Computational Phantoms used in Internal Dosimetry for Radiation Protection and Medicine

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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

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

<table>
<thead>
<tr>
<th>Age</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Newborn</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>1 year</td>
<td>76</td>
<td>76</td>
</tr>
<tr>
<td>5 years</td>
<td>109</td>
<td>109</td>
</tr>
<tr>
<td>10 years</td>
<td>138</td>
<td>138</td>
</tr>
<tr>
<td>15 years</td>
<td>167</td>
<td>161</td>
</tr>
<tr>
<td>Adult</td>
<td>176</td>
<td>163</td>
</tr>
</tbody>
</table>

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)
Reference computational phantoms – Characterisation

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

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$^3$
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.
ICRP 110 Reference Phantoms – limitations due to voxel resolution

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

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

Small tissues cannot be properly represented:
- Extrathoracic airways, bronchi and bronchioles
- Blood vessels
- Skin
- Eye lenses, ...

EURADOS Winter School 2017, Karlsruhe
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 μm) 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

Conversion to primitive polygon-surface model

Smoothness of boundary of polygon-surface model

Decrease in the number of polygons

Increase in the number of polygons

Adjustment of organ mass to reference value
Developed Phantoms

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.