A Monte Carlo-based Spectroscopic Characterization of a Cs-137 Irradiator with Attenuating Material

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Purpose: Cesium-137 (Cs-137) irradiators are often used for calibration of health physics and radiation protection instrumentations, including ion chambers, Geiger-Mueller (GM) counters, and scintillators that are used as survey meters. Although ionization chambers have a relatively flat energy dependence, GM and scintillator survey meters show more substantial energy-dependent variations in response. The primary air-kerma rate standard at the National Institute of Standards and Technology (NIST) for the calibration of these irradiators is a variety of spherical graphite ionization chambers with very little energy-dependent effects, but the response of the survey meters may be affected by the spectral changes caused by the addition of lead attenuators that are used to modulate the exposure rate. Effects of the changes in spectrum on detector response is not currently accounted for. This study uses an experimentally validated irradiator geometry modeled in the MCNP5 (Monte Carlo N-Particle 5, Los Alamos, New Mexico) transport code to characterize the effects of attenuation on the energy spectrum of the primary beam.

Methods: This study uses a Hopewell Designs (Alpharetta, Georgia) dual-source G-10 model Cs-137 irradiator which houses a 416 Ci and a 5 Ci Cs-137 source. The irradiator geometry for the 416 Ci source was modeled in MCNP5 and validated by comparing measured and simulated percent depth dose (PPD) and cross-field profiles. The PDDs were measured using an A12 farmer-type ionization chamber and a custom-built water tank with a 1/16-inch acrylic entrance window and chamber position software. The water tank was modeled in MCNP5 and an energy deposition tally was used in cells centered on the detector position. Field profiles were measured using EBT3 film in a custom-made acrylic phantom providing 3.14 cm of buildup and 9.60 cm of backscatter acrylic (Figure 1b). A single 120-minute irradiation was performed, giving an estimated dose of 1.20 Gy in air. An optical density profile was used for analysis and was normalized to an optical density value obtained by averaging over the center of the field. The phantom was modeled in MCNP5 and a modified flux tally across a water-equivalent tally cell was performed. The geometry of the model was validated with no attenuators placed in front of the beam path.

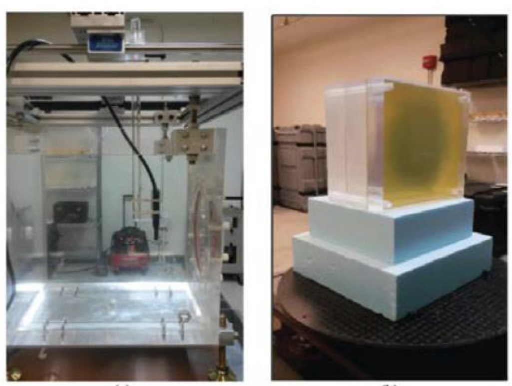

Figure 1. (a) Exradin A12 farmer-type ionization chamber aligned in a custom-built water tank with a horizontal PMMA window and chamber position software, and (b) PMMA phantom with film, post irradiation

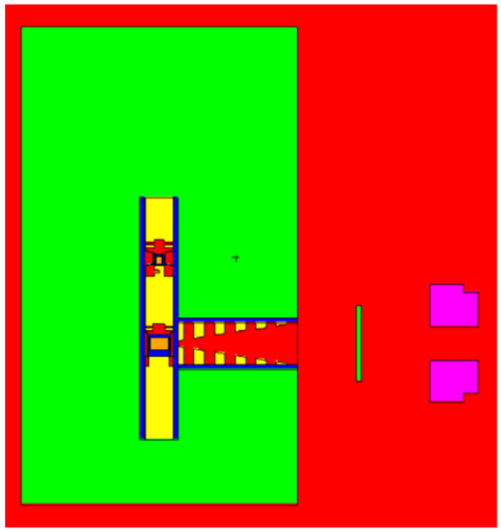

Figure 2. Monte Carlo rendering of a validated Cs-137 irradiator model with lead attenuators.

The validated irradiator geometry (Figure 2) was used to investigate spectral changes due to the addition of lead attenuators in the primary beam path. The Hopewell G-10 irradiator has four attenuators including a 2x, 4x, 10x, and 100x with lead thicknesses of 0.635 cm, 1.22 cm, 2.22 cm, and 4.32 cm, respectively, which provide attenuation in combinations from 0x to 8000x. MCNP5 was used to tally the spectra in 4 cm x 4 cm x 4 cm cube at a distance of 100 cm from the source with various amounts of attenuation. The average energy and the relative intensity of the 662 keV peak of the simulated spectra were analyzed.

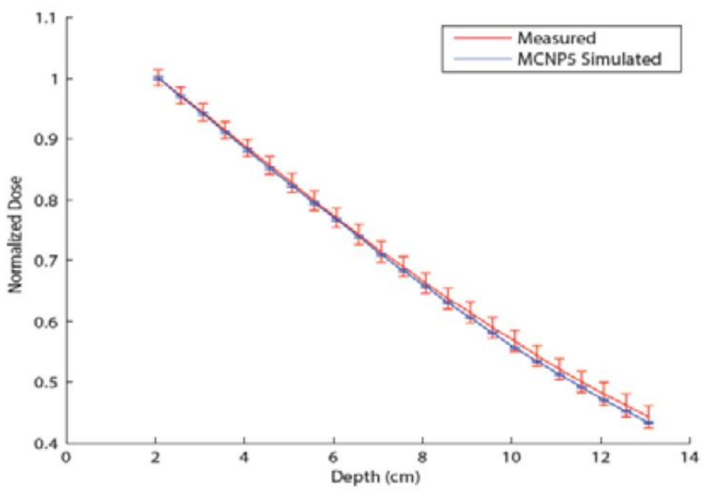

Figure 3. Measured and simulated PDDs

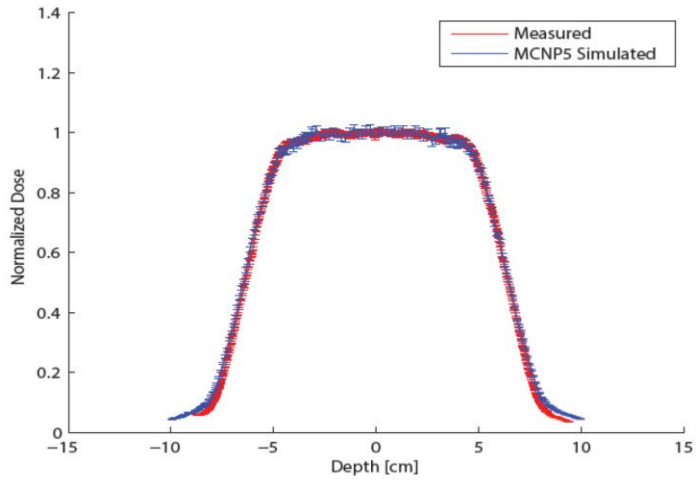

Figure 4. Measured and simulated cross-field profiles

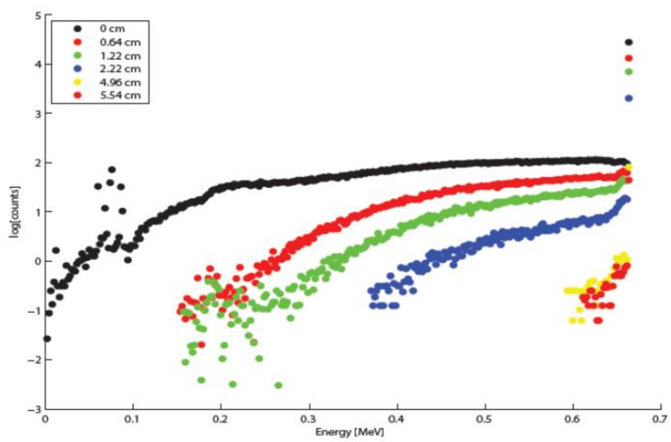

Figure 5. MCNP5 simulated energy spectra with lead attenuation thicknesses ranging from 0 cm to 5.54 cm

Results: Simulated and measured PDDs (Figure 3) and profiles (Figure 4) agreed within 1.2%, which was within the uncertainties of both experimental and MCNP5 datasets. An MCNP5 simulated spectral tally showed that the average energy for 0x, 2x, 4x, 10x, and 100x attenuation was 582 keV, 626 keV, 637 keV, 646 keV, and 652 keV, respectively, with uncertainties ranging from 0.11% to 1.69% (Figure 5). The intensity of the 662 keV peak, normalized to the intensity of the 662 keV peak from the no attenuation simulation was 47.2%. 25.3%, 7.3%, and 0.6% for 2x, 4x, 10x, and 100x attenuation, respectively.

Conclusions: This study successfully used MCNP5 and a validated geometry to characterize the effects of increasing attenuation on the energy spectrum through analysis of average energy and 662 keV peak intensity of the Cs-137 irradiator. The aim of future work will be to determine the impacts of these spectral deviations on the response of ionization chambers and various types of survey meters.

Relevance to CIRMS: This work is a subset of the doctoral work pursued by the first author based on the understanding of attenuator effects on the energy spectrum of a Cs-137 irradiator. This work relates to the CIRMS mission, as NIST uses a series of Cs-137 irradiators for the determination and maintenance of primary standard chambers for the units of air-kerma and exposure. Understanding of spectral changes may play a role in better understanding of detector response in the given beam. The first author aims to become an academic/clinical medical physicist and currently works in a laboratory focused on metrology.