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OBJECT ORIENTED DESIGN OF ANTHROPOMORPHIC PHANTOMS AND GEANT4-BASED IMPLEMENTATIONS

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ABSTRACT

Various models of anthropomorphic phantoms have been developed in the past decades for usage in Monte Carlo simulation for radiation protection and other medical physics applications; they adopt two alternative approaches, either modelling the body components through analytical geometrical representations or through voxelized geometries. An original system has been developed associated with the use of the Geant4 simulation toolkit. It exploits Geant4 advanced capabilities to model geometrical components, and the object oriented technology to provide a variety of models of the human body usable in a simulation application. The flexible software design allows the creation of both analytical and voxel phantoms. The system allows the creation of phantoms of different sex and age; phantoms based on established models are provided, as well as the option for the user to assemble customized phantoms.

Key Words: Geant4, Monte Carlo, radiation protection, medical physics.

1. INTRODUCTION

Realistic software models of the human body are useful tools in various domains, such as radiation protection, oncological radiotherapy or nuclear medicine. Their most common application is to study the effects of radiation by means of Monte Carlo simulation.

Several models of anthropomorphic phantom have been developed over approximately four decades. They are characterized by two different approaches to the description of body components: their shape is described either through mathematical representations, or through an approximation by means of voxels. Various software implementations have been developed based on both approaches; however, most of the software codes of anthropomorphic phantoms described in literature are not publicly available to the scientific community.

The issue of which modeling approach is superior has been debated at length in the scientific community; both the analytical and the voxelized approaches present advantages and drawbacks in terms of computational complexity and modeling accuracy.

The project described in this paper represents an innovative approach to modeling anthropomorphic phantoms for Monte Carlo simulation. It exploits the Geant4 [1,2] simulation toolkit for and an original software design to model anthropomorphic phantoms; various phantom models have been implemented in this context.

2. SOFTWARE DESIGN

A set of software components, which use the Geant4 simulation toolkit, has been developed to model anthropomorphic phantoms; these components can be used in Geant4-based simulation applications.

The software design exploits the object oriented technology and several design patterns [3]. Different implementation options can be treated transparently through the same design, thus allowing for a flexible, extensible and customizable system.

A Builder design pattern handles the process of assembling an anthropomorphic phantom out of body organs. Concrete Builders offer the option of building phantoms of different sex (i.e. encompassing different body components), or partial representations (for instance, just a torso with the organs it contains).

The phantom models profit of the rich functionality for geometry modelling and efficient navigation across volumes available in the Geant4 toolkit: for instance, the mathematical phantoms exploit the ample variety of Geant4 solid models, while the voxel one take advantage of the nested parameterisation technique to optimize the simulation performance.

The design allows to use analytical and voxel models, both individually and in mixed configurations; the user can thus exploit the advantages of both approaches in terms of computational speed and modelling accuracy.

Thanks to the flexibility of the software design, the user has the possibility of customizing the phantom model down to a fine granularity, according to the requirements of his/her specific experimental application.

3. IMPLEMENTATION

The design allows for a variety of implementations. A preliminary one has been described in [4] and released as a Geant4 advanced example.

Further refinements to the design and new implementations have been recently developed by the authors; they encompass both mathematical and voxel phantoms.

The implementation of mathematical phantoms exploits Geant4 advanced geometrical capabilities. The Geant4 toolkit offers sophisticated options to configure solids, which can be used by analytical phantom models to describe the shapes of body organs.

One of the implementations is based on the male adult mathematical phantom known as ADAM and the female phantom EVA [5]. The hermaphrodite phantom of the MIRD5 [6] scheme has also been implemented with improved capabilities with respect to the version distributed in Geant4 example.

Developments related to a voxel phantom are also presented. Geant4 parameterised volumes can be used to construct voxel geometries effectively; voxels can be parameterized according to various features, such as, for instance, their material composition. Techniques like the “nested parameterization” available in Geant4 allow for efficient navigation across the voxel geometry of an anthropomorphic phantom, thus speeding up the simulation execution. The voxel phantoms by Zubal et al. [7] and by Kramer [8] have also been implemented.

Figure 1 shows an implementation of the hermaphrodite MIRD5 phantom. Figure 2 shows the Zubal head voxel phantom; the picture was produced using Geant4 visualization for OpenInventor.

4. RESULTS

Thanks to the adopted component design, the phantom can be embedded in any Geant4-based geometry model and can be exposed to any radiation environment by activating any of the physics models of particle interactions provided by Geant4. The developed tool allows users to calculate the dose released to various body parts in a variety of simulation application configurations.

Dose distributions in the various body components calculated in phantom models are generated in various irradiation configurations. The results are discussed also in the context of pertinent literature.

An example of organ doses calculation is shown in figure 3, where a plane source irradiates the ADAM phantom with 50 keV photons in Anterior-Posterior geometry. Organ doses are compared with the values obtained by Zankl et al. [9] in the same configuration.

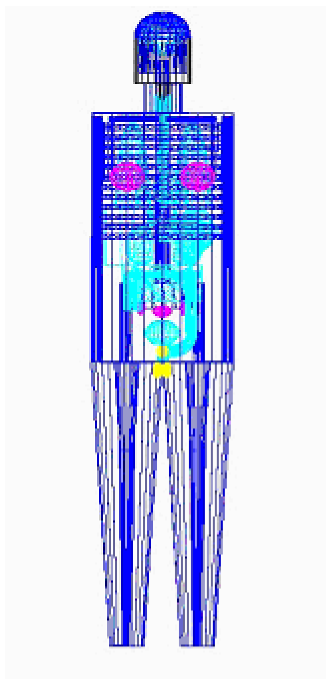

Figure 1: The MIRD5 schema hermaphroditic phantom.

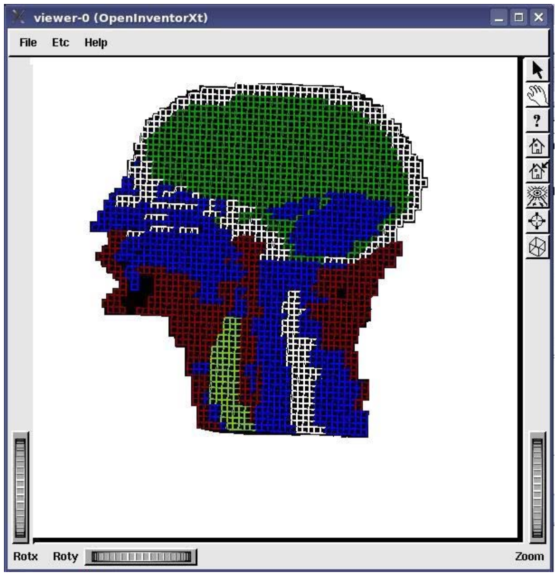

Figure 2: The Zubal head voxel phantom.

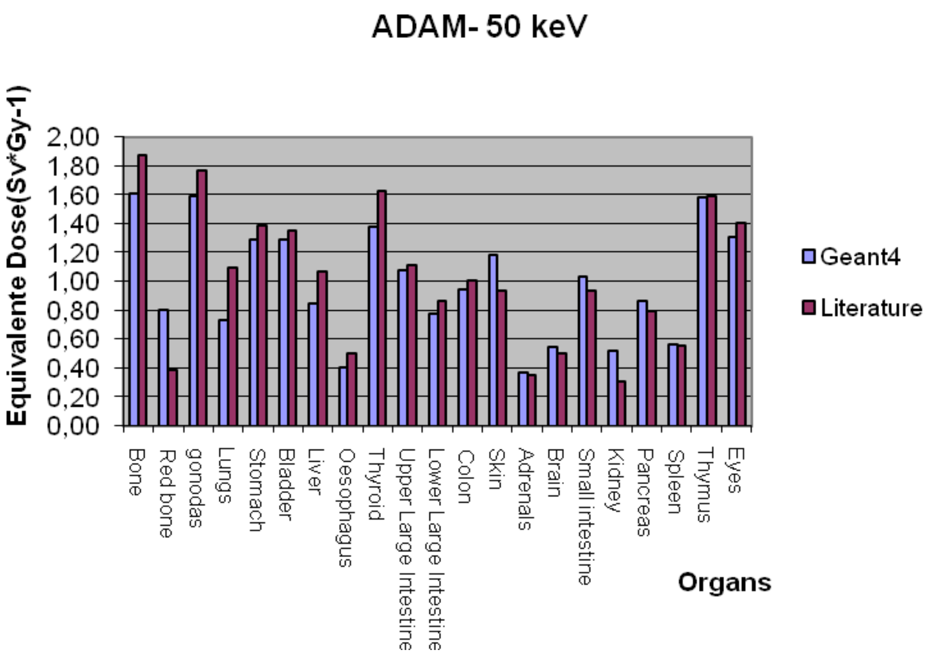

Figure 3: Equivalent Dose in organs per Air kerma for the ADAM mathematical phantom. 50 keV photons incident on the phantom in AP plane geometry irradiation. Results obtained with Geant4 are referenced to those published by Zankl et al. All results are PRELIMINARY

The same evaluation has been performed with the voxel phantom, now comparing the results obtained with Geant4 with those obtained by the Visual Monte Carlo (VMC) [10]. VMC is a Monte Carlo code designed specifically for dose calculations in voxel phantoms. This software allows one to position a point source close to a phantom, choosing the photon energy and the number of histories to obtain organ doses and effective doses. In this example, a source was positioned at 1.0 m distance in front of the phantom's eyes and 100 keV photons were generated isotropically. The results are shown in figure 4.

In this respect, it is worth stressing that the dose calculations performed with Geant4 profit of the accuracy of its physics models along with the geometrical capabilities of anthropomorphic phantom modeling.

3. CONCLUSIONS

The implementation of anthropomorphic phantoms using the Geant4 toolkit was summarized, showing that it is possible to calculate the dose in each organ, or to simulate the whole or specific parts of the body.

The versatility of phantom modeling combined with the precision of Geant4 physics and with Geant4 power functionality allows a fresh look into anthropomorphic phantom simulation.

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