AbstractID: 14112 Title: Monte Carlo optimization of a three-stage Compton camera for prompt gamma imaging and spectroscopy: materials and geometry

Purpose: Prompt gamma photons emitted from biological tissues under proton irradiation carry dosimetric and spectroscopic information that can provide treatment verification and indicate biological response. We optimize the materials and geometry of a three-stage Compton camera for prompt gamma detection and to calculate the efficiency of such a detector.

Method and Materials: A three-stage Compton camera was modeled in Geant4 as a series of parallel square detector stages. The assembly was placed 15 cm from an isotropic point source of mono-energetic gamma-rays. The primary energies considered were 2.33, 4.44, and 6.13 MeV, which are characteristic emission energies of Nitrogen, Carbon, and Oxygen. Certain detector arrangements were characterized over the energy range from 0-1 MeV in 0.25-MeV increments and from 1-10 MeV in 0.5-MeV increments. The scintillating materials evaluated in this study include germanium, BGO ($Bi_4Ge_3O_{12}$), NaI, Xenon, and $LaBr_3$. For each material, the thickness of each stage was optimized to produce the maximum number of relevant interactions.

Results: For the primary and secondary stages, each material exhibits peak production of single Compton-scatter events at thicknesses ranging from 2 cm for BGO to 4 cm for Xenon. Transportation efficiency, or the fraction of interacting photons that enter the next stage, decreases linearly with thickness. Peak efficiencies for the primary and secondary stages vary from 15-25% per stage, depending on energy and material. In the final stage, all interactions are used, making detection efficiency an increasing function of thickness. At 10 cm thickness, BGO detection efficiency approaches 80%, while germanium and $LaBr_3$ exhibit 70% efficiency.

Conclusion: The most important contributors to detection efficiency are thickness and material. The most efficient detector configurations are BGO-Germanium-BGO, with a peak efficiency of 2.25×10^{-3} at 2 MeV, and Germanium-Germanium-BGO, which is the most efficient detector below 1.5 MeV and above 4 MeV.