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Short Communication

HPGe Detector Energy Response Function Calculation Up to 400 keV Based on Monte Carlo Code

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Abstract

A high purity germanium detector (HPGe) of crystal size of diameter 4.91 cm and length of 3.6 cm was modeled in accordance with the Pop Top cryostat configuration (model no. GEM10P4). The energy response function was calculated in the air using Monte Carlo simulation with mono-energy γ-ray photon up to 400 keV. The distance between the source and the front surface or end cap to detector was 20 cm and the source was assumed as an isotopic point source. The aluminum absorbing layers of thickness 0.127 cm was also taken into consideration in the simulation model. The input number of particles was 10^7 for each mono-energetic γ-ray photon. The simulated energy response functions were verified with the measured energy response functions obtained using calibration sources in order to prove the accuracy of the modeling. The comparison between the measured energy response functions and the simulated energy response functions after normalization were also performed.

Keywords: HPGe; Gamma-ray spectrum; Monte Carlo.

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1. Introduction

Determination of the absolute efficiency of high-purity germanium (HPGe) detector has been a long-standing problem in gamma-ray spectroscopy and numerous reports have been published during the last decades [1]. Response function of an HPGe detector can be determined with experimental measurements for a specific geometry and for the energy range of interest by using radioactive sources with known activity and emission probability. There are few mono-energetic radionuclides with photon energy emission that

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falls in the X-ray energy range (20-150 keV) where the detector's efficiency presents a great variation. Therefore, it is very difficult to achieve good results experimentally [2]. Due to the difficulties in determining the response functions experimentally, Monte Carlo calculation can be very useful. However, the calculation of the response function for Germanium detector is difficult because it's high-resolution requires narrower bins around the peak and the geometry of the cryostat-cane is complicated.

This work performed the modeling of an HPGe detector for low-energy gamma-ray and its validation with experiment using standard gamma-ray sources placed in open space at a distance of 20 cm on axis from the detector end cap.

2. Materials and Methods

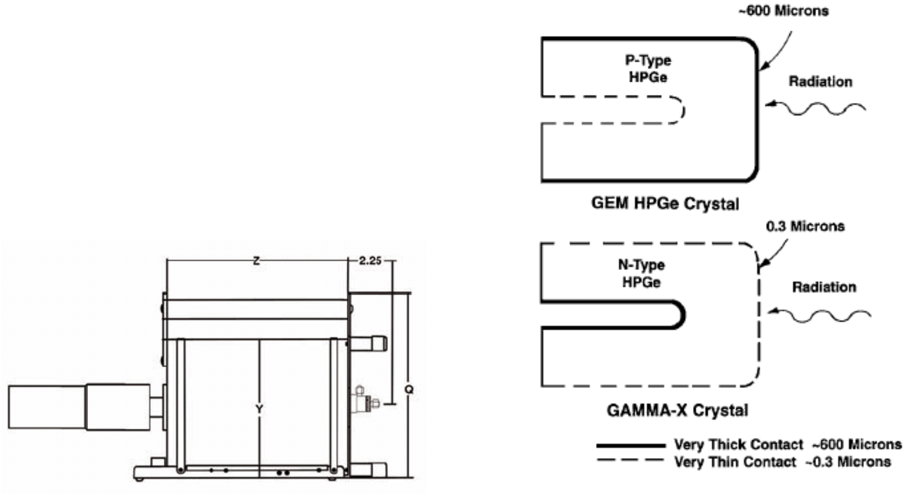
2.1. *Experimental*

The detector used in the present study was a GEM series HPGe coaxial detector system. The detector model no. GEM10P4, Cryostat configuration: PopTop, Preamplifier model: A257P (Preamplifier S/N: 06166260), H.V. Filter Model: 138 EMI (H.V. Filter S/N: 6271438). The resolution (FWHM) of the detector is 1.75 keV at 1.33 MeV, ^{60}Co and relative efficiency at 1.33 MeV, ^{60}Co is 10 %. The characteristics given by the manufacturers are shown in Fig. 1. The crystal has a diameter of 49.1 mm and a length of 36.0 mm and end cap to detector distance 3.0 mm. The detector has absorbing layers of aluminum 1.27 mm and inactive germanium 700 µm.

Standard electronics and a 2448 channel MCA card with Ortec high voltage module were used. The program MAESTRO-32 was used to acquisition of the gamma-ray spectrum. Two standard gamma-ray sources ^{57}Co (122 keV) and ^{133}Ba (mainly 303 and 356 keV) were used to obtain the measured gamma-ray spectrum. It was mounted on a thin aluminum holder by tape that was placed at 20 cm from the front –face of the HPGe detector and aligned with the detector's axis. All spectra were analyzed by means of origin 7 program [3] and background counts were subtracted. A re-binning algorithm was applied to the measured spectrum in order to match with simulated spectrum in the same scale.

2.2. *Detector simulation*

The experimental setup, detector and source, was simulated with the MCNPX Monte Carlo code [4]. For the detector simulation, the crystal and its surrounding materials were considered [5-7]. Fig. 1 shows a representation of the detector's structure. As shown in Fig. 1, the germanium crystal was simulated with two dead layers; the top one was very thin, about 0.3 µm, and the bottom one was thicker, about 600 µm. These layers are not suitable for photon detection since they are conductive due to an excess of doping ions to promote the electrical contact. For this work, the history of each photon is followed between the collisions, recording energy deposition, throughout its life to its death, until its energy is low enough to be killed. The detector diagram provided by the manufacturer was inserted as an input geometry in the simulation codes. Parts with unknown constitution such as the detector's end were filled with aluminum. Response function was calculated with an F8 tally. Over 10^7 photons were sampled in order to get good statistics. The Gaussian distribution, rather than a single value at each bin, was applied in the calculation to fit the peak to the measured pulse height distribution.



(a) (b)

Fig. 1. (a) HPGe detector of crystal diameter 4.91 cm and length 3.6 cm (Ortec, PopTop, model: GEM10P4) used to calculate the detector response function, (b) inner structure of the HPGe detector.

3. Results and Discussion

3.1. Validation of the simulated response functions

A few of the typical simulated response functions are shown in Fig. 2 (a, b, c and d). To validate the simulated response functions, the experimentally measured gamma-ray pulse height distribution obtained with two standard gamma-ray sources ^{57}Co (122 keV) and ^{133}Ba (mainly 303 and 356 keV) are compared with the simulated response functions of the same energies as shown in Fig. 3 (a, b). As shown in Fig. 3, comparison shows some discrepancies at the 75 keV and 85 keV peaks. The discrepancies seem mainly due to the imperfect duplication of the real experimental conditions. Because we used a number of lead bricks surrounding the detector except front face, a slight deviation of the real experimental conditions seemed to cause the noticeable difference in producing the characteristics X-rays of the lead. Furthermore, the discrepancies between the simulated and measured response functions might be caused either by the scattered beam from the surroundings materials in the room that were not considered in the simulation model or by the uncertainties given from the simulation, especially at low energies.

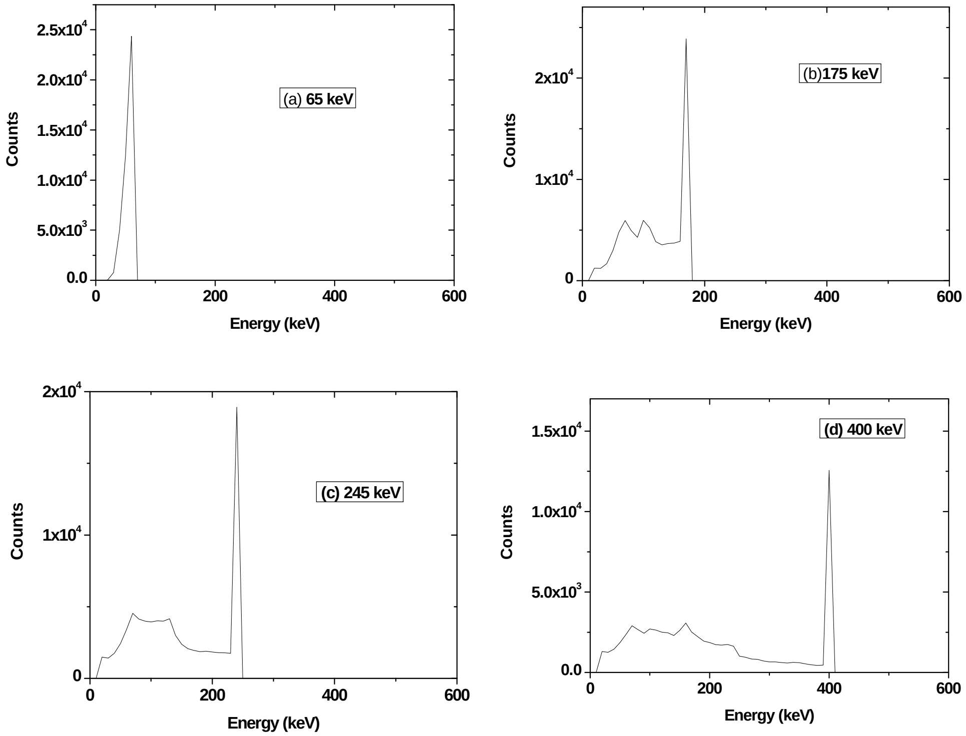


Fig. 2. Simulated respose functions of HPGe detector for (a) 65 keV, (b) 175 keV, (c) 245 keV and (d) for 400 keV.

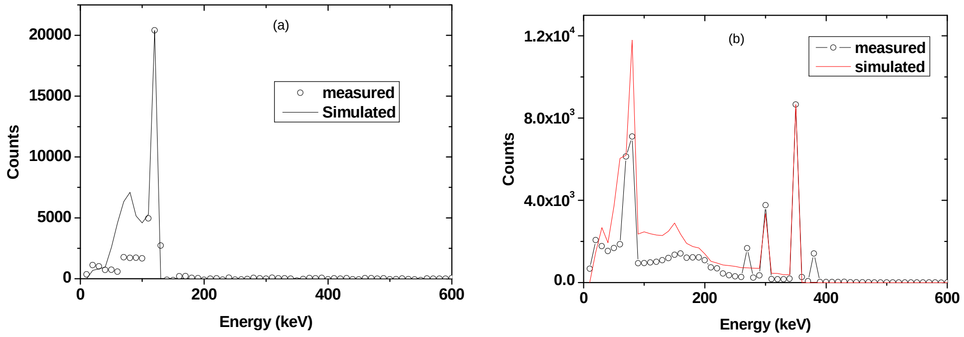


Fig. 3. Comparison of measured and simulated response functions for (a) ^{57}Co (122 keV) and (b) ^{133}Ba (main peaks are 303 and 356 keV)

4. Conclusions

Detector's simulation can provide powerful means to precisely determine detector's response function, overcoming difficulties such as the unavailability of radiation sources with the required photon energies. The Gaussian distribution, rather than a single value at each bin, was adopted in the simulation to fit the peak with the measured ones at the strongest peaks such as a 122 keV peak for ^{57}Co and 303 & 356 keV peaks for ^{133}Ba. The envelope of simulated pulse height distribution showed good agreement with the measured one for each radioactive source with small discrepancies. The small discrepancies suggest that the applied simulation system may be a useful tool to study in the area of radiation protection.

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