Estimation of Radiation Dose for a Sitting Phantom Using PIMAL

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INTRODUCTION

To assess the radiation dose in different configurations when needed (e.g., occupational exposure or public exposure in a radiologically significant event), the mathematical phantom has recently been revised to enable freely moving abilities for arms and legs. The revised phantom is called **PIMAL**: **P**hantom w**I**th **M**oving **A**rms and **L**egs [1, 2]. Additionally, a graphical user interface has been developed to assist the analyst with input preparation and output manipulation [1, 3].

To investigate the impact of the phantom configuration on the estimated organ doses, PIMAL has been used in a different posture than the standard vertical-upright position. In this paper, the estimated organ and effective dose values for a representative posture, the phantom in a sitting position, compared with those for the phantom in standing position, are presented.

DESCRIPTION OF MODEL

To assess the impact of different postures on the computed organ doses, PIMAL has been used to generate a sitting phantom. PIMAL in standard vertical-upright position and in sitting position is shown in Fig. 1. In this figure, the exterior shape for the standing phantom is shown on the left. To display the internal organs, skin and soft tissue are removed, as shown in the middle. The phantom in sitting position is shown on the right.

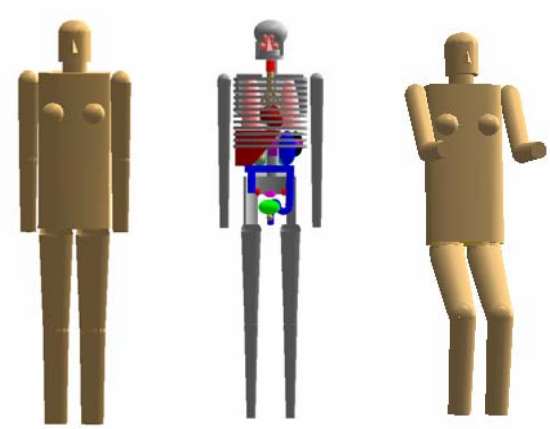

Fig. 1. Phantom with moving arms and legs in standing position (left); showing internal organs with skin and soft tissue removed for display purposes (middle); and in sitting position with arms slightly open (right).

The absorbed organ dose values for both postures are computed using the MCNP5 [4] Monte Carlo radiation transport code. Computations were performed for monoenergetic neutron and photon sources for three of the standard International Commission on Radiological Protection (ICRP) source geometries: Left Lateral (LLAT), Right Lateral (RLAT), and Isotropic (ISO). For neutrons, the source energy range varied from 10^{-9} MeV to 14 MeV. For photons, the source energy range varied from 50 keV to 10 MeV. The computations were performed on a Linux cluster. The number of particles used in the simulations varied from 20 million to 100 million depending on the source energy.

Since different types of radiation cause different effects in tissue, the absorbed dose in an organ or tissue T is multiplied by the corresponding radiation weighting factor (w_R) to obtain organ equivalent dose (H_T). The radiation weighting factor for gammas is 1, and for neutrons, the values vary as a function of neutron energy and are taken from ICRP-60 [5].

The effective dose (E) was calculated using Eqn. 1.

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R} \quad (1)$$

where w_T is the tissue weighting factor, w_R is the radiation weighting factor, H_T is the equivalent dose, and $D_{T,R}$ is the absorbed dose averaged over a tissue or organ. The tissue weighting factors, , from ICRP-60 [5], which are given in Table 1 are used in the analysis.

Table 1. Tissue weighting factors specified in ICRP-60.

Organ	w_T
Gonads	0.20
Lungs, Stomach, Colon, Red Bone Marrow	0.12
Breast, Esophagus, Liver, Thyroid, Bladder, Remainder*	0.05
Skin, Bone surface	0.01

*Remainder: Adrenals, brain, small intestine, kidneys, muscle, pancreas, spleen, thymus, uterus. The weighting factor 0.05 is applied to the average dose of these organs.

RESULTS AND FUTURE WORK

The absorbed organ dose values for all the organs are computed using MCNP5. The effective dose values are computed using the relation given in Eqn. 1.

The ratios of the effective dose values for the phantom in the sitting position compared with those for the phantom in standing position are shown for neutron and photon sources in Figs 2a and 2b, respectively. As shown in the figures, for the isotropic geometry, the differences in the estimated effective dose values for these two configurations is relatively minimal for both neutron and photon sources. However, for the RLAT and LLAT geometries, the differences are clear and significant. For photon source, for the RLAT and LLAT geometries, the effective dose for the sitting phantom is higher than that for the standing phantom (ratio>1), especially at lower energies. The effective dose ratio approaches to 1 as the source energy increases. For neutrons, the ratio first increases as a function of the energy for the same geometries. The maximum difference in the estimated effective dose is approximately 40% higher for the sitting phantom compared with that for the phantom in standing position.

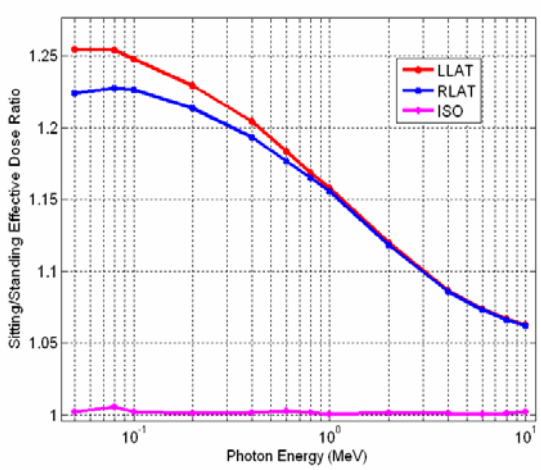

Fig. 2a. The effective dose ratios for the phantom in the standing position vs those for the phantom in sitting position for the photon source.

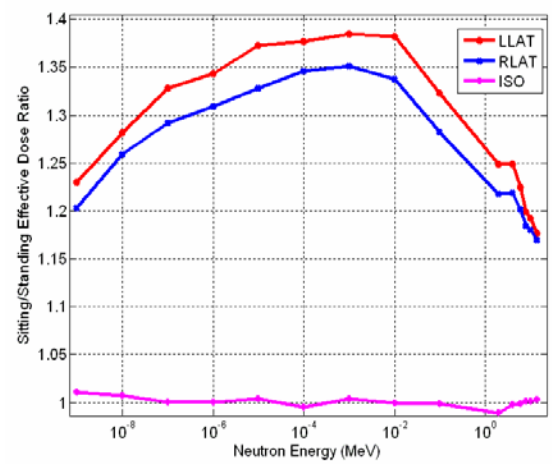

Fig. 2b. The effective dose ratios for the phantom in the standing position vs those for the phantom in sitting position for the neutron source.

The ratio of the absorbed dose values for the colon from neutrons is shown in Fig. 3a and that for photons is shown in Fig. 3b. As shown in the figures, the absorbed dose values for this organ show similar behavior with the effective dose. However, the relative change in the estimated dose values is more significant for this organ. Although the effective dose values between these two postures differ by a maximum of 25% for the photon and 40% for the neutron source, the absorbed dose values for the sitting phantom differ by a factor of two or more for this organ, depending on the source energy.

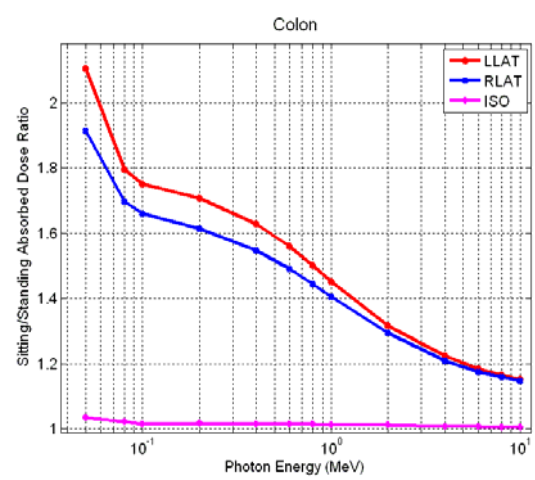

Fig. 3a. The absorbed dose ratios to the colon for the phantom in the standing position vs those for the phantom in sitting position for the photon source.

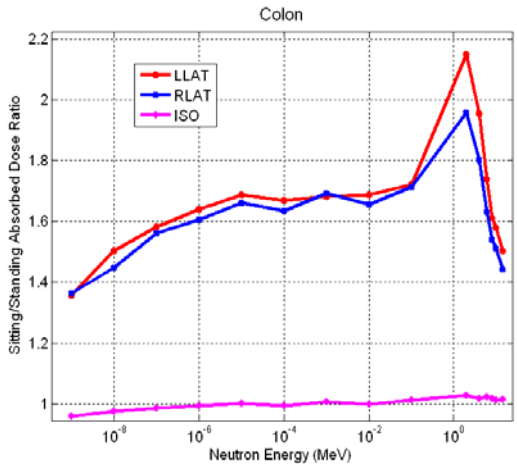

Fig. 3b. The absorbed dose ratios to the colon for the phantom in the standing position vs those for the phantom in sitting position for the neutron source.

The differences in the estimated organ dose values for internal organs are mainly due to the decreased shielding effect with the arms being away from the torso. Despite the fact that the arms are not fully extended in the sitting posture, as shown in Fig. 1, the impact on the estimated organ dose values is evident, as shown in Figs. 2 and 3. Although only the absorbed dose to the colon is presented in this summary, similar behavior has been observed for the majority of the organs, including the lungs, stomach, liver, small intestine, kidneys, pancreas, and uterus, all of which are considered as important for radiation protection purposes for both neutron and photon sources.

Based on the computational results, it can be concluded that it is not only important to have the correct source geometry and energy defined but also to have a realistic configuration for the posture. PIMAL facilitates the estimation of organ doses for realistic configurations.

In this paper, preliminary analysis results for idealized source configurations (uniform, monoenergetic) with no surrounding media are presented. The results indicate that the posture can have a significant impact on the effective and absorbed dose values. The same analysis could be carried for a heterogeneous source with surrounding media (e.g., a worker in front of a glove box in a room).

REFERENCES

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