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PODIUM
Personal Online Dosimetry Using computational Methods

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D9.104– Database of phantoms of different statures and postures

Lead Author: Pasquale Lombardo

With contributions from: Maria Zankl

Reviewer(s): Filip Vanhavere and CONCERT coordination team

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Abstract

The goal of the PODIUM project is to develop a software application that allows calculating the radiation worker doses of interest by combining positioning information from a staff monitoring system and information on the radiation field. The aim is to provide fast dose calculations for workers moving in realistic workplace fields. These calculations will be based on Monte Carlo (MC) methods and need to employ a variety of computational body phantoms, assuming various postures inside the radiation field (e.g., standing, bending over something, hands stretched out into the radiation field) and having different body statures (tall, small, broad). This deliverable describes the various phantoms that were developed for this purpose, and that will be used during the PODIUM project. The computational phantoms for the MC calculations of this project encompass the following: Boundary representation (BREP) phantoms will be used to assume various postures in a workplace field, and several voxel phantoms are representing various body statures.

Content

D9.104 Development of phantoms that can be used in the Monte Carlo calculations (HMGU, SCK•CEN) M1-9

I. Introduction: computational phantoms and their role in PODIUM

The objective of the first deliverable of PODIUM WP2 is to provide a set of computational phantoms to be used for calculating occupational doses with Monte Carlo (MC) simulations. In consideration of the requirements of WP2 and of the other Work Packages, we decided to deliver 4 phantoms. These phantoms were selected to represent a heterogenous cohort of workers with different sex, statures and postures.

Computational phantoms (CP) are computer models of the human anatomy. They are used to simulate the transport of ionizing particles through the body, and thus to calculate the energy depositions within radiosensitive tissues. CPs are already fundamental in dosimetry and radiation protection. However, their role is even more central in PODIUM, since in our innovative approach to dosimetry, we rely solely on computational methods for assessing doses.

In a few words, computational phantoms for MC simulations are models constituted by:

1) a geometry, made of a set of surfaces defining shape and volume of the human tissues, and
2) by a set of tissue materials, defining the probabilities of interaction and energy deposition during particle transport.

Since the development of the first human models in the 1960s, CPs have been constantly evolving, increasing their anatomical accuracy together with their level of complexity. Nowadays, researchers identify phantoms based on the technology used for modeling the anatomy. Among the available technologies, voxel phantoms and B-Rep phantoms are the ones of greater interest for the objectives of PODIUM. Voxel phantoms are highly realistic human models derived from medical scans of patients undergoing medical exams. These phantoms are stored in form of volumetric datasets made of millions of voxels, and they can contain several dozen tissues. Typically, the resolution of a whole-body voxel phantom ranges from 1 to 2 mm in the transversal plane, and from 2 to 10 mm along the longitudinal axis of the phantom. B-Rep phantoms, instead, are created with the same 3D modeling tools that are used in engineering and in computer design. Compared to voxel phantoms, they are characterized by smoother surfaces which can theoretically model even thin radiosensitive tissues with sub-millimetric dimensions. However, this level of anatomical accuracy is not necessary for PODIUM. More importantly, the real advantage of B-Rep phantoms to PODIUM comes from the deformability of B-Rep surfaces, which can be used to simulate different body postures.

We selected the 4 computational phantoms based on the requirements of PODIUM. First, these phantoms represent a good variety of anatomies, including both sexes. Secondly, they belong to two different generations of phantoms. Each generation has complementary advantages and disadvantages. Lastly, they were developed by two partner institutes with experience in computational phantom modeling. This allowed us to make aimed modifications to the phantoms, like the adding of the lead apron.

On the one hand, we will make use of 3 female phantoms from the well-established HMGU family of voxel phantoms, developed in the Helmholtz Zentrum München. These 3 phantoms were selected because they represent female doctors and nurses with a diversified and realistic range of body statures. On the other hand, we will also make use of the recently developed Realistic Anthropomorphic Flexible (RAF) adult male phantom, which is characterized by a high level of flexibility. In this case, the phantom will represent male doctors and nurses with body dimensions close to that of the ICRP reference man (ICRP 2002).

II. B-Rep phantoms: Realistic Anthropomorphic Flexible phantom and Interactive Posture Program

The Realistic Anthropomorphic Flexible phantom belongs to the B-Rep generation of computational phantoms. The RAF phantom represents an average Caucasian adult male, so its anthropomorphic measurements (176 cm, 76 kg) are close to those of the ICRP reference adult male. Differently from the ICRP reference voxel phantom, however, the RAF phantom is made of polygonal mesh (PM) surfaces, a type of B-Rep. The PM representation is, by far, the most widespread computer graphic modeling technique. For this reason, modern computer hardware was evolved and optimized to work with PM. GPUs can process billions of polygons per seconds, making it possible to apply complex mathematical operations to deform the mesh surfaces in real-time.

Nevertheless, making use of RAF phantom in PODIUM applications would have not been practical, as it requires specialized software and experience in B-Rep modeling. For this reason, we developed a software, named Interactive Posture Program (IPP), which allows to make use of the RAF phantom through a simple interactive user interface, illustrated in figure 1a. With IPP, the posture of the RAF phantom is controlled by 9 selectable objects, called end-effectors. Five end-effector are used to defines the point that needs to be reached by each limb (hands, feet and head of the phantom). Additionally, 4 end-effectors can be turned on to adjust finely the orientation of elbows and knees. Thanks to IPP, we can easily share the RAF phantom among PODIUM partners, which will be able to create versions of phantoms mimicking realistically the workers posture. For assessing correctly doses to medical staff in Interventional Radiology, protective garments are included in our simulations. For this reason, in IPP the RAF phantom can also be equipped with an apron, a thyroid collar and a cap (all 0.5 mm thick). The garments are activated through a toggle in the IPP interface (figure 1b).

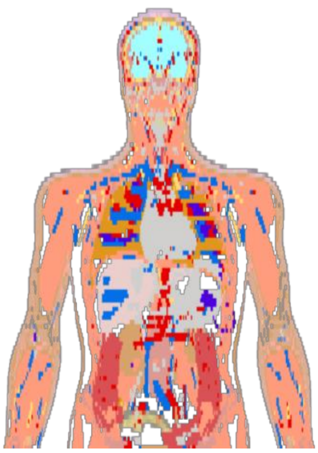
1a 1b

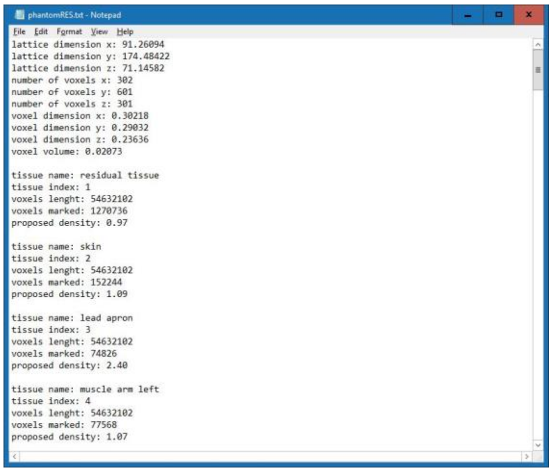
Figure 1: a) graphical interface of the Interactive Posture Program (IPP) for controlling the posture of the RAF phantom, and b) RAF phantom equipped with protective garments.

Another aspect that needs to be taken into account with B-Rep is that polygonal mesh surfaces, by definition, do not enclose fixed volumes, so they can overlap one over the other. This constitutes an additional complexity in the development of a computational phantom and in its implementation in MC transport codes, where volumes must be defined unambiguously and without overlaps. For this reason, we developed a special processing within IPP, in which the polygonal surfaces are attributed of a volume. This processing can be performed in 2 ways, depending on the MC transport code that is used. They consist in:

- converting the RAF phantom to mesh files compatibles with Geant4, and in
- converting the RAF phantom to a voxel phantom, compatible with most MC transport codes (MCNP, EGS, Penelope, Geant4).

Due to the large experience with MCNP, EGS and Penelope within WP2 participants, the voxelized version of the RAF phantom is the one of greater interest for PODIUM. In this case, the voxels are stored into a text image file, which can be easily loaded by image visualization tools like ImageJ, and converted to MC input file, as shown in figure 2a. The resolution of the voxelization process can be selected depending on the application and on the anatomical accuracy required for the phantom. It is important to underline that, on the one hand, the voxel resolution affects the mass and the thickness of the tissues. The higher the resolution, the more accurate masses and thicknesses are. On the other hand, high voxel numbers require higher computational performances and entail larger memory footprint, which could reduce dramatically the number of simulations that could be performed within short timeframes, needed for PODIUM. Ideally, for not compromising the anatomical accuracy of the RAF phantom and for maintaining reasonable computing performances, the voxel dimension should be kept between 1 to 3 mm in the axial plane, and between 2 to 4 mm along the longitudinal axis of the phantom. Together with the text image file, the Interactive Posture Program prints a text file with the specifications of the voxelized RAF phantom (figure 2b). The specification file include the dimensions of the phantom, the voxel resolution (in cm), the identifier and the number of voxels for each tissue, and a *proposed density value* (in g cm^{-3}). The proposed density value is calculated by IPP to fit the masses of the voxelized tissues to the masses of the PM version of the RAF phantom. If the proposed tissue density differs by more than 10% from that of the PM RAF phantom, a warning message is printed. In the case of the lead garments, the proposed density value is calculated to achieve a lead equivalent thickness of 0.5 mm along the sagittal axis (i.e. the **z** direction of IPP).





phantomRES.txt - Notepad

File Edit Format View Help

```
lattice dimension x: 91.26094
lattice dimension y: 174.48422
lattice dimension z: 71.14582
number of voxels x: 302
number of voxels y: 601
number of voxels z: 301
voxel dimension x: 0.30218
voxel dimension y: 0.29032
voxel dimension z: 0.23636
voxel volume: 0.02073

tissue name: residual tissue
tissue index: 1
voxels lenght: 54632102
voxels marked: 1270736
proposed density: 0.97

tissue name: skin
tissue index: 2
voxels lenght: 54632102
voxels marked: 152244
proposed density: 1.09

tissue name: lead apron
tissue index: 3
voxels lenght: 54632102
voxels marked: 74826
proposed density: 2.40

tissue name: muscle arm left
tissue index: 4
voxels lenght: 54632102
voxels marked: 77568
proposed density: 1.07
```

2.a 2.b

Figure 2: a) Frontal slice of a voxelized version of the RAF phantom, and b) the related information text file generated by IPP

The IPP program will be distributed to PODIUM partners that will need to do simulations through the restricted section of PODIUM website.

III. Voxel phantoms

The following voxel phantoms from the HMGU phantom family (Fill et al., 2004; Zankl, 2010) are used for the PODIUM project: Irene and Donna. Irene is a slim person (51 kg, 163 cm), and Helga is large (79 kg, 176 cm). Furthermore, RCP-AF, the ICRP/ICRU reference adult female computational phantom (60 kg, 163 cm), is also used (ICRP, 2009). The main characteristics of these voxel phantoms are given in Table 1.

For the simulations in the interventional radiology workplaces, the phantoms Donna and Irene have been equipped with protective garment (apron and collar). This garment is represented by one voxel layer of protective material surrounding the phantom outline (see Fig. 3 and Fig. 4). The material and density of this voxel layer has to be assigned in the MC simulations such that the voxel dimension properly reflects the material and thickness of the protective garment. For Donna and Irene, whose voxel in-plane resolution is 1.875 mm, a "modified" lead density of 3.0267 g cm^{-3} should be used to simulate 0.5 m of lead (compared to the physical lead density of 11.35 g cm^{-3}).

	Donna	Irene	RCP-AF
Height (cm)	176	163	163
Mass (kg)	79	51	60
Slice thickness (voxel height, mm)	10	5	4.84
Voxel in-plane resolution (mm)	1.875	1.875	1.775
Voxel volume (mm3)	35.2	17.6	15.25

Table 1: Main characteristics of voxel phantoms Donna, Irene, and RCP-AF

Figure 3: Transversal slice of Donna at height of the breast with added voxel layer representing a protective apron.

Figure 4: Transversal slice of Donna at height of the neck with added voxel layer representing a protective collar.

The voxel phantoms Irene and Donna with protective garment have been stored on the restricted area of the PODIUM website. They can be made available to the scientific community upon request.

IV. Conclusions

With this deliverable, WP2 provides a set of computational phantoms with a wide range of anatomies and postures. Thanks to the 3 female voxel phantoms and to the IPP tool, we will be able to perform simulations which represent occupationally exposed workers and the real working scenarios that PODIUM dosimetric approach will be monitoring. On the one hand, we will make use of well-established female voxel phantoms from the HGMU family, which could serve as *reference.* On the other hand, we will also make use of the more recently developed RAF phantom, which is flexible in his posture. We expect that with this variety of phantoms, we will make PODIUM's approach to dosimetry not only more innovative, but also more individualized, for the benefit of accuracy.

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