USTUR Case 0102 Voxel Phantom For External Radiation Detector Response Simulation

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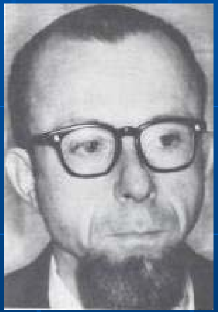
ABSTRACT

The United States Transuranium and Uranium Registries (USTUR) is a resource of human tissue voluntarily donated by past workers with documented occupational actinide exposures. This research focuses on case 102 (a substantial accidental intake of $^{241}AmO_2$) which was the first whole body donation to USTUR (in 1979). Half of this skeleton is encased in tissue equivalent plastic and serves as a unique "human phantom" for the calibration of whole body counting systems at United States Department of Energy (USDOE) and other laboratories (http://www.ustur.wsu.edu/voxel/index.html). This paper reports progress in building a 3D voxel model of the case 0102 ^{241}Am phantom in order to simulate the experimental response of external planar germanium detectors variously positioned over the extremities (head, knee, ankle, and wrist). Segmentation of sequential CT-scan images and generation of surface rendered images of these parts of the case 0102 phantom are achieved using the 3D Doctor® Software package. The 3D surface model (Non-Uniformal Rational B-Spline, NURBS) is then voxelized using a MATLAB® code into a final computational phantom. This can be imported into a Monte Carlo code for radiation transport and detector response simulation.

INTRODUCTION

The U.S. Transuranium Registry received its first whole body donation in 1979. The donor, Stuart E. Gunn, was a radiochemist who had worked with a significant amount of ^{241}Am during his graduate research. Collection and analysis of follow-up urine samples with positive alpha counts indicated that an intake had occurred between March 1952 and March 1954. The uptake was determined to be from a large unsealed ^{241}Am source which was used during his doctoral research (Breitenstein et al., 1985).



Stuart E. Gunn (Dedication in Health Phys. 49(4), 1985)

In-vivo measurements were performed from 1962 through 1978 at the Lawrence Berkeley Laboratory (LBL) and Lawrence Livermore National Laboratory (LLNL) in order to estimate the initial systemic burden. Measurements at LBL indicated a skeletal burden between 3.4 and 15 µCi of ^{241}Am which was approximately 100 times more than the estimated values from the urine data. Based on the results of the chest count performed at LLNL in 1972, the estimate of skeletal burden was 0.11 µCi which was closer to values estimated from urine data. The head in-vivo measurements were done in 1978 indicating the total skeletal burden of 0.11 µCi. At that time, it was assumed that intake occurred by inhalation of contaminated air. However, the post mortem radiochemical tissue analysis indicated that the skin and soft tissue of the left hand contained more ^{241}Am than those of the right hand. This observation suggested that the intake occurred as a result of contaminated wound (Heid and Robinson, 1985).

While the one half of the donor's body was radiochemically analyzed, the other half was encased in tissue equivalent plastic as a unique anthropomorphic phantom (the USTUR Case 0102 ^{241}Am phantom) for calibrating whole body counting systems. The phantom consists of a left arm, a left leg, a skull, and a chest/torso phantom. It was designed such that half of the skull contains bone from the case 0102 skeleton and the other half contains unlabeled bone from a different cadaver. Likewise, half of the chest/torso phantom contains case 0102 bone and half contains unlabeled bone (USTUR, 2008). The phantoms are composed of 100% ICRU muscle-equivalent polyurethane-based tissue substitute, over both actual and simulated bone (DOE, 2008). The phantom is shown on Fig. 1.

Fig. 1. The USTUR ^{241}Am phantom: a left arm, a left leg, a skull, and a chest/torso.

CURRENT STATUS

Anthropomorphic computational phantoms are virtual models of the human body. These computerized models are widely used in the evaluation of dose to humans from different radiation sources, usually external. Currently, two classes of computational phantoms are widely used for the dose assessment: stylized phantoms and voxel phantoms. Stylized phantoms can be very flexible for changes in organ shape and positioning, but they are limited in the ability to fully capture complex anatomic structures. Voxel phantoms provide much better perception of anatomical complexities. However, they are limited in defining organs presented in low contrast within the CT images (Lee et al., 2007).

This work is contributed to building a 3D voxel model of the case 0102 ^{241}Am phantom in order to simulate the experimental response of external planar germanium detectors variously positioned over the head, knee, ankle, and wrist of the phantom. Manual segmentation of sequential CT-scan images and generation of surface rendered images of these parts of the case 0102 phantom can be achieved with 3D Doctor Software package. However, for practical applications automatic segmentation techniques are necessary. Figure 2 shows the initial input and the segmented product for transition from raw two dimensional CT images to the 3D voxelized phantom.

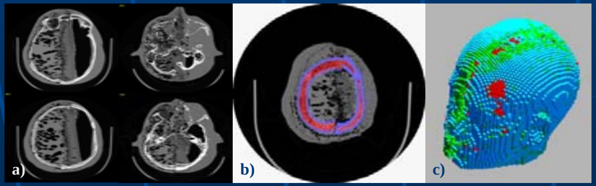


Fig. 2. The 3D voxelized phantom; a) Raw CT images of the case 0102 ^{241}Am phantom; b) Segmented CT image (adopted from Deanna Hasenauer); c) Example of the voxelized head phantom (Adopted from Dr. Gary H Kramer).

RESULTS

The product of this development is:

- Manual segmentation of CT images using 3D Doctor software package (as quality assurance for automated segmentation);
- Evaluation of techniques for automatic segmentation of CT images;
- Voxelization of the NURBS model using a MATLAB code;
- Creation of the final computational voxel phantom;
- Importing the voxel phantom (source and absorber regions) into a Monte Carlo radiation transport code;
- Simulation of external planar germanium detector response.

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