Micro Power Radiation Detector

SAND2014-16073D

iSAFE
Interns for Security, Arms control and Force protection Engineering

Manager:
Shawn Taylor
6612/6613

Edward Norris
Missouri S&T
MS IN NE, May 2015

Project Mentor:
Gene Kallenbach, 6831

The goal of this project is to create a Geant4 model of a scintillation detector in order to predict the number of optical photons that will reach a photodiode. After creation, the model must be verified with experimental results to ensure accuracy. Currently, the model is running on the RedSky cluster at Sandia and has yielded initial results similar (±50%) to the experimental data collected.

Monitoring radioactive materials is routinely required for both treaty verification and safeguards applications. Ideally, this monitoring occurs on a continuous basis, providing a real-time indication of the status of the material. Portable, battery powered monitoring devices require few changes to the facilities and do not impede existing operations making them the preferred solution. Such radiation sensors must consume as little power as possible to extend battery life. Ideally, a zero-power device is desired. To develop such a device, a computational model is required to explore different materials, techniques and optimize the efficiency. Such a model will facilitate significant advances in power reduction. The goal of this project is to identify the materials and configurations that optimize the effectiveness of such a device.

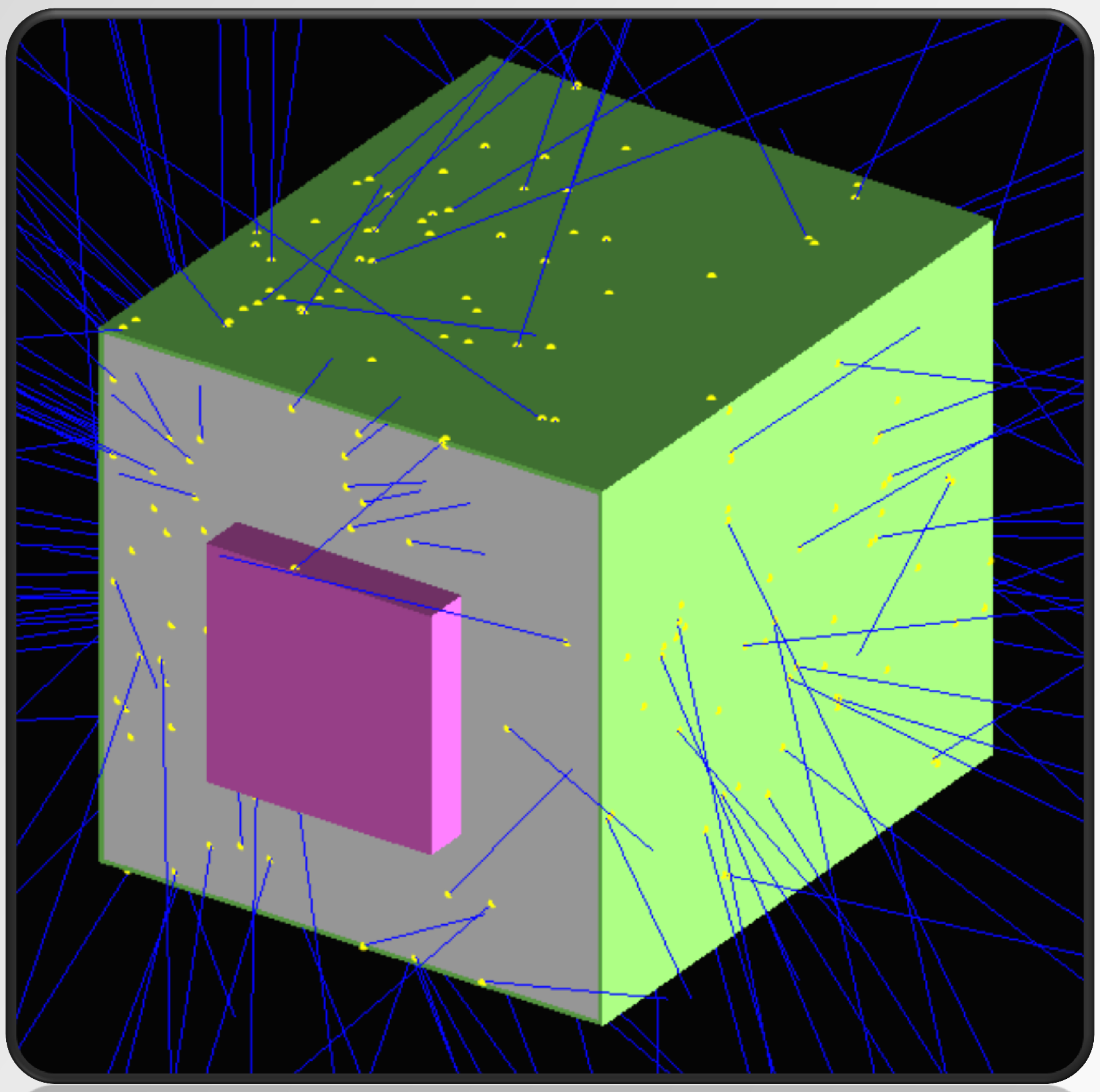

Figure 1. The modeled geometry for a cuboid crystal. The crystal itself is light gray, the reflective tape is green, and the photodiode is pink. Yellow dots denote particle-surface collisions and blue lines are optical photons escaping into the air.

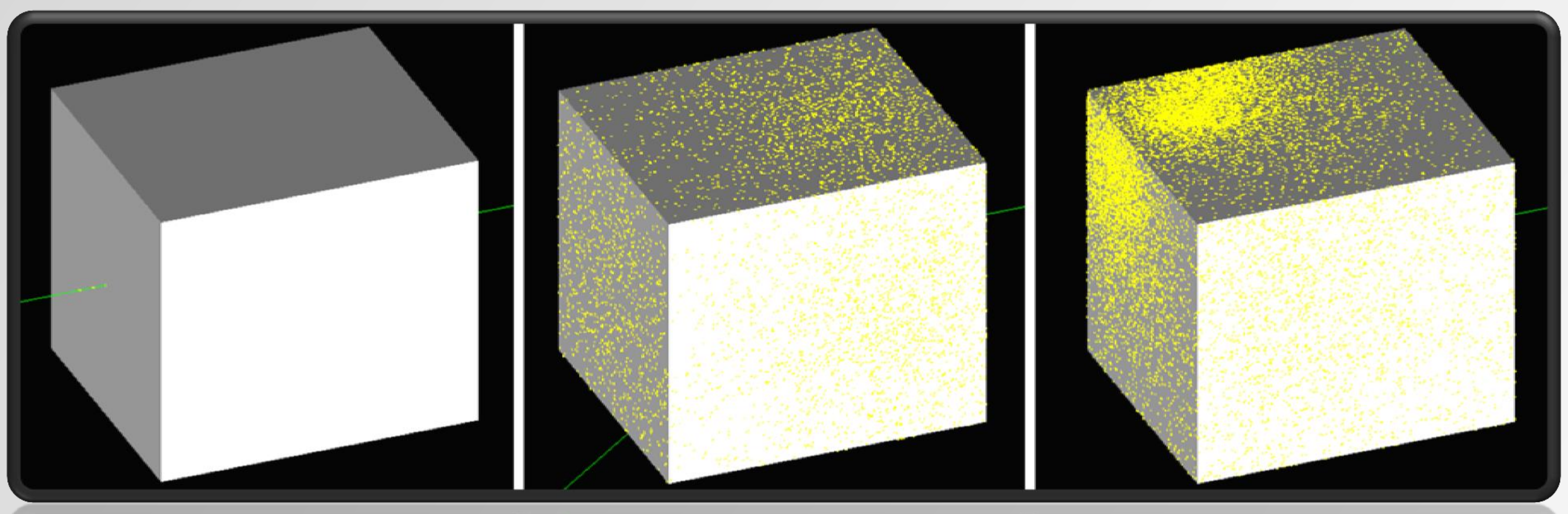

Figure 2. Three cases of incident gamma interactions. (Left) The incident gamma passes through the crystal without interacting. (Middle) The gamma ray interacts with a crystal atom, releasing scintillation photons before scattering back out of the crystal. (Right) The incident gamma is completely absorbed, converting all of its energy into visible light and excited electrons.

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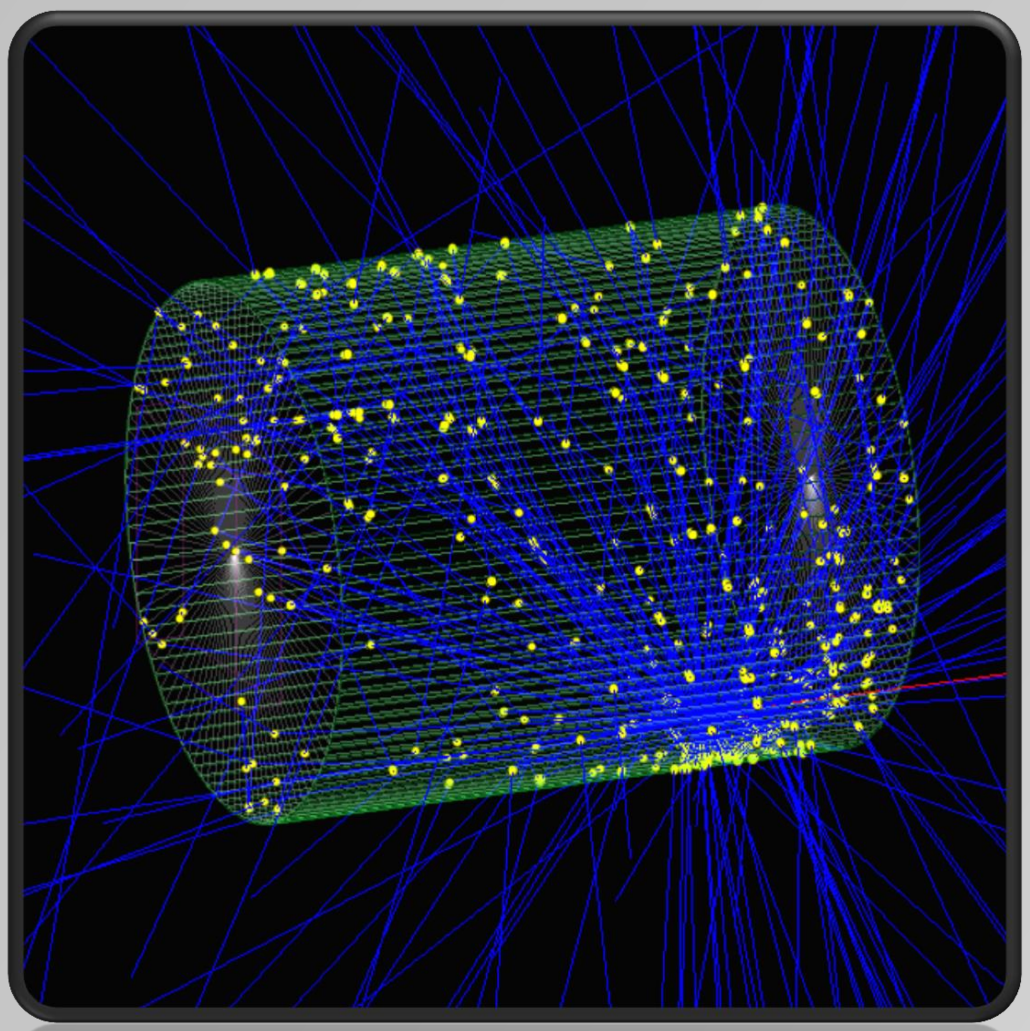

Figure 3. A scintillation event in the cylindrical geometry of the crystal used for the verification of the Geant4 model.

The proposed detection system was analyzed with some rudimentary analytical methods based on integrating the solid angle subtended by a rectangular photodiode. A computational model of the geometry was then made using the Geant4 software published by CERN. Geant4 is a general-purpose Monte Carlo code designed for high energy physics, but also has physics models for low energy electromagnetics. The computational model was designed using a Cesium Iodide crystal doped with 1% Thallium by weight (CsI:Tl) for its high optical photon emission rate and energy spectra compatible with silicon photodiodes. Experimentally, the number of optical photons hitting the photodiode can be estimated by measuring the current through the photodiode with an electrometer. The number of incident optical photons is back-calculated using number of electron-hole pairs needed to produce the observed current and applying a conversion factor to account for the electron-hole production efficiency.

The analytical approximations are too large due to the model not accounting for actual energy deposition and subsequent multiple scattering phenomena, it instead assumes that 100% of the incident gamma energy is converted into optical photons upon collision. The Geant4 model is also much larger than the experimental results due to electronic inefficiencies in the photodiode.

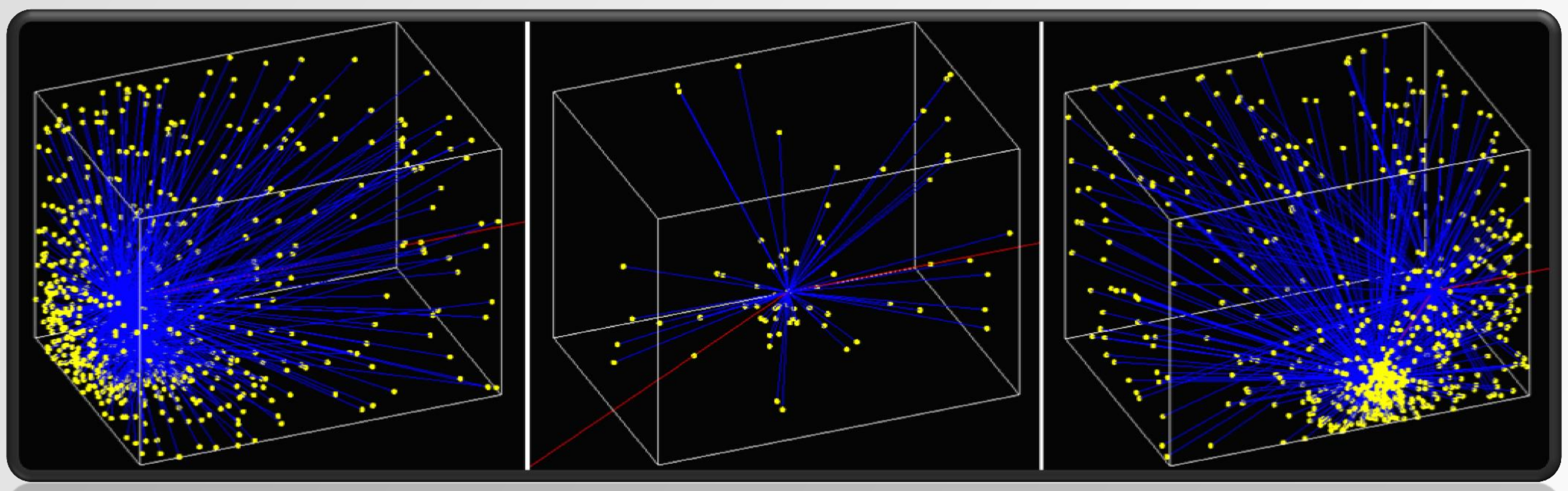

Figure 4. High energy (above 1 keV) gamma rays are red, optical (below 10 eV) photons are blue, and photon-surface collisions are highlighted in yellow. (Left) A gamma ray deposits all of its energy in a single collision resulting in a large number of isotropically distributed optical photons. (Middle) A photon scatters producing optical photons whose total energy is much smaller than the original gamma ray. (Right) A gamma ray scatters once before complete absorption.

The next steps that will be done are further improvement and validation of the Geant4 model against experimental data and improvement of the analytical model since it can be run many times faster than the full Monte Carlo simulation. Further investigation of the process that converts photons into electron-hole pairs is needed. Once empirical data for this process has been obtained, the entire process from source gamma generation to current measurement can accurately be modeled in software. This model will allow users to better choose materials and geometries to optimize detector systems designed for material monitoring.

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