Geant 4
Anthropomorphic Phantoms

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Anthropomorphic phantoms

A precise representation of the human body is important for accurate dosimetry

- Oncological radiotherapy
- Radiation protection studies
- Space science
- etc.

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Mathematical Phantoms

The size and form of the body and its organs are described by mathematical expressions (combinations/intersections of planes, circular and elliptical cylinders, spheres, cones, tori, etc.)

**MIRD5**: Estimates of Absorbed Fractions for Mono-energetic Photon Sources Uniformly Distributed in Various Organs of a Heterogeneous Phantom


Many derivations from the MIRD5 phantom

- MIRD5 revised (1978)
- Rosenstein et al (1979)
- Kramer et al (1982): Adam and Eva
- Jones and Wall (1985)
- Jones and Shrimpton (1991)
- etc.

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Voxel Phantoms

Based on digital images recorded from scanning real people
Computed Tomography (CT) or Magnetic Resonance Imaging (MRI)

<table>
<thead>
<tr>
<th>Model</th>
<th>Reference</th>
<th>Images</th>
<th>Race</th>
<th>Age and sex</th>
<th>Subject</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child</td>
<td>[18]</td>
<td>CT</td>
<td>Caucasian</td>
<td>7-year-old female</td>
<td>Leukemia patient</td>
<td>Small for age (5 to 7-year-old)</td>
</tr>
<tr>
<td>Baby</td>
<td>[18]</td>
<td>CT</td>
<td>Caucasian</td>
<td>8-week-old female</td>
<td>Cadaver</td>
<td></td>
</tr>
<tr>
<td>VoxelMan²</td>
<td>[49, 50]</td>
<td>CT</td>
<td>Caucasian</td>
<td>Adult male</td>
<td>Diffuse melanoma</td>
<td>Head and torso</td>
</tr>
<tr>
<td>NORMAN</td>
<td>[14, 30]</td>
<td>MRI</td>
<td>Caucasian</td>
<td>Adult male</td>
<td></td>
<td>Only 10 ribs</td>
</tr>
<tr>
<td>Golem</td>
<td>[26, 42]</td>
<td>CT</td>
<td>Caucasian</td>
<td>38-year-old male</td>
<td>Leukemia patient</td>
<td></td>
</tr>
<tr>
<td>ADELAIDE</td>
<td>[51]</td>
<td>CT</td>
<td>Caucasian</td>
<td>14-year-old female</td>
<td>Patient</td>
<td>Torso</td>
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<tr>
<td>VIP-man</td>
<td>[35]</td>
<td>Colour photos</td>
<td>Caucasian</td>
<td>38-year-old male</td>
<td>Cadaver (VHP)</td>
<td>One testicle only</td>
</tr>
<tr>
<td>Otoko</td>
<td>[20]</td>
<td>CT</td>
<td>Japanese</td>
<td>Adult male</td>
<td>Cadaver</td>
<td>Small for age</td>
</tr>
<tr>
<td>UF newborn</td>
<td>[38]</td>
<td>CT</td>
<td>Caucasian</td>
<td>6-day-old female</td>
<td>Cadaver</td>
<td></td>
</tr>
<tr>
<td>UF 2 month</td>
<td>[38]</td>
<td>CT</td>
<td>Caucasian</td>
<td>6-month-old (=2) male</td>
<td>Cadaver (VHP)</td>
<td></td>
</tr>
<tr>
<td>Visible-human</td>
<td>[23]</td>
<td>CT</td>
<td>Caucasian</td>
<td>38-year-old male</td>
<td>Patient</td>
<td>Head and torso</td>
</tr>
<tr>
<td>Frank</td>
<td>[23, 52]</td>
<td>CT</td>
<td>Caucasian</td>
<td>48-year-old male</td>
<td>Patient</td>
<td></td>
</tr>
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<td>Donna</td>
<td>[17, 52]</td>
<td>CT</td>
<td>Caucasian</td>
<td>40-year-old female</td>
<td>Patient</td>
<td>Legs absent below mid-thigh</td>
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<tr>
<td>Helga</td>
<td>[17, 23]</td>
<td>CT</td>
<td>Caucasian</td>
<td>26-year-old female</td>
<td>Patient</td>
<td></td>
</tr>
<tr>
<td>Irene</td>
<td>[17, 23]</td>
<td>CT</td>
<td>Caucasian</td>
<td>32-year-old female</td>
<td>Patient</td>
<td></td>
</tr>
<tr>
<td>MAX³</td>
<td>[24]</td>
<td>CT</td>
<td>Caucasian</td>
<td>Modified VoxelMan</td>
<td>Reference man dimensions</td>
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<tr>
<td>Nagaoka man</td>
<td>[32]</td>
<td>MRI</td>
<td>Japanese</td>
<td>22-year-old male</td>
<td>Volunteer</td>
<td>Head and torso</td>
</tr>
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<td>KR-man</td>
<td>[37]</td>
<td>MRI</td>
<td>Korean</td>
<td>28-year-old male</td>
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<td></td>
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<tr>
<td>Un-named</td>
<td>[53]</td>
<td>CT</td>
<td></td>
<td>9-month-old male</td>
<td></td>
<td></td>
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<tr>
<td>Pregnant woman</td>
<td>[54]</td>
<td>CT</td>
<td></td>
<td>30 weeks pregnant</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

M. Caon, *Voxel-based computational models of real human anatomy: a review*  
Still a hot topic...

Monte Carlo 2005 Conference, Chattanooga (TN)
Session on Tomographic Models for Radiation Protection Dosimetry

- GSF Male And Female Adult Voxel Models Representing ICRP Reference Man (K. Eckerman)
- Effective Dose Ratios for the Tomographic Max and Fax Phantoms (R. Kramer)
- The UF Family of Paediatric Tomographic Models (W. Bolch and C. Lee)
- Development and Anatomical Details of Japanese Adult Male/ Female Voxel Models (T. Nagaoka)
- Dose Calculation Using Japanese Voxel Phantoms for Diverse Exposures (K. Saito)
- Stylized versus Tomographic Models: an Experience on Anatomical Modelling at RPI (X. G. Xu)
- Use of MCNP with Voxel-Based Image Data for Internal Dosimetry Applications (M. Stabin)
- Application of Voxel Phantoms for Internal Dosimetry at IRSN Using a Dedicated Computational Tool (I. Aubineay-Laniece)
- The Use of Voxel-Based Human Phantoms in FLUKA (L. Pinsky)
- The Future of Tomographic Modelling in Radiation Protection and Medicine (Panel discussion)
Anthropomorphic Phantoms revisited

A fresh look at an old problem

Exploit modern software technology
Focus on architectural issues, rather than implementation details
Open source code

- Based on Object Oriented technology
- Powerful geometry modeling
- Detailed material description
- Versatility and precision of physics for dosimetry
Which technique is better?

Both!

Each one has its pro and contra

(\textit{precision}, \textit{memory usage}, \textit{speed of simulation execution}…)

Which one is “better” depends on one’s own specific use case

Take the best of both worlds

And what about a novel unorthodox approach?
Which one is the best for my dosimetry study?

- All
- None of the existing phantoms
- My own phantom

Mix & match

- ORNL liver + MIRD heart + Max frame + Frank head…

And what about embedding an organ from my own CT scanning into a standard phantom model?
Analysis & Design

Domain decomposition

Abstraction of the process of building a phantom

Abstraction of the model of body organs
Assembling a phantom

The process of assembling a phantom is handled through a **Builder** design pattern.

Concrete builders treated polymorphically through their base class.

**Builder Pattern**

Build a phantom by adding anatomy components one by one.

Customization

Derive your own class (e.g. head only).

Implementations

G4MaleBuilder
G4FemaleBuilder

G4PhantomBuilder
Build just the components you want (e.g. head only)
Standard Phantom Models

Abstract Factory Pattern

An Abstract Factory (*G4VBodyFactory*) is responsible for the creation of anatomy components. Concrete factories (e.g., *G4ORNLBodyFactory*, *G4MIRDBodyFactory*) implement specific phantom models.

Mix & Match

A Builder may instantiate different BodyFactories, treated through the same abstract interface, and pick organs from different phantom models, or mix organs from standard phantom models with user-created ones.
Phantom parameters

Parameters of anatomy components
- Geometry, sizes
- Position and rotation of body elements
- Materials

Stored in satellite files for some standard phantom models
- Use GDML (Geometry Description Markup Language)
- GDML Reader can create a Geant4 geometry out of the stored GDML description

Easy to provide user-defined phantom parameters
- Supply your own GDML file with parameters
- Use one of the standard Factories/Builders to assemble a phantom with your own sizes, materials, positions etc.

But you are not forced to use GDML, if you don’t wish so…
Components in G4PhantomBuilder

- Skull
- Thyroid
- Lungs
- Breasts
- Heart
- Liver
- Upper Large Intestine
- Uterus
- Urinary Bladder
- Spine
- Esophagus
- Arm Bones
- Spleen
- Pancreas
- Stomach
- Kidneys
- Pelvis
- Ovaries
- Lower Large Intestine
- Leg Bones

Not visible: Brain (inside the skull)
Female ORNL Anthropomorphic Phantom

3 materials
- skeleton
- lung
- soft tissue

Geant 4
G4FemaleBuilder + G4ORNLBodyFactory
Anatomical components can be defined as Geant4 SensitiveDetectors.
Energy deposit collected in Geant4 Hits.

![Diagram of shielding effectiveness with dose measurements for various organs.](image-url)

**Shielding: 10 cm of water**

- **Skull**: 1.20E-09 Gy
- **Upper Spine**: 1.00E-09 Gy
- **Middle Lower Spine**: 8.00E-10 Gy
- **Arm Bones**: 6.00E-10 Gy
- **Leg Bones**: 6.00E-10 Gy
- **Pelvis**: 6.00E-10 Gy
- **Stomach**: 6.00E-10 Gy
- **Upper Large Intestine**: 8.00E-10 Gy
- **Lower Large Intestine**: 6.00E-10 Gy
- **Liver**: 4.00E-10 Gy
- **Pancreas**: 2.00E-10 Gy
- **Spleen**: 2.00E-10 Gy
- **Kidneys**: 2.00E-10 Gy
- **Urinary Bladder**: 2.00E-10 Gy
- **Breasts**: 2.00E-10 Gy
- **Ovaries**: 2.00E-10 Gy
- **Uterus**: 2.00E-10 Gy
Mix & Match
Mathematical phantom with one voxel breast

MIRD mathematical breast

Dance & Hunt voxel breast

D. R. Dance and R. A. Hunt, REPORT RMTPC 02/1005
Dosimetry in mixed mathematical-voxel phantom

Dose in analytical organs

Energy deposit

Dose in each breast voxel
Conclusions

- OO technology
- A novel approach to an old problem
- Geant4 powerful functionality

= Geant 4

- Versatility of modeling
- Precision of Geant4 physics

Public release in Geant4 8.2 – December 2006
Open source