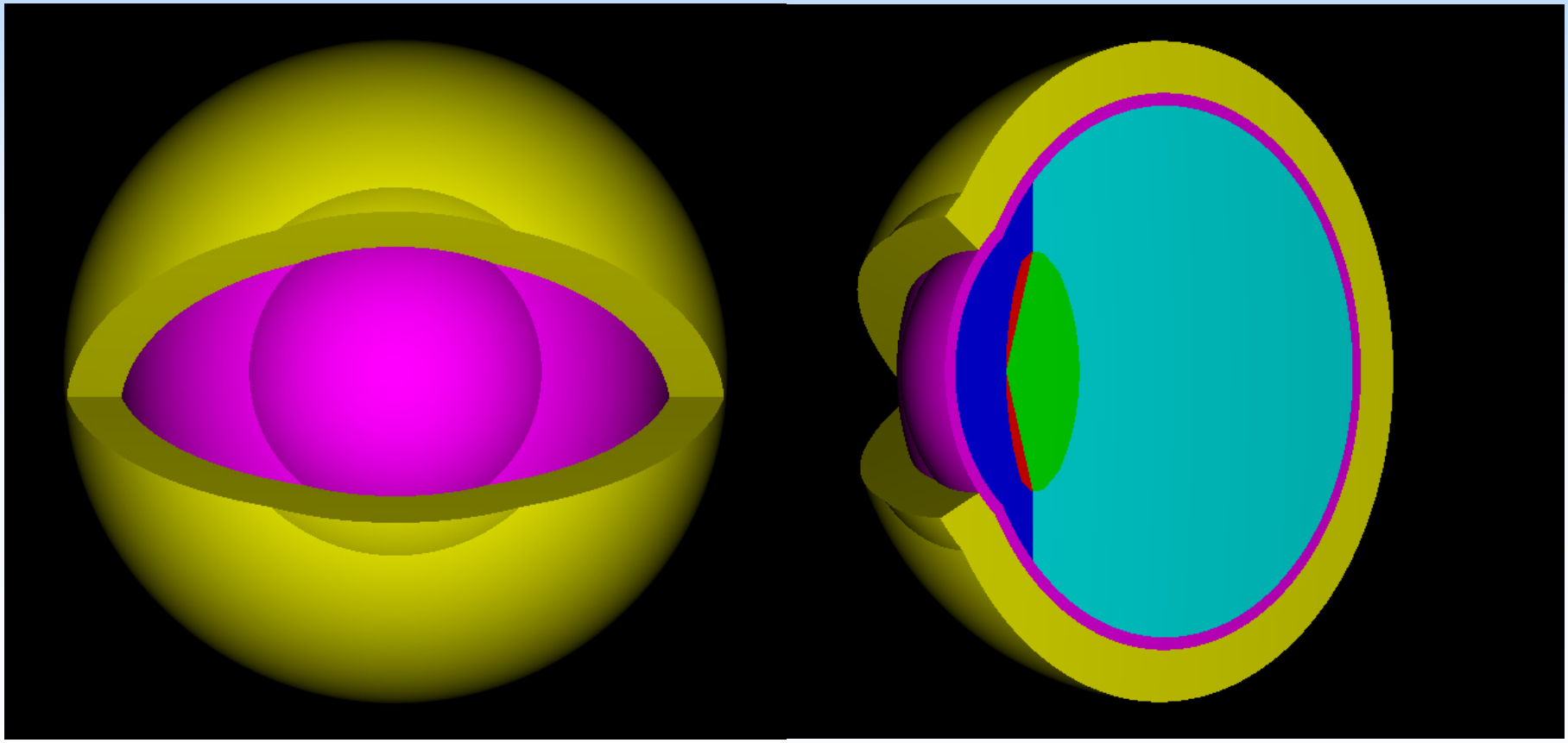
Detailed model of anatomy of the eye (Behrens et al.)

Recent epidemiological data on cataract induction have led to increasing interest in doses to the eye lens which is not well represented in the voxel-type reference computational phantoms.



Based on work by Charles and Brown 1975

Representation of eye geometry for MC calculations by R. Behrens *et al*.



This detailed eye model is being used for simulations of external irradiation with weakly penetrating radiation types and energies.

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 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.
- They are defined to enable calculations of the protection quantities organ and tissue equivalent dose and effective dose.
- For weakly penetrating radiations, a separate mathematical phantom of the eye with detailed definition of the eye lens has been used in addition to the voxel reference phantoms.
- Further work addressing limitations of the reference computational phantoms due to voxel resolution will be presented in the next talk …

Thank you very much for your attention!

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