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PHITS Benchmarking for HPGe Detector Efficiency

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Abstract

Particle and Heavy Ion Transport code System (PHITS) validation for gamma-ray detector efficiency evaluation was performed. A coaxial type, 280 cm^3 high-purity Ge (HPGe) detector efficiency that was measured in previous experiments and calculated by Cyltran and MCNP was simulated by PHITS Ver. 2.82. The methodology and model on the previous works were carefully replicated to have a proper model of experimental apparatus and fair code comparison. Simulation was done by taking a single calculation for each energy line and setting the PHITS tally to simulate a pulse height detector. The energy cut-off was set low enough to accommodate the energy loss carried away by photons and electrons escaping from the active region of the detector, thus reducing the calculated efficiency into a more realistic result. Energy bin width in the tally was also set low to 0.2 keV, similar to the previous works. For the photon energy ranging from 40 keV to 1800 keV, PHITS calculation results show a fairly good agreement with experimental results, generally having discrepancies of less than 1%.

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Keywords: PHITS; benchmark; HPGe, efficiency, Cyltran, MCNP

1. Introduction

One of the most important applications of gamma-ray spectrometry is for the determination and quantification of radionuclides. The relatively excellent energy resolution of germanium detector fits the requirement of spectrometry which allows the separation of closely spaced gamma-ray energies.

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Prior to the usage, the detector must undergo calibration which is normally carried out with the standard radioactive sources to observe its response function and peak efficiency over a certain energy range of interest. Despite this method is very reliable, it is time and resources consuming.

Meanwhile, there are available computer codes which have the capability in simulating the photon transport phenomena to a great detail. Some of the Monte Carlo codes, such as Cyltran and MCNP, have been proved to be able to simulate the source and detector response with good accuracy by carefully modeling the geometry.

Helmer et al. [1] have carefully conducted calibration experiments of a coaxial germanium gamma-ray detector followed by Cyltran benchmarking calculations for photon energy range of 22 keV to 1800 keV. Their works on the simulation were then used by Hau et al. [2] in validating MCNP code for similar geometry as in Cyltran case. While most of the code validation done by others was conducted by accepting and using all the dimension data provided by the detector manufacturer and then adjusting the code to give similar results with the experiment, Helmer et al. have done the validation in somewhat different way. In their work, they had optimized and refined some of the detector parameters to match the measurement and calculation results, thus the calculated results can be used for interpolation over a wide range of energy.

Another Monte Carlo code that deals with particle transport is the multi-purpose Particle and Heavy Ion Transport code System (PHITS) [3]. This code has been extensively used and validated for spallation neutron source design [4], low-energy neutron-induced reactions [5], heavy ion transport [6], absorbed dose [7] galactic cosmic radiations [8] and others. Despite of a wide range application and validation, a published PHITS validation for gamma-ray detector response is difficult if none to find, thus the current work is aimed to further benchmark PHITS code, version 2.82, in simulating the source and pulse-height mode of a coaxial High Purity Germanium (HPGe) detector response.

2. Methodology

The basis for the current benchmarking calculation is the experimental data results that was conducted by Helmer et al. Thus, in order to have an accurate model and fair code comparison, the final optimized geometry of the Cyltran model by Helmer et al. was carefully replicated. Their model was prudently built and adjusted from the actual 280 cm^3 N-type coaxial HPGe detector used for the experiment. The plastic-encapsulated point source is positioned 15.1 cm in front of detector end-cap.

2.1. PHITS settings

Starting from version 2.70, PHITS has integrated the EGS5 algorithm for photons, electron and positron transport in addition to original PHITS algorithm. This EGS5 option was chosen for the current calculation since it is a robust algorithm for photon and electron transport as suggested by the developer. By default, when this option is set, the lower energy cut-off for photon, electron and positron are 1 keV, 100 keV, and 100 keV respectively, while their

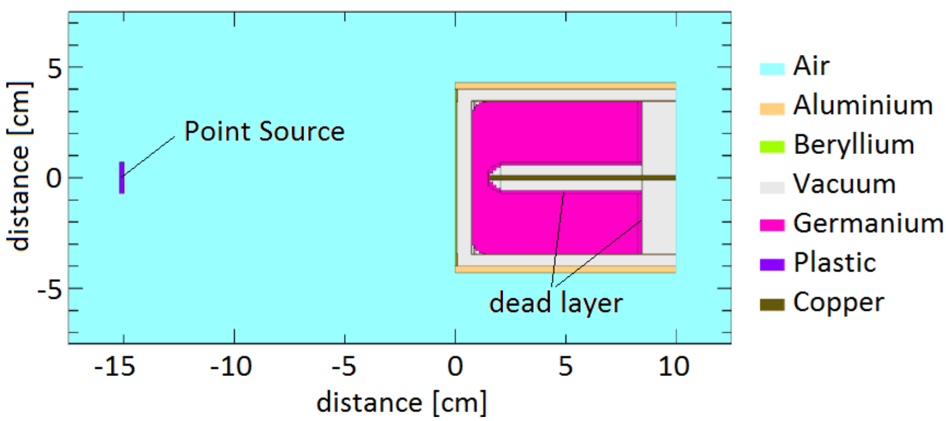

Fig. 1. PHITS-generated geometry model