Gamma- Ray Spectroscopy By HPGe detector

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Abstract

The main objectives of this study is to gain a basic understanding of the concepts involved in familiarized to gamma ray spectroscopy with the performance characteristics of a HYPER-PURE Germanium detector. Three sources: ^{137}Cs, ^{60Co} and ^{57}Co, were demonstrated to study the interaction of gamma ray with this detector. Germanium spectrometer is the highest resolution gamma ray detector, and has poor efficiency, the calibration of the HPGe was performed with three sources, it can see from the result the energy resolution of them was ranged it found to be 0.1779%,0.0440%and 0.0300% for energies of 601.39, 3272.73 and 5805.11 KeV, and three types of detection efficiency which are absolute efficiency and intrinsic full energy peak efficiency and intrinsic full energy peak efficiency were determined and found to be respectively for the ^{137}Csat 601.39. The relationship of the resolution and energy was studied, and the gradient was found to be -1.2771, it can see clearly that FWHM increase in the case of high energies. Finally, a spectrum for an unknown source was collected and identified from the peak centriod energies and intensities. The intrinsic peak efficiency of gamma ray emission signal in ^{152}Eu was estimated.

Keywords: HPGe detector; gamma ray spectroscopy; efficiency; Resolution, Peak Shape.

1- Introduction

High energy photons are one of the three main types of ionising radiation resulting from natural radioactivity. They are an energetic from of electromagnetic radiation and occur in the form gamma or x- rays. The atom consists of nucleus by surrounded be electrons that rotate it. When gamma rays, an electromagnetic radiation emitted from exited nuclei . Interact with matter. The transmission of gamma –ray energy of the matter differs from charged particles. When gamma ray interacts with matter, there are three types of natural interaction mechanisms which are known for gamma rays: photoelectric absorption, Compton scattering and pair production. In these interactions the gamma ray photon transfers to electron energy and ejects it from the atom. The photoelectric effect is generally the dominant attenuation mechanism for incident photon energies <200KeV. In Compton describes the interaction of photon with an outer shell electron in this case. The way in which energetic electrons produced by these three processes interacts in the detector material [1].

In this paper is used the HPGe detector to research electronics to measure gamma ray energies. HPGe semiconductor detectors spectra general features are comparable with those from scintillation detectors. Which is the energy resolution of scintillations is poor. However Germanium detector has typical energy resolution. Moreover, Germanium detector is clearly preferred for the complex gamma ray spectra for many peaks [2].

The purpose of this experiment was studied about properties of the HPGe detector of gamma interaction, when a gamma ray enters a detector to produce an electron by one of three main of interaction it is measured before. Furthermore, the detector efficiency and resolution will be determined. All the results will be presented and discussed [3].

2-Background Theory

2.1- Scintillation Mechanism

Gamma ray spectroscopy is much more widely used technique than Alpha and Beta spectroscopy. The characteristic of Germanium detector is their excellent energy resolution when applied to gamma ray. In addition, the Germanium detector must be cooled to reduce the leakage current, that Germanium crystal must be operated at liquid nitrogen temperatures in order to minimise the thermal leakage current. HPGe detector comprises a germanium crystal diode, when a high voltage reverse bias is applied. The detector signal is passed to a low noise charge sensitive preamplifier after which the signals are treated by comparable electronics to those outlined for the Nal(Tl) detector. For gamma rays there are three types of interaction which are important in radiation measurements: photoelectric absorption, Compton scattering and pair production. The response of a detection system to a particular gamma- ray source is not a simple function of the emitted radiation[3].

The energy resolution, R, of a detector is a measure of ability to resolve small differences in the energy of incident photons and is defined in equation 1.the full width at half maximum (FWHM) is expressed in terms of channel number from the energy spectrum and H_0 is the peak centroid channel number.

$$R = \left(\frac{FWHM}{H0}\right) \times 100\% \qquad \rightarrow (1)$$

Where, FWHM is the full width of the- energy peak at Half Maximum height and H_0 is the channel number.

A small value resolution means that detector is more likely to be able to identify two energy peaks which fall close together. The full energy peak for any type detector can be approximated as a Gaussian curve[4-6].

The FWHM can be expressed as:

$$FWHM \propto E_{\gamma}^{\frac{1}{2}} \qquad \rightarrow (2)$$

$$R = \alpha \frac{E_{\gamma}^{\frac{1}{2}}}{E\gamma} = E_{\gamma}^{-\frac{1}{2}} \qquad \rightarrow (3)$$

Furthermore, there are definitions of detector efficiency are encountered:

The absolute total efficiency ε_t, relates the number of gamma rays emitted by the source to the number of counts recorded by the detector. The efficiency can be calculated by equation:

$$\varepsilon_t(\%) = \left(\frac{C_t}{N_{\gamma}}\right) \times 100\% \qquad \rightarrow (4)$$

Where is the $\mathbf{C_t}$ is the total number of count rates recorded per unit time and N_{γ} is the number of gamma emitted by the source per unit time, it can calculated from equation:

$$N_{\gamma} = D_S I_{\gamma}(E_{\gamma}) \qquad \rightarrow (5)$$

Where the $\boldsymbol{D_S}$ *is* the disintegration rate of the source and $\boldsymbol{I_{\gamma}\ (E_{\gamma})}$ is the factional number of gammas emitted per disintegrations and it is equal to 0.85 for the ^{137}Cs [7].

Intrinsic total efficiency is the ratio of the number of pulses produced by the detector to total number of gamma rays which are incident on the detector. This efficiency can be calculated by using the equation(4). Where, N_{γ} is the total number of gamma rays which are incident on the detector and defined as :

$$N_{\gamma} = \left(\frac{\Omega}{4\pi}\right) D_S\, I_{\gamma}\,(E_{\gamma}) = \left(\frac{\Omega}{4\pi}\right) N_{\gamma} \qquad \rightarrow (6)$$

Intrinsic photo peak efficiency is the probability that a gamma ray at a specific energy, which is incident on the detector, will be recorded. It can be expressed as:

$$\varepsilon_t = \left(\frac{C_p}{N_{\gamma}}\right) \times 100\% \qquad \rightarrow (7)$$

$\boldsymbol{C_p}$ ***is*** the net count number under the full energy peak[7-8].

3. MATERIALS AND METHODS

3.1 Interpretation of Gamma-Ray Spectroscopy:

Firstly, the HPGe detector was connected to a preamplifier and to a shaping amplifier, and high voltage power supply. The shaping time was set up to 6µs while the HV control was setup to 351volt. Secondly, the ^{137}Cs source was pleased˜5cm from the front face of the detector. By using the MCA, the spectrum was collected for the source and the spectrum peaks were identified in the life time 300s, allowing a good statistical. Then, with the same source the spectrum was recorded again, and increasing the gain on the shaping time amplifier in order. It can be seen more clearly the right and low energy peaks. The next steps return the gain to the original setting to collect spectrum. Then ^{60}Co source placed close to the front window of the detector and another spectrum was recorded.

3.2 Detector characterisation

In this part of the experiment, there are three properties of gamma spectroscopy examined. These are the energy calibration, energy resolution and detection efficiency. These quantities are dependent on the energy of the incident radiation.

3.2.1 Energy Calibration

As mentioned before, the feature of any gamma ray detector is linearity of energy response. The distance of source – detector was˜5 cm. The three spectrums of the ^{137}C, 60Co and ^{57}Co source were obtained, the peak centroid channel of full energy was determined from the monitor by eye, and then the graph of channel number versus the peak energy of each peak was plotted. After that the peak centroid channel were measured by using function on the MCA for each peak, and the graph of the channel number against the peak energy was plotted. The aim of that was to compare between these two ways. All the sources are placed in the front of the detector to the calibration by using MCA for each peak.

3.2.2 Energy Resolution

The energy resolution of the detector is measure of its ability to resolve small difference in the energy of incident gamma –rays. By recording the centroid channel number and the FWHM of each peak by using equation 1 . The graph of log R versus log E was plotted and the gradient was calculated.

3.3.3 Detection Efficiency

The ^{137}Cs was placed in the front face of the detector to collect a spectrum. Than the total count under the spectrum was recorded for measuring the detector efficiency . Also, for measuring the intrinsic photo peak efficiency the count under the full peak of the ^{137}Cs was recorded.

3.4 Complex Radiation Spectrum

A spectrum of ^{152}Eu source . This source emits many gamma rays in the range 122KeV to 1458keV, and then the spectrum was calibrated by using MCA. The spectrum unknown source was collected for 30 minutes.

4- Results and Discussion

4.1 Interpretation of gamma- Ray Spectra

In this part of the experiment, the spectrum of three sources ^{137}Cs, ^{60}Co and ^{57}Co, were collected by using the HPGe detector. Figure 1 clearly shows that the characteristic features for the ^{137}Cs spectrum. It can be seen tow peaks which are the full energy peak at 662 KeV and characteristic x-ray peak. It can be noticed that the full energy peak at 662 KeV result from interaction gamma photon with detector crystal as photoelectric effect interaction. The photon disappeared and its energy is transferred to one of the atomic electron. Then this interaction is followed by emission of characteristic x-ray. Moreover, the spectrum show Compton continuum which is a result of the interaction between gamma ray and free electron in the atom. When the ^{60}Co source was placed in the front face of the detector with the ^{137}Cs. it can be noticed that two peaks of energies were observed at 1173,1332 KeV, the sum coincidence peaks at 2505 Kev for the ^{60}Cs, where the peak at 662KeV for ^{137}Cs.

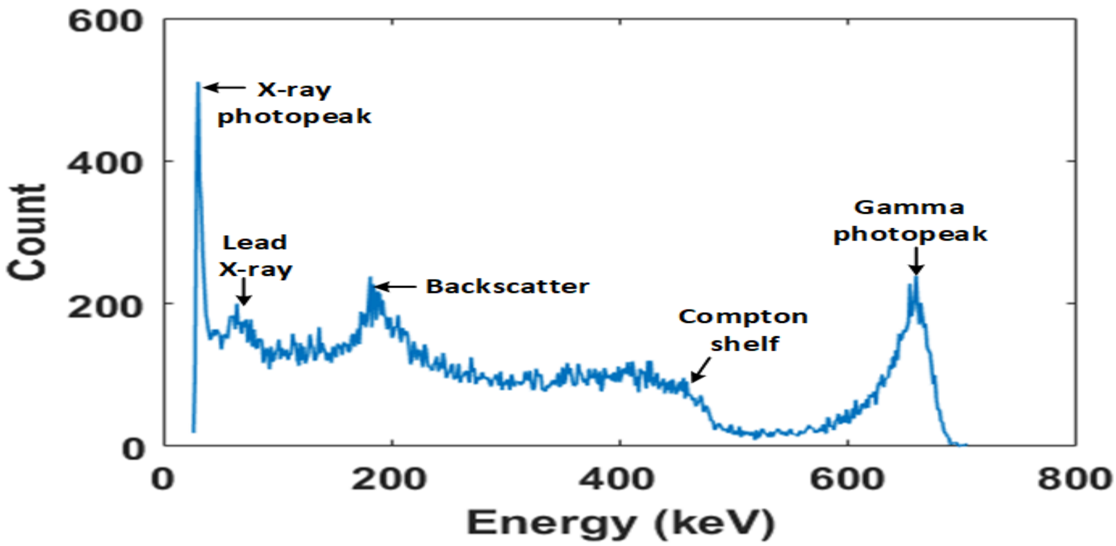

Figure 1. shows that the characteristic features for the ^{137}Cs spectrum.

4.2 Detector Characterisation

4.2.1 Energy Calibration

In this part of the experiment is divided into two parts where three sources ^{137}Cs, ^{60}Co and ^{75}Co were used. In The first part is to determine the channel number by eye. The figure 2 below shows the relationship between the channel number versus the energy of ^{137}Cs, ^{60}Co and ^{57}Co, as determined by eye and. By using the data from the tables 1 .

tables (1) Energy Calibration Manual (by eye) for HPGe detector.

Source	Channel number By eye	Energy (KeV)
^{137}Cs	3273	661.7
^{60}Co	6594	1332.5
^{60}Co	5805	1173.2
^{57}Co	673	136
^{57}Co	601	122

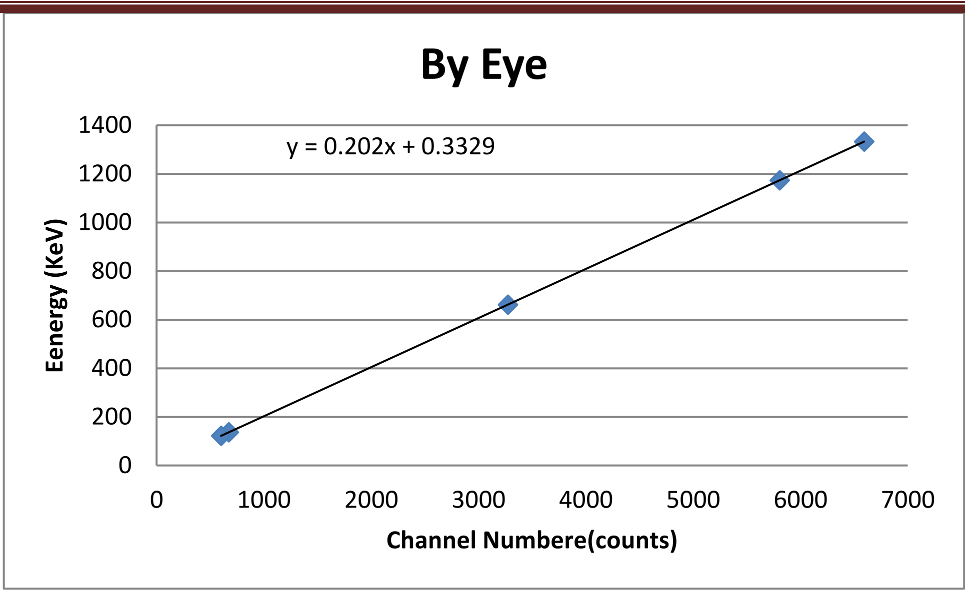

Figure (2). Energy Calibration Manual (by eye) for HPGe detector.

In the second part of this experiment, the linearity of channel number against peak energy by using the MCA. The result from the table 2 .

tables (2) the linearity of channel number against peak energy by using the MCA

Source	Channel number By MCA	Energy (KeV)
^{137}Cs	3272.73	661.7
^{60}Co	6593.46	1332.5
^{60}Co	5805.11	1173.2
^{57}Co	672.57	136
^{57}Co	601.3	122

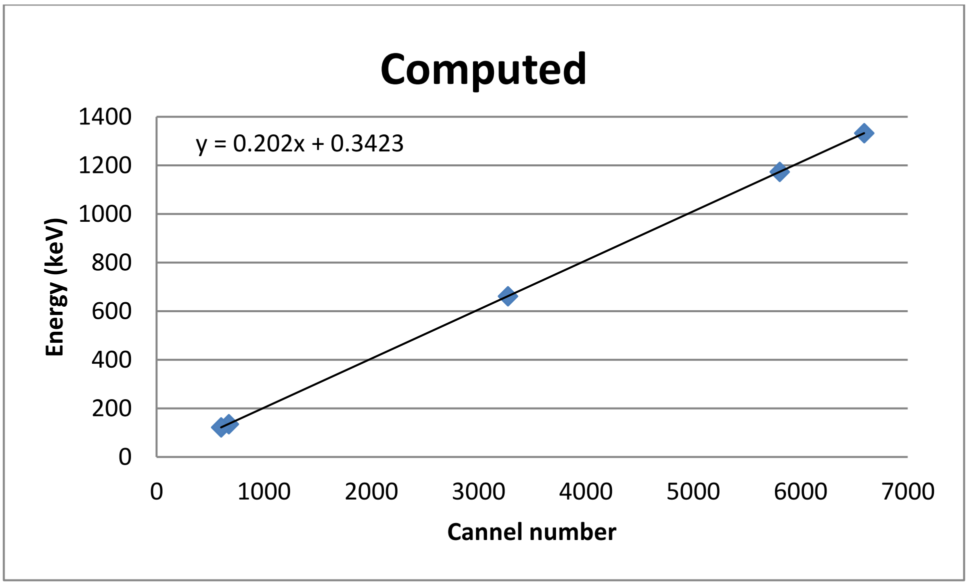

Figure (3). Energy Calibration Manual (by MCA) for HPGe detector

Furthermore, it can be seen that from the figures (2,3) the relationship between channel number and peak energy, the plotted graphs reveal a linear relationship between the channel number and energy which can be presented as:

$$Y = a\,x + b \qquad \rightarrow (9)$$

Where y axis represents the energy and x represents the channel number.

4.2.2 Energy Resolution

It can be seen from the table 3 below the energy resolution of HPGe detector as calculated from equation 1. It can be noticed that the values of energy resolution ranged between 0.1779% to 0.0281% for gamma energies 122- 1332 KeV. This means that as the incident photon energy decrease.

Table (3) resolution of HPGe detector

H_0	FWHM	Resolution R(keV) %	Energy (KeV)	Log E	Log R	Log FWHM
601.39	1.07	0.1779%	122	2.08636	-2.74977	0.029384
3272.73	1.44	0.0440%	662	2.820858	-3.35655	0.158362
5805.11	1.74	0.0300%	1173	3.069298	-3.52326	0.240549
6593.47	1.85	0.0281%	1333	3.12483	-3.55194	0.267172

By using the data from the table 3 to plot a graph of log E versus energy log R resolution and log E versus log FWHM as shown in figure 4 and 5 respectively.

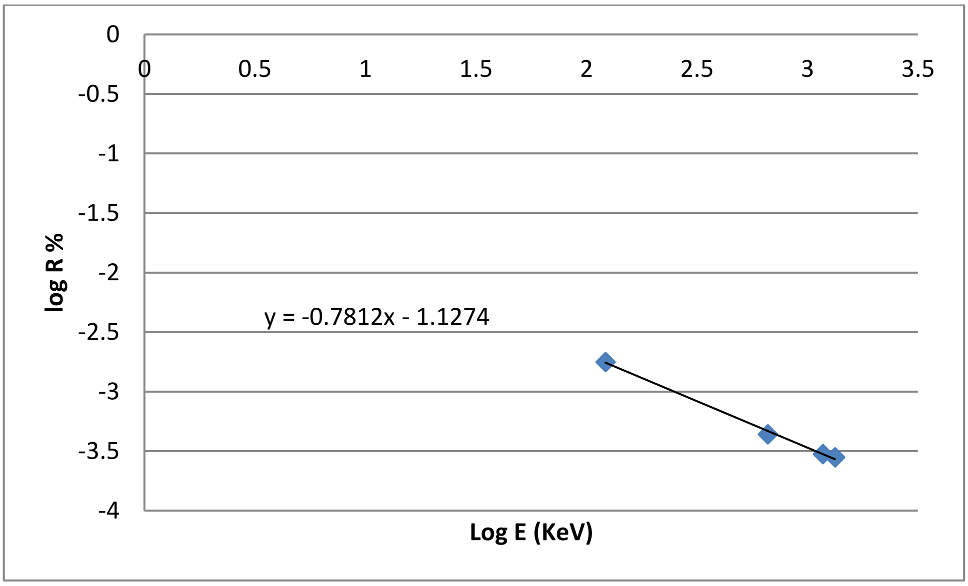

Figure 4. Energy resolution of HPGe detector

From the figure 4 the gradient and the intercept of the straight line were calculated and found to be -0.7812 and -1.1274 respectively. It can be noticed from the graph the relationship between the energy resolution and peak energy which can be expressed as follows:

$$\mathbf{R \propto E_{\gamma}^{1/2} / E_{\gamma} = E_{\gamma}^{-1/2}}$$

$$\mathbf{SO\ R= E_{\gamma}^{-1/2}}$$

$$\mathbf{Log\ R=-1/2\ Log\ E}$$

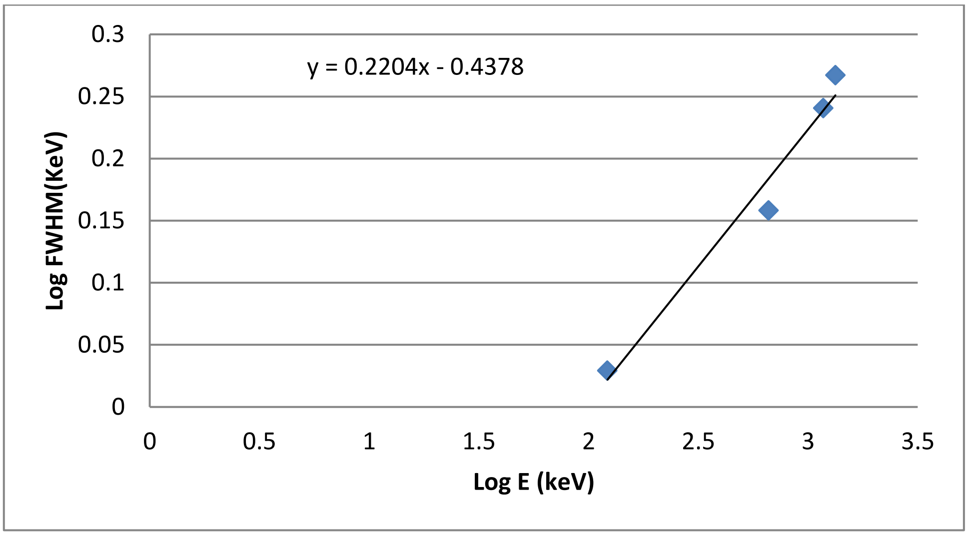

Figure 5. Energy vs FWHM for HPGe detector

The relation between energy and FWHM can be expressed using the following equations:

$$\mathbf{FWHM \propto E_{\gamma}^{1/2}}$$

$$\mathbf{Log\ FWHM =1/2Log\ E}$$

It can be seen from the results in table 3 that the energy resolution of these sources ^{137}Cs, ^{60}Co, ^{60}Co and ^{57}Co are good resolution for HPGe detector.

4.3.3 Detection Efficiency

The detector efficiency depends the density, size of the detector material, distance between the source and the detector and type and energy resolution. The HPGe detector ~5 cm and atomic number Z= 32 of its iodide constituent.

Absolute total efficiency can be calculated from equation 4 and 5

There is D_S, is the activity of the ^{137}Cs which was 249.340KBq at 01/12/1988 and at the day of the experiment was 249.225× 10^6Bq.

$$N_\gamma = D_S \, I_\gamma \, (E_\gamma)$$

$$N_\gamma = 249.225\times 10^6 \times 0.85 = 211841250 \ Bq.$$

$$\varepsilon_{t,}(\%) = (C_t / N_\gamma)\times 100$$

$$c_t = \text{total count/live time}$$

$$c_t = 685175/300$$

$$c_t = 2283.91 s^{-1}$$

$$\varepsilon_{t,} \% = (2283.91/211841250)\times 100$$

$$\varepsilon_t \% = 1.078123359\times 10^{-5} \%$$

4.3 Complex Radiation Spectra

In the figure 6 shows the spectrum for ^{152}Eu source many gamma rays were emitted.

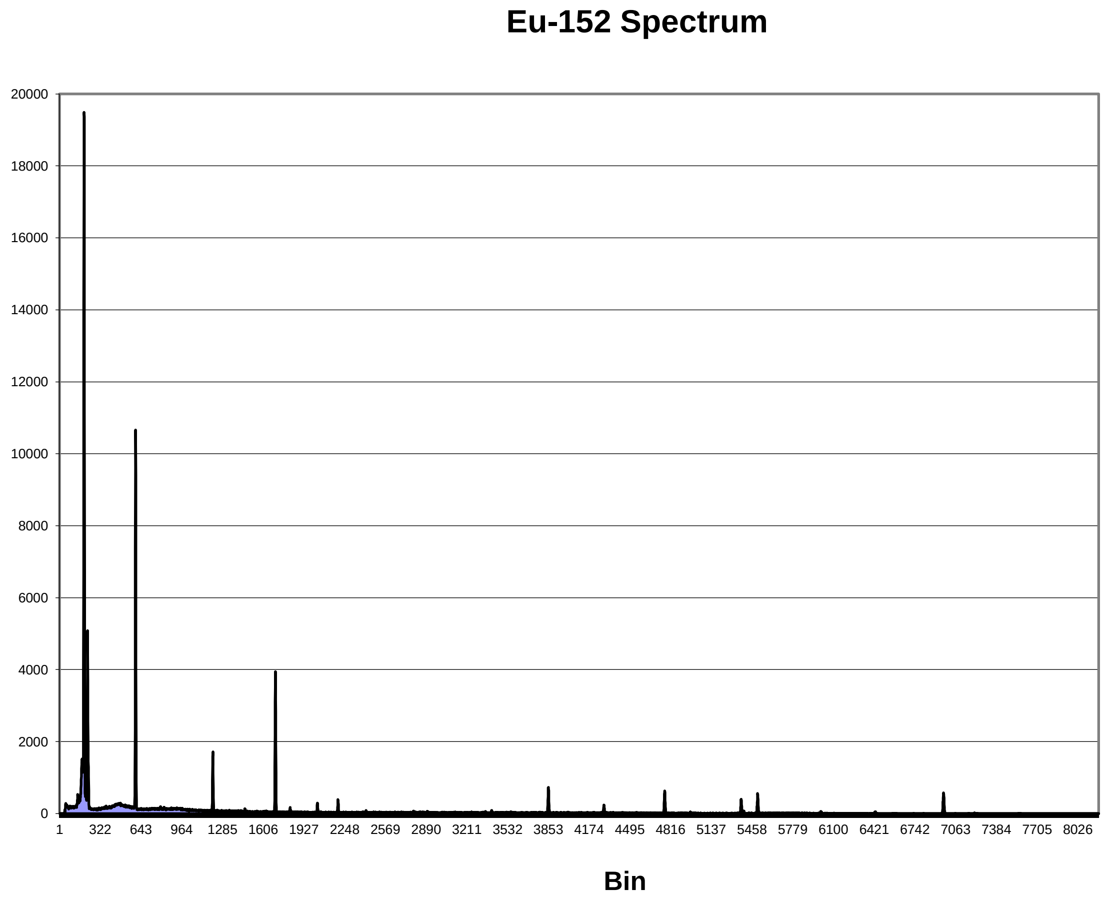

Figure 6 a spectra of ^{152}Eu

Conclusion

In this paper, has the general features of gamma ray spectra and the performance characteristics of HPGe detector has been investigated, firstly, in the figure 2 and 3 the spectra was collected from the ^{137}Cs and ^{60}Co source, it can seen clearly the collected spectra of gamma rays present main features, full energy peak, x- ray peak, Compton scattering, Compton edge and backscatter peak. Secondly, the energy calibration of the HPGe was performed by eye and MCA. It can be noticed form the graph figure 2and 3, relationship between the channel number and peak energy there was very little difference between the reading by eye and MCA. The energy resolution of the HPGe detector was measured and it was found to be ranged between 0.1779% to 0.0281% for gamma energies 122- 1332 KeV. It can see that the incident photon energy increase. Moreover, from the experiment data it was found the HPGe detector has better resolution than a Nal (Tl) detector. In addition, there are three types of efficiencies were calculated for the detector wit ^{137}Cs .the absolute total, intrinsic total and intrinsic peak efficiencies were found to be

Furthermore, the ability of HPGe detector to analyse complex spectra was determined. In the figurer 6 shows the spectra obtained for the^{152}Eu source.

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