Initial Simulation and Measurement Results of a New Aperture-Based Imaging System for High-Energy Gamma Rays

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Introduction

Detection and imaging of high-energy gammas (2-10 MeV) poses a unique challenge due to the deep penetration in materials by photons at these energies. With applications in nuclear security and medicine, a variety of methods are being explored to detect and localize high-energy gamma rays. This work presents initial simulation and experimental results of a novel multi-knife-edge slit collimator design. The 7.5 cm thick tungsten collimator performs as a coded aperture and provides 2-dimensional imaging capability for high-energy gamma rays.

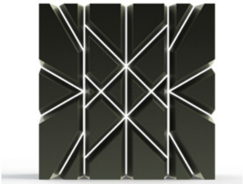


Figure 1: CAD image of multi-knife-edge collimator

Methods

A multi-knife-edge slit collimator has been designed, constructed, and characterized via simulations and experimental measurements. Initial simulations were performed using the TOPAS[1] Geant4-based Monte Carlo package. Iterative reconstruction methods were combined with simulated point response functions to characterize the imaging performance of the system. Experimental characterization was performed using 2.6 MeV gamma-rays from a Th-228 source.

Results

Figure 2 shows the experimental setup of the imaging system. The collimator is constructed of 22 individually cut tungsten blocks, each separated by 2 mm from their closest neighboring blocks.

Figure 3 provides an example projection as seen at the detector plane, resulting from an actual measurement.

The remaining figures show image reconstruction results from the simulation study. Figures 4 and 5 are reconstructed images of a point source in 2-dimensions; demonstrating that the resulting image produces a point response as expected (with a FWHM of approximately 4.3 mm). Figure 6 is a composition of several, individual point source simulations reconstructed along one axis. Each point is spaced by 5 mm.

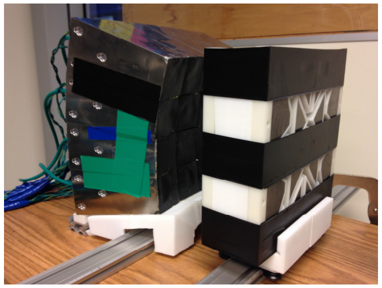


Figure 2: Experimental setup with LSO detector array and multi-slit tungsten collimator held in place by plastic supports.

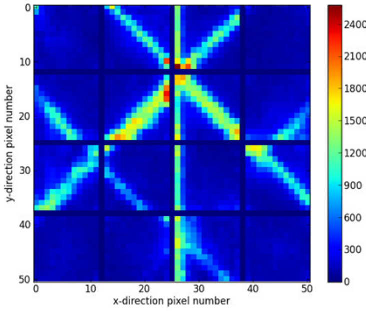


Figure 3: Example of a projection at the detector plane. This projection was produced by a Th-228 point source in an actual measurement. LSO detectors in a 4x4 grid.

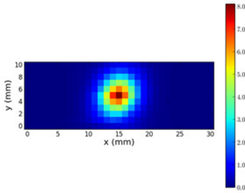


Figure 4: 2-D reconstruction of point source. Results from a simulated point source at 2.6 MeV

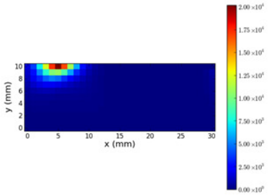


Figure 5: 2-D reconstruction of point source. Results from a simulated point source at 2.6 MeV

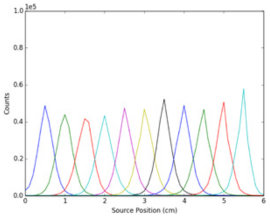
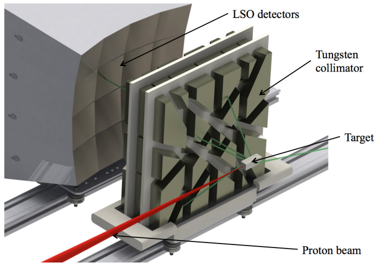


Figure 6: 1-dimensional reconstructed image of point source at varying location. Demonstrates spatial resolution across 1-dimension. Simulation results.

Goals, Objectives, Deliverables



Next steps

Perform measurements at LBNL 88" cyclotron to benchmark simulation work and demonstrate system performance

Prompt gammas from (p,p') reactions on carbon and oxygen will be used as a source of high-energy photons. These measurements will test performance of the imaging system in a high gamma flux environment.

How is this work pertinent to the DNN R&D (NA-22) nonproliferation mission?

The multi-slit pattern is designed to increase detection efficiency and provide spatial information in 2-dimensions -- an improvement over a single-slit collimator design. The thickness and density of the collimator will allow this detection system to perform well in an environment with high gamma flux, while providing resolution on the order of 2-3mm. Designed specifically for high-energy gamma rays, this collimation system could be used to detect and image passive signatures that transmit through spent fuel cask materials.

Literature cited

1. Perl, J., Shin, J., Schümann, J., Faddegon, B., & Paganetti, H. (2012). TOPAS: An innovative proton Monte Carlo platform for research and clinical applications. *Medical Physics*, 39, 6818.
2. Lesko, K.T., et al. (1988). Measurements of cross sections relevant to γ-ray line astronomy. *Physical Review C*, 37(5), 1808.

Acknowledgments

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Conclusion

This work has characterized, via simulation and measurements, a novel multi-knife-edge slit collimator in front of a more conventional position-sensitive LSO scintillator detector. Initial results indicate that this system is capable of imaging high-energy gamma sources in 2-dimensions.