Nuclear Science and Technology Division (94)

PIMAL: Computational Phantom with Moving Arms and Legs

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To be submitted to
The American Nuclear Society Annual Meeting
June 24–28, 2007
Boston, MA

[*] Managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract No. DE-AC05-00OR22725.

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INTRODUCTION

Computational phantoms have been used for the assessment of organ doses for internal and external radiation sources for over three decades [1]. Although changes have been made with respect to the internal organs (in terms of number, organ size and locations, and elemental composition [2]), the exterior shape of the phantom (i.e., arms and legs) has remained the same with the exception of a few cases that are discussed below. Further, the computational phantoms have almost always been in the vertical upright position, with arms attached to the torso as well as rigid arm and leg structure, which does not allow movement or bending. In some cases, different positioning of the arms and legs is needed for the assessment of the organ doses.

In a few instances, computational phantoms for posture other than vertical upright have been used in the assessment of radiation dose. For example, to evaluate the organ doses for the A-bomb survivors, a phantom in a sitting position was used [3]. Similarly, for the evaluation of organ doses for a worker sitting in a chair, the leg model was revised [4]. The shape of the upper trunk of the phantom was modified in simulating thyroid counters [5]. In these cases, the arms were still part of the torso. For the evaluation of the JCO criticality accident, arms and legs were separated [6]. To our knowledge, in all these previous works, the phantom was revised specifically for the case in hand—that is no capability of moving arms and legs freely existed.

To model different exposure geometries more freely, a computational phantom based on the Oak Ridge National Laboratory (ORNL) phantom [1, 2] with moving arms and legs has been developed. The revised phantom model is called **PIMAL**: **P**hantom w**i**th **M**ovable **A**rms and **L**egs. In this paper, the PIMAL model is presented.

DESCRIPTION OF PIMAL

In the original phantom, arms were attached to the torso. First, arms were separated from the torso and divided into parts that are connected at the shoulders and elbow. Similarly, legs were reshaped and divided into parts that were connected at the hip and knee. Therefore, in the revised phantom, arms have the capability of bending from the shoulder and elbow; legs have the capability of bending at the hip and knee.

While modifying the phantom, attention was given to retain the original volumes and masses of the arms and legs. Figure 1 shows the original phantom, on the left, and the modified phantom with moving arms and legs, in the middle. On the right, an illustrative posture generated using this approach is shown. In this configuration, it is assumed that the phantom is sitting in a chair and the arms are on the armrests.

Currently, there is no capability of bending the torso with a repositioning of the internal organs. However, for the torso, the assessment of organ doses in different postures can be done by changing or rotating the source location relative to the torso.

RESULTS AND FUTURE WORK

In order to compute the organ doses, radiation transport simulations are performed using the MCNP5 [7] Monte Carlo code. The MCNP input file has been revised to implement these modifications. Arms and legs were modeled using the macrobodies feature of MCNP. For a given movement, instead of using transformation cards, the corresponding surface cards are recalculated and modified in the input file. Furthermore, a graphical user interface (GUI) has been developed to assist the user with generating the input file for the desired posture and to perform the computations. The GUI for PIMAL is described in more detail in Ref. [8].

In order to ensure that the modifications do not cause any statistically significant change in the computed organ doses, a series of benchmark computations were performed. Benchmark computations were performed for the original phantom, with rigid arms and legs, and PIMAL, with modified arms and legs, in the same vertical, upright position. Computations were performed for monoenergetic neutron and photon sources for the standard ICRP source geometries: Antero Posterior (AP), Postero-Anterior (PA), Left Lateral (LLAT), Right Lateral (RLAT), and Isotropic (ISO) geometries. For neutrons, the source energy range varied from 10^{-9} MeV to 20 MeV. For photons, the source energy range varied from 30 keV to 10 MeV. The computations were performed on a Linux cluster using 20 million particles at each energy. To reduce the statistical uncertainty at lower energies, the number of particles was increased to 100 million.

The computational results show that the organ doses from both phantoms are in good agreement with each other for both neutron and photon sources.

The computational phantom used in this study is hermaphrodite, with gender-specific organs of both genders. Hence, the same features can be extended to ORNL's gender- and age-specific phantoms as well as the pregnant female model in future work. Further, these models can be included in the pull down menu of the GUI. Some specific case studies with different postures using this phantom are planned as additional future work.

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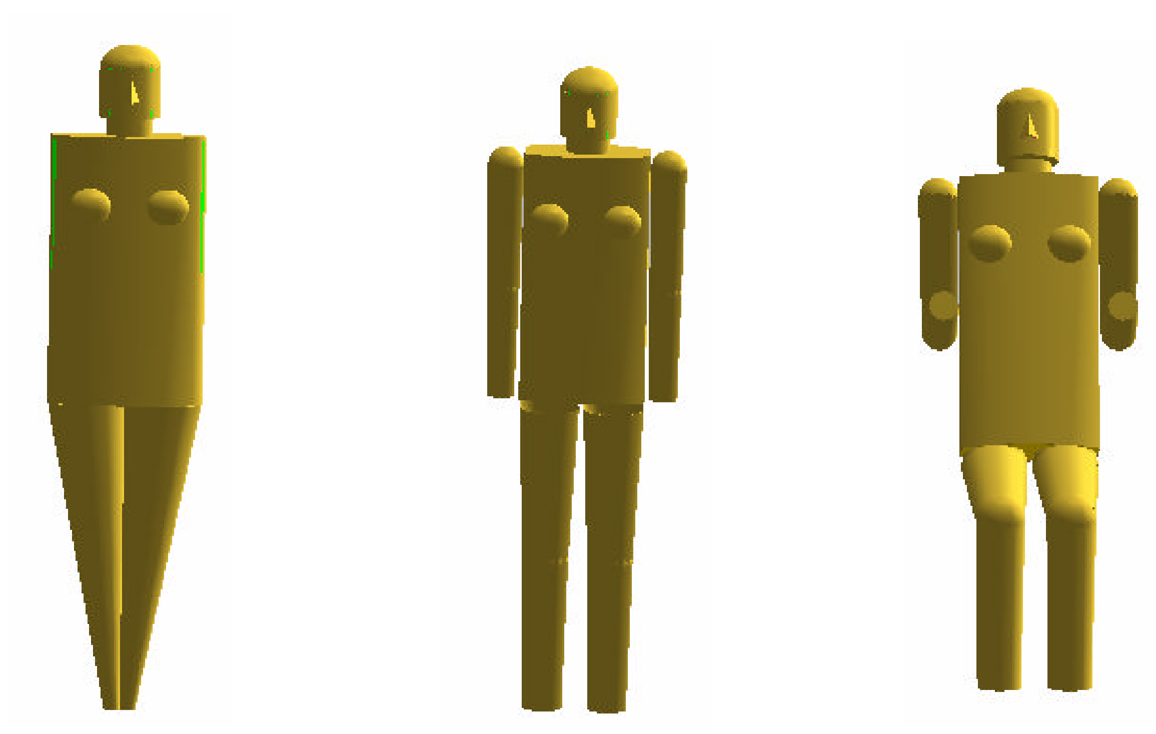

Fig. 1. The traditional phantom in the vertical, upright position with arms attached to torso and rigid legs (left), phantom with movable arms and legs (middle), and phantom in sitting position with arms on armrest (right).