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Studying of characteristic of GEM40P4 HPGE detector by experiment

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Abstract. Radioactive sources which used to study were the standardized radioactive of common monoenergetic radionuclide Cs^{137} and standardized multigamma Co^{60}, Ba^{133}, Eu^{152}. Determination of the absolute efficiency curve and energy resolution as a function of energy of GEM40P4 HPGe spectrometer are presented in this paper.

Keywords: GEM40P4 HPGE detector, relative efficiency, absolute efficiency, energy resolution.

1. Introduction

The high purity germanium (HPGe) spectrometer is used for analysis of environmental sample and determination of radioisotope concentration due to its excellent resolution. This detector has better characteristics and more sensitive to the detection of impurities. When purchasing an HPGe detector, operating characteristics such as resolution, absolute efficiency were commonly used to compare different systems and to judge performance.

1.1. Absolute eficiency of HPGE detector

As we known that the absolute efficiency of HPGe detector is the ratio of the number of counts in the full- energy photo-peak to the total number of gamma rays emitted from a source and can be determined by formula[1-4]:

$$e(E) = \frac{N}{A.B_r.t_r} \tag{1}$$

where $\varepsilon(E)$ is the absolute detection efficiency at energy of E, N is number of counts in the photo-peak (net area), A is activity of gamma source at measurement time, B_r is branching ratio corresponding to the energy of E, and t_r is denotes the real time taken for each successive measurement.

In principal, efficiencies of germanium detectors can be estimated from published measurements or calculations for detectors of similar size, the accuracy of results based on these values will not be much better than 10-20% [1]. One major difficulty that the dimensions of these detectors are not

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standardized to any degree, and it is very difficult to determine precisely their active volume (include dead layer). On other hand, absolute efficiency are depend not only detector properties but also on the details of the counting geometry (primarily the distance from the source to the detector). Hence, in some case we also need to calculated absolute efficiency as geometry function (the function of the distance between source and detector). Furthermore, long-term changes in charge collection efficiency and window thickness can lead to drifts in the detector efficiency over periods of time.

For these reasons, we must normally carry out our own periodic efficiency calibrations of our germanium detectors. To calculate the energy dependence of the detector efficiency, a set of several reference gamma source which known nuclide activity and gamma emission probability is needed to cover the energy ranges of interest (IAEA, 1991; Sima *et al.*, 2001; Sima and Cazan, 2004). If we use multi-energy sources summing effect would affect the result of absolute efficiency. To avoid this error, single energy gamma sources were usually used. However, almost of them have short half life and only use in a few months. That's why, the multi-energy gamma sources were used in this paper to calculate the efficiency calibration.

It can be assumed that in gamma measurements using multi-energy sources the counting loss ratios in every peak caused by the summing effect were about the same [2]. Then, if we known relative efficiencies and transformation factor, the absolute efficiencies can be obtained by follow relation.

$$e(E) = t(E)e_r(E) \tag{2}$$

where $\varepsilon(E)$ is the absolute detection efficiency at energy of E, $t(E)$ is the transformation factor corresponding to energy of E, $\varepsilon_r(E)$ is the relative efficiency value at energy of E [2].

To determine the relative efficiency curve we used two gamma sources ^{133}Ba (source 1) and ^{152}Eu (source 2). By chose the photo-peak efficiency at energy E_i (source 1) equal 100%, we obtained the value of relative efficiency at energy E_j (source 2) as follow:

$$e_{2,re}(E_j) = e_{1,re}(E_i) \cdot \frac{n_2(E_j)}{n_1(E_i)} \cdot \frac{A_1}{A_2} \cdot \frac{B_{r1}(E_i)}{B_{r2}(E_j)} \tag{3}$$

where $e_{1,re}(E_i)$ is the relative efficiency for energy E_i of source 1, usually it is taken as 100%, $e_{2,re}(E_j)$ is the relative efficiency for energy E_j of source 2, $n_1(E_i)$ and $n_2(E_j)$ are the count rates of source 1 at energy E_i and source 2 at energy E_j, A_1 and A_2 are the activities of source 1 and source 2 at the measurement time, $B_{r1}(E_i)$ and $B_{r2}(E_j)$ are branching ratios of source 1 and source 2 [2].

1.2. Energy resolution as a function of energy

The energy resolution is a measure of the detector's ability to distinguish closely spaced lines in the spectrum. 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 electric noise. Which of these factors dominate depends on the energy of the radiation and the size and inherent quality of the detector in use. The full width at half maxium W_τ of a typical peak in the spectrum due to the detection of a monoenergetic gamma ray can be synthesized as follows

$$W_t^2 = W_D^2 + W_X^2 + W_E^2 \tag{4}$$

Where the W_τ values on the right-hand side are the peak widths that would be observed due only to effects of carrier statistics, charge carriers, and electronic noise created.

- The first of these factors, W_D^2, represents the inherent statistical fluctuation in the number of charge carriers and is given by:

$$W_D^2 = (2.35)^2 FeE$$

Where F is Fano factor, ε is energy necessary to create one electron-hole pair, and E is the gamma-ray energy.

- The contribution of the second term, W_X^2, is due to incomplete charge collection and is most significant in detectors of large volume and low average electric field.

- The third factor, W_E^2, represents the broadening efffects of all electronic components following the detector [1].

2. Experimental setup and measurements

GEM40P4 detector which was located in Nuclear Department (Hanoi University of Siences) were produced by ORTEC company. It is the first detector have cooled down by X-cooler in Vietnam. The detector were HPGe coaxial detector (with 1 mm Al window) which are placed inside low background lead shield (model 747). The integrated signal processor consists of a pulse height analysis system to transform pulses, which are collected and stored by a computer-based MCA. The signal processor contains high-resolution spectroscopy amplifier with a pile-up rejector. In our measurements the input rise time is set to 12 μs corresponding to shaping time is 6 μs.

Operating parameters of the system are governed and controlled by the computer program MAESTRO 32 [5]. Data stored in 16384 sequential channels. Automatic correction for the dead time is obtained by collecting data for a given live time. The detector diagram and the materials made up each part of it can be shown in Figure 1 and Table 1.

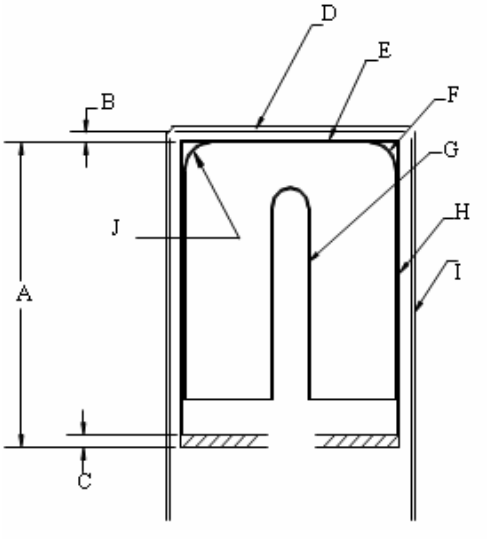

Fig. 1. GEM40P4 Detector Diagram.

Table 1. Miscellaneous detector assembly dimensions and materials

IDENTIFIER	DIMENSION	DESCRIPTION	MATERIAL(S)
A	105 mm	MOUNT CUP, LENGTH	ALUMINUM
B	4 mm	END CAP TO CRYSTAL GAP	N.A.
C	3.2 mm	MOUNT CUP BASE	ALUMINUM
D	1 mm	END CAP WINDOW	ALUMINUM
E	0.03/0.03 mm/mm	INSULATOR/SHEILD	MYLAR/ALUMINIZED MYLAR
F	700 microns	OUTSIDE CONTACT LAYER	LITHIUM
G	0.3 microns	HOLE CONTACT LAYER	BORON
H	0.76 mm	MOUNT CUP WALL	ALUMINUM
I	1.3 mm	END CAP WALL	ALUMINUM

3. Results and discussion

In this paper, we used four radioactive sources of IAEA standard source including Cs^{137} (661.66 keV), Co^{60} (1173.228 keV and 1332.492 keV), Ba^{133} (80.997 keV, 302.96 keV, 356.013 keV and 383.848 keV) and Eu^{152} (121.77 keV, 244.697 keV, 344.34 keV, 778.94 keV and 964.09 keV) as shown in table 2. In table 2, N is number of counts in the photo-peak and t is counting time.

We calculated relative efficiency of GEM40P4 detector by chose efficiency at energy of 356.013 is equal 100% and used the formula (3) to calculated relative efficiency of other energy. Absolute efficiency can be calculated by the formula (1). The result of relative and absolute efficiency can be shown in Table 2.

Table 2. Calculation of relative and absolute efficiency of GEM40P4

E (keV)	N	t (s)	Br (%)	Relative efficiency (%)	Absolute efficiency (%)
80.997	10817	260.22	34.06	108.520 ± 0.218	0.737 ± 0.009
121.77	221677	768.64	28.58	168.531 ± 0.569	1.145 ± 0.015
244.697	54728	768.64	7.58	132.965 ± 0.725	0.903 ± 0.013
302.96	29751	260.22	18.33	113.702 ± 0.762	0.772 ± 0.011
344.34	146839	768.64	26.5	102.315 ± 0.435	0.695 ± 0.009
356.013	88575	260.22	62.05	100.000 ± 0.475	0.679 ± 0.009
383.848	10757	260.22	8.94	93.507 ± 0.861	0.635 ± 0.010
661.66	14518	20.9	85.1	62.658 ± 0.511	0.426 ± 0.006
778.94	33815	768.64	12.94	53.556 ± 0.308	0.364 ± 0.005
964.09	32510	768.64	14.61	45.014 ± 0.267	0.306 ± 0.004
1173.22	10897	401.38	99.97	36.003 ± 0.334	0.245 ± 0.004
1332.49	10093	401.38	99.99	32.526 ± 0.320	0.221 ± 0.004

After the analysis of recorded spectra and evaluation of obtained data for efficiency at given energies, calibration curves were obtained by fitting(Fig 2). The analytical expression of obtained efficiency curves is given by following formula [2,6,7]:

$$e = \sum_{n=0}^{5} a_n \left(\ln E\right)^n \tag{5}$$

The relative efficiency of Ortec detector (GEM40P4) was plotted against logarithm of the gamma ray energy to relate the detection efficiency of the HPGe detector system as a function of energy.

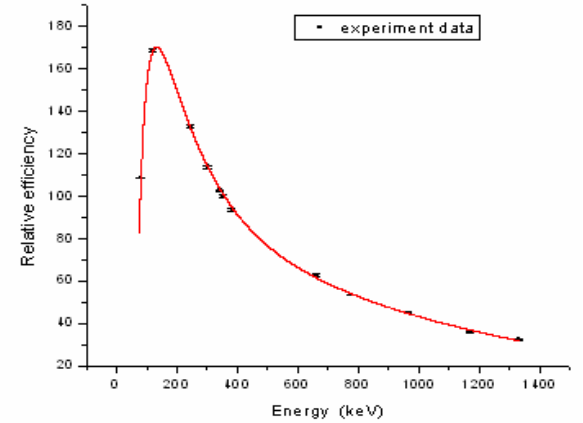

Fig. 2. The relative efficiency curve of Ortec detector (GEM40P4), $e = \sum_{n=0}^{5} a_n (\ln E)^n$ in which a_o = -65846.43 ± 7155.23, a_1 = 52460.94 ± 6363.59, a_2 = -16510.74 ± 2246.33, a_3 = 2577.13 ± 393.43, a_4 = -199.93 ± 34.19, a_5 = 6.17 ± 1.18, with the value of R^2 is 0.99979.

The absolute efficiency curve was obtained by multiplying a_n with $t(E)$. The value of $t(E)$ was calculated by using the 661.657 keV gamma-line. The total uncertainty of the calculated absolute detector efficiency includes relative uncertainties of the gamma peak area, the calibration source activity and also co-variances introduced in the curve fitting (Fig 3).

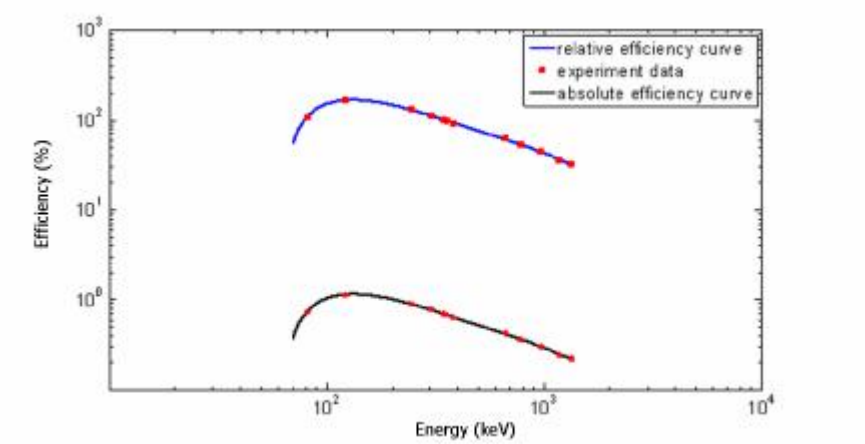

Fig. 3. The relative efficiency curve (blue line) and absolute efficiency curve (dark line) of Ortec detector (GEM40P4).

In order to evaluate the dependence of the HPGe energy resolution on the gamma-ray energy, the FWHM of the Gaussian curve, fitted to each corrected histogram of each gamma-ray peak. The difference FWHM of the peak width varies with the gamma-ray energy, as shown in Fig. 4.

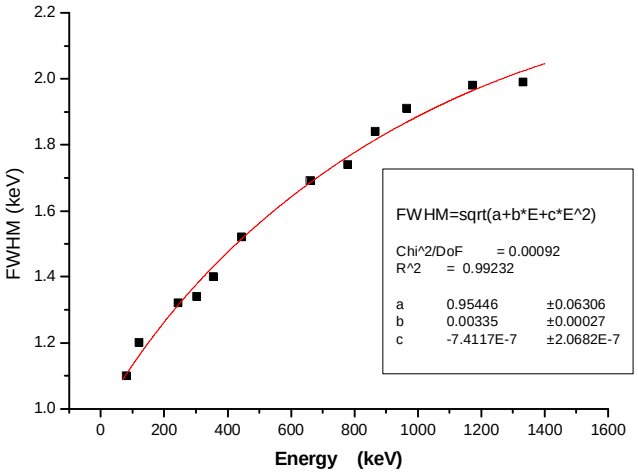

Fig. 4. The energy resolution curve as the function of energy of GEM40P4 detector.

4. Conclusion

The efficiency and energy resolution curves are in good agreement with measurement nuclear data. But in this paper we didn't discuss the result of detector efficiency between calculated and experimental efficiencies in low-energy region (< 60 keV). Because the fact that the calculated efficiency for very-low energies is very sensitive to the thicknesses of the germanium dead layer and of the detector entrance window, which strongly attenuate low energy photons. Therefore, it was necessary to optimize the thickness of the Ge inactive layer in order to bring into accordance the experimental and calculated efficiencies for very-low energies.

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