*The American Nuclear Society's 14th Biennial Topical Meeting of the Radiation Protection and Shielding Division, Carlsbad New Mexico, USA. April 3-6, 2006*

# Photon Beam Transport in a Voxelized Human Phantom Model: Discrete Ordinates vs Monte Carlo

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## INTRODUCTION

With recent development of new methods such as intensity modulated radiation therapy (IMRT) for radiation delivery, dose fields can, in principle, be generated in near-conformal three-dimensional (3-D) distributions around a designated treatment volume, while minimizing exposure to vital organs. Because the intended dose distributions are sensitive to the assumed treatment geometry, the new delivery methods demand accurate dose calculations, particularly to reduce the considerable uncertainties like those associated with body cavity inhomogeneities and surface curvatures. Although much effort has been devoted to developing Monte Carlo codes for external beam therapy, the codes have not been widely implemented into clinical use because of long computing times and often the lack of a completed validation protocol. Rigorous and computationally more efficient deterministic methodologies are desired. To this end, comparative photon-only deterministic transport calculations have been performed employing a human phantom lung model with the 3-D discrete ordinates code TORT[1] and the Monte Carlo (MC) code EGSnrc[2].

## TRANSPORT MODEL AND SIMULATION

The phantom lung model was based on reformatted CT scan data obtained from the Department of Radiation Oncology at the University of North Carolina (UNC) at Chapel Hill. The geometry employed in the calculations consisted of 4-mm cubic voxels containing water, with the density in each voxel set equal to the shifted CT number (0-4095) divided by 1000. Newly written routines prepared the geometry input data for both codes, and a voxel geometry package was written to perform the particle tracking in EGSnrc. The photon source employed in all calculations was represented using a single isotropic point source located 100 cm from the CT scan isocenter and consisted of collimated and scattered components. The collimated beam component was isotropic within the solid angle subtended by a 10 × 10 cm square centered at the scan isocenter. The scattered component was also isotropic but extended over the solid angle subtended by a 35.35-cm-radius disk similarly centered. The energy distributions of the components were derived from phase space data also supplied by UNC.

In the EGSnrc calculations, the source was sampled using rejection techniques. In the deterministic calculations, the source was input into a slightly modified version of the GRTUNCL3D code[3] to obtain energy- and angular-dependent uncollided fluxes and first-collision source moments throughout the TORT geometric model. TORT transports the photons emanating from the first-collision sources to compute collided fluxes. The total photon flux throughout the patient/phantom geometry was then obtained by simply adding the collided and uncollided fluxes. Energy deposition was obtained using photon kerma factors and by scoring the collisional energy loss of the photons. The cross sections employed in the EGSnrc calculations were processed directly from the continuous-energy cross-section data supplied with EGSnrc. The cross sections employed in the discrete ordinates calculations were taken from the VITAMIN-B6 fine-group library[4] with angle-to-angle scattering transfers represented using $P_5$ Legendre expansions.

**RESULTS**

Pointwise comparison of coronal and sagittal total photon flux and kerma indicated good agreement between the TORT and EGSnrc calculations in all voxels except those in the steep gradient along the beam edge. At these locations, large differences occur as GRTUNCL3D estimates only to cell centers, and the uncollided flux may be either high or low depending on whether a voxel center lies inside or outside the beam path. It should be possible to reduce these discrepancies through modification of GRTUNCL3D.

To compare the discrete ordinates and MC calculated results on a global or overall basis, differences in these results were divided by the MC uncertainty in each voxel and by the total number of voxels. This procedure yields fractional frequency distributions (FFDs). Photon flux and kerma FFDs were constructed and compared using results from six different TORT calculations. These calculations differed because of the order of Legendre expansion used to represent scattering (i.e., either $P_3$ or $P_5$) and because each calculation was either run to completion or terminated after one or two iterations. Narrow FFDs were not obtained for the $P_5$ calculation terminated after one iteration or for any of the $P_3$ calculations. However, both the $P_5$ calculation run to completion and the one terminated after two iterations resulted in very similar narrow FFDs centered about zero. This outcome indicates that adequate photon flux and kerma distributions might be obtained deterministically with a reduction of five or more in computational cost.

**REFERENCES**


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