Research Article

Gaussian Energy Broadening Function of an HPGe Detector in the Range of 40 keV to 1.46 MeV

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High-purity germanium (HPGe) detectors are widely used in nuclear spectroscopy (e.g., neutron activation analysis) due to their high resolution. Resolution function of a GMX series coaxial detector system (model number GMX40P4-83) in the range of 40 keV to 1.46 MeV has been measured using standard γ -ray sources. The energy response function also was calculated using Monte Carlo simulation through the precise modeling of the detector structure. The simulated energy response function was verified with the measured energy response function obtained using calibration sources. A new approach was used and the agreement between both results has been improved.

1. Introduction

The use of germanium detectors has completely revolutionized gamma spectroscopy. The great superiority of the germanium system in energy resolution allows the separation of many closely spaced gamma-ray energies, which remain unresolved in the NaI(Tl) spectrum [1]. Our final aim is to benchmark MCNPX code with experiment to be used in neutron activation analysis because creating a library to train a neural network to analyze the measured spectrum obtained from activated sample under irradiation of neutrons by experiment is irritating, cost-intensive, and time consuming. The Monte Carlo simulation can be used for this reason to generate this library making it easier and cheaper. In this case we need the exact response function of the HPGe which is needed to account for any possible noises that may have influence on FWHM in order to create a nearly real simulation. Resolution function of an HPGe detector can be determined with experimental measurements for the energy range of interest by using radioactive sources. Only few studies deal with the use of germanium detectors in both low- and middle-energy range of gamma-ray which is important in the field of activation analysis [2–4]. This

work performed modeling of an HPGe detector for low-energy to middle-energy gamma-ray and its validation with experiment using standard gamma-ray sources. In addition a , b , and c as parameters specifying the Full Width at Half Maximum in the GEB option have been extracted to make efficient Monte Carlo simulations of germanium detectors.

2. Material and Methods

2.1. Experimental Approach. The detector used in this study was a GMX series HPGe coaxial detector system: the detector model number: GMX40P4-83; cryostat configuration: CFG-PG4-1.2; preamplifier model: A257N; HV filter model: 138 EMI. The resolution (FWHM) at 1.33 MeV, ^{60}Co is 2.02 keV and peak-to-Compton ratio, ^{60}Co is 59:1 and relative efficiency at 1.33 MeV, ^{60}Co is 40%. The crystal has a diameter of 60.6 mm and length of 66.9 mm and also has a 0.3-micron Ge/B dead layer and 700-micron Ge/Li dead layer. The characteristics given by the manufacturers are shown in Figure 1. Standard electronics and a multichannel analyzer with 8000 channels have been used. The program

FIGURE 1: (a) HPGe detector (Ortec, PopTop, model: GMX40P4-83) used to measure and calculate the detector response function, (b) inner structure of the HPGe detector.

TABLE 1: Seven standard photon sources including eleven energies in the range from 40 keV to 1.460 MeV.

Radionuclide	E_γ (MeV)	Half-life	Rad. type
Eu-152	0.040118	9.3116 hrs	X KA1
Am-241	0.059540	432.2 yrs	Gamma
Ba-133	0.080997	10.52 yrs	Gamma
Co-57	0.122060	271.79 days	Gamma
Eu-152	0.244697	9.3116 hrs	Gamma
Eu-152	0.344278	9.3116 hrs	Gamma
Ba-133	0.356012	10.52 yrs	Gamma
Cs-137	0.661657	30.04 yrs	Gamma
Co-60	1.173228	5.2714 yrs	Gamma
Co-60	1.332492	5.2714 yrs	Gamma
K-40	1.460822	1.277E + 09 yrs	Gamma

GammaVision-7 was used for the acquisition of the gamma-ray spectrum. Experimental setup used in this study is to take γ -ray spectrum from standard γ -ray sources to obtain relatively good spectra; the HPGe detector is located 20 cm from the γ -ray source.

The overall energy resolution achieved in a germanium system is normally determined by a combination of three factors: the inherent statistical spread in the number of charge carriers, variations in the charge collection efficiency, and contributions of electronic noise [1]. In Monte Carlo MCNP code Gaussian energy broadening (GEB) is a special treatment for tallies, to better simulate a physical radiation detector in which energy peaks exhibit Gaussian energy broadening. GEB is called by entering FTn card in the input file of MCNP. The tallied energy is broadened by sampling from the Gaussian [5]:

$$f(E) = Ce^{-(E-E_0)/A)^2}, \quad (1)$$

where E is the broadened energy; E_0 is the unbroadened energy of the tally; C is a normalization constant; and A is the Gaussian width.

The Gaussian width is related to the Full Width at Half Maximum (FWHM) by

$$A = \frac{\text{FWHM}}{2\sqrt{\ln 2}}. \quad (2)$$

The desired FWHM that is specified by the user-provided constants, a , b , and c , shows a nonlinear response:

$$\text{FWHM} = a + b\sqrt{E + cE^2}, \quad (3)$$

where E is the incident γ -ray energy. The units of a , b , and c are MeV, $\text{MeV}^{1/2}$, and MeV^{-1} .

Seven standard γ -ray sources including eleven gamma energies in the range from 40 keV to 1.46 MeV (Table 1) were used to obtain the measured gamma-ray spectrum for determining a , b , and c as parameters specifying the Full Width at Half Maximum in the GEB option. All spectra were analyzed by means of Origin 8.5 program [6] and background counts were subtracted.

According to this work the author has extracted the following parameters in the GEB option to generate detector responses (Figure 2):

$$\begin{aligned} a &= 5.86828E - 4 \text{ MeV}, \\ b &= 3.95113E - 4 \text{ MeV}^{1/2}, \\ c &= 7.46793 \text{ MeV}^{-1}. \end{aligned}$$

2.2. Monte Carlo Simulation. The experimental setup, detector and source, was simulated with the MCNPX Monte Carlo code [5]. The data required for the detector's simulation are found in its certificate provided by the manufacturer, which describes its characteristics and dimension. Figure 3 shows a representation of the precise simulated detector's structure. The distance between the source and the front surface or end cap of the detector was 20 cm and the source was assumed as an isotopic point source which is the same as real condition. Response function was calculated with F8 tally (pulse height tally). A history of 5×10^7 photons was sampled in order to get good statistics. The initial responses of the MCNPX calculation were broadened with the GEB option by entering obtained a , b , and c parameters in FTn card.

FIGURE 2: Diagram of FWHMs versus measured gamma-ray energy spectra used to fit on $FWHM = a + b\sqrt{(E + cE^2)}$ equation for extracting a , b , and c parameters.

FIGURE 3: Schematic representation of the simulated HPGe detector.

TABLE 2: A comparison between simulated and measured values at 1.173 MeV peak.

Energy	Simulated value	Measured value	Relative difference (%)
1173.58	0.58	0.59	1.6
1173.77	0.63	0.70	10.0
1173.97	0.78	0.81	3.0
1174.17	0.86	0.93	3.7
1174.36	1.00	1.00	0.0
1174.56	0.91	0.90	1.1
1174.76	0.73	0.79	6.0
1174.96	0.69	0.72	3.0
1175.15	0.65	0.63	3.1

3. Results and Discussion

HPGe response function to Co-60 standard gamma-ray source was measured and compared with the simulated results to validate the simulated response function. Figure 4

shows a good agreement in the energy range of two photoelectric peaks and Compton edge for the Co-60 gamma-ray spectrum. For a better comparison a quantitative table of first Co-60 peak is tabulated in Table 2. In spite of this good agreement between simulated and measured response, the low discrepancies might be caused by the scattered beam from the surrounding materials in the room or might be due to peak tailing which caused incomplete charge collection or by pulse pile-up with electronic noise or other detected photon and to Doppler broadening of inelastically scattered photons that smooth the Compton edges.

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. This work has presented a way to simulate the response functions of HPGe by using GEB as a special treatment for tallies in MCNPX. Results show that MCNPX simulations by using GEB fit all the Gaussian peaks arising from standard gamma-ray sources in a wide range of energy with small discrepancies; typically Co-60

FIGURE 4: Comparison between simulation and experimental gamma-ray spectrum of the Co-60 point source.

spectrum was shown. In this work based on our future works, the coefficients a , b , and c as described in Section 2.1 have been extracted to generate a library for delayed gamma neutron activation analysis for cement material using Monte Carlo code. Note that GEB parameters are different for each configuration of experimental setup.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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