Assessment of Organ Doses for a Glovebox Worker Using Realistic Postures with PIMAL and VOXMAT

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INTRODUCTION

In an earlier effort, the Oak Ridge National Laboratory (ORNL) mathematical phantom has been revised to enable assessment of radiation dose for different postures in occupational exposures by enabling freely positioning arms and legs. The revised phantom is called **PIMAL**: **P**hantom w**I**th **M**oving **A**rms and **L**egs [1,2]. Further, to assist the analyst with input preparation and output manipulation for different postures, a graphical user interface has been developed [1,3].

Also, at ORNL a hybrid computational phantom, which uses a combination of voxelized and stylized geometry, for radiation dose assessment was recently developed [4]. This phantom is based on the International Commission on Radiological Protection's (ICRP's) male phantom model [5] and is called VOXMAT. For VOXMAT, the head and torso, which contain significant anatomical details, were described using voxel geometry. The arms and legs, which contain less-detailed anatomical structures, were modeled using the mathematical equations (stylized approach). With this approach the number of voxels was reduced from 7 million to 2.3 million, which translated into a proportional reduction in computational time and memory requirements. More importantly, VOXMAT allows easy the movement of arms and legs for radiation dose assessment for realistic postures.

To determine/demonstrate the importance of the realistic posture for a case study, PIMAL and VOXMAT are applied to assess the dose to a glovebox worker. In this paper, the comparative computational results for the estimated dose are presented.

APPLICATION OF PIMAL AND VOXMAT FOR ESTIMATING THE DOSE TO A GLOVEBOX WORKER

To investigate the impact of the posture on the estimated organ doses, PIMAL and VOXMAT have been used in a more realistic posture, compared to the standard vertical upright position, to represent a glovebox worker. For the vertical upright position, ICRP's fully voxelized phantom male model was also used to determine if there were any differences between VOXMAT and ICRP's fully voxelized model. The computations were performed using the MCNPX [6] code.

PIMAL as a glovebox worker standing in the traditional vertical upright position and in a realistic posture is shown in Fig. 1. The glovebox and worker were placed in a room of $3 \times 3 \times 3$ m, and the effect of the room was investigated. Although not shown in the figure, the same geometry was applied to VOXMAT.

For the glovebox, a standard glovebox from Ref. 7 was modeled. In Ref. 7 the dimensions of the glovebox were specified as $116 \times 182 \times 87$ cm. The glovebox itself was made of stainless steel with a density of 8.0 g/cm^3. As shown in the figure, a lead brick was placed at the bottom of the glovebox for shielding purposes. For illustration purposes the source location is shown with a light blue sphere. The windows were constructed of 0.79 cm boroscillate glass. The glovebox contained four glove ports, each with a radius of 10.16 cm. Between each pair of glove ports was a small viewing window 16 x 26.67 cm. For the traditional upright position, the phantoms were placed 25 cm away from the source. Then the postures of the phantoms were modified to evaluate the dose for a more realistic posture. More specifically, the arms were placed in the glovebox ports, and the torsos were bent, as shown in Fig. 1.

The source spectrum, based on clean weapons-grade plutonium, was taken from Ref. 7. The neutron source spectrum is given in Fig. 2 [7].

The absorbed organ dose values for both postures for all phantom models were computed using the MCNPX [5] Monte Carlo radiation transport code. In addition to the total dose, the neutron and photon doses were calculated separately.

RESULTS

As the first step, the mathematical phantom (PIMAL), ICRP's fully voxelized phantom model, and a hybrid phantom (VOXMAT) were placed in front of the glovebox to represent the worker. The computed organ dose values for these three phantoms were compared for the standard vertical upright position. The computational results showed that the computed values for all three phantoms were in agreement within a few percentages for all organs.

The impact of the room on the computed organ dose values was investigated by performing the computations with and without the presence of the room. When the room was present, the glovebox was placed standing right next to one of the walls. The dimensions of the room were

*Oak Ridge National Laboratory is managed and operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

taken as 3 × 3 × 3 m. A standard concrete with a density of 2.5 g/cm^3 was used for the analysis. The computational results showed no statistically significant impact of the room on the computed organ dose ratios.

Then the posture for PIMAL and VOXMAT was modified to represent the glovebox worker as shown in Fig. 1 (right) for PIMAL. The ratios of the estimated organ dose values for some of the organs for realistic posture versus vertical upright posture are shown in Fig. 3. The figure on the left shows the ratios for PIMAL and the one on the right for VOXMAT. As shown in the figures, the estimated organ dose values for realistic postures are up to 50% higher than for the standard vertical upright position for the majority of the organs, including the stomach, lungs, thyroid, which have higher tissue weighting factors. As is clear from the figures, similar behavior was obtained for both PIMAL and VOXMAT.

The computational results show that the posture of the worker has a significant impact on the estimated organ dose values. Therefore, it is necessary to take into account the posture change for shielding and design analysis.

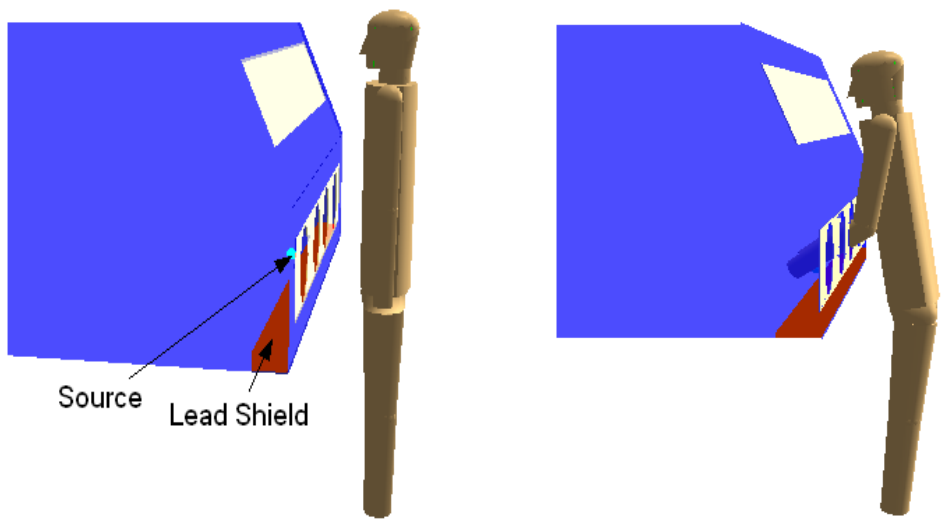

Fig. 1. PIMAL as a glovebox worker in traditional vertical upright position (left) and in realistic posture for better representation of the worker's posture (right).

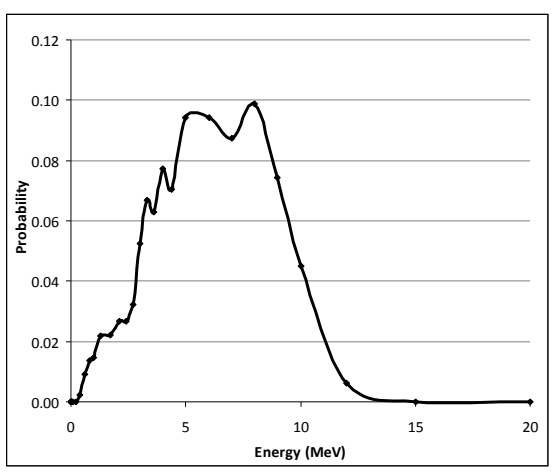

Fig. 2. Neutron source spectrum

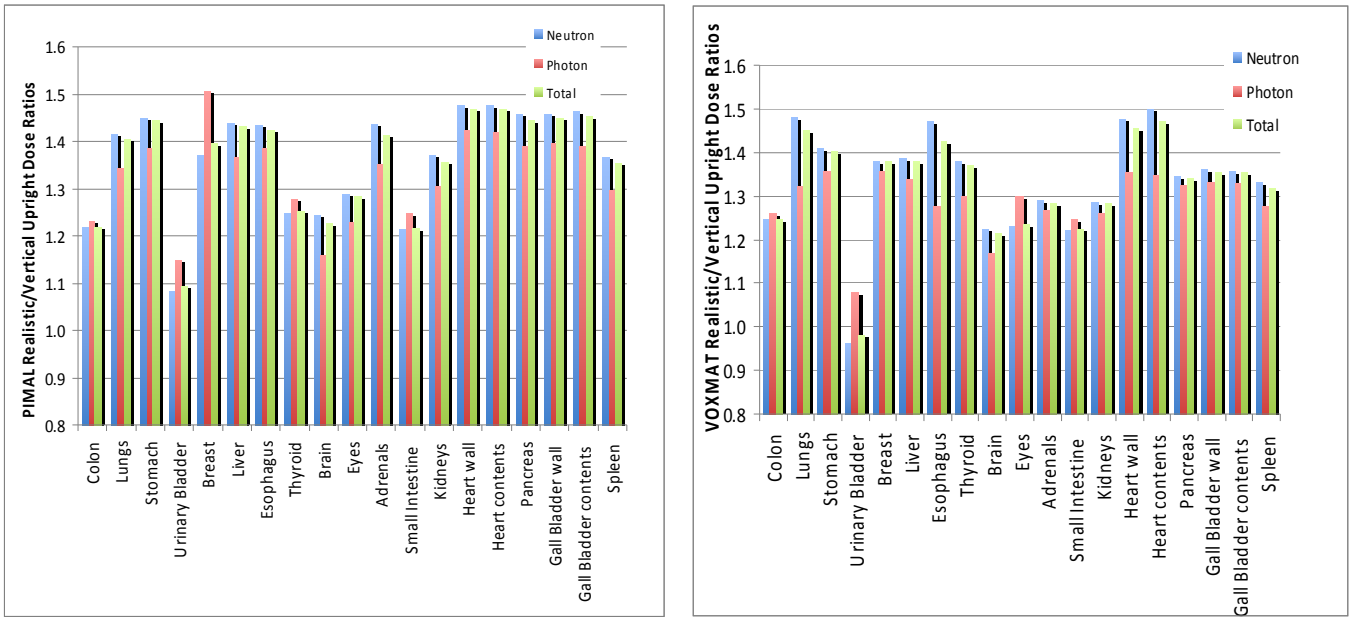

Fig. 3. The ratio of the organ dose values for realistic posture to vertical upright posture for PIMAL (left) and VOXMAT (right).

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