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Study of the characteristics of a clover detector

P.K. Joshi[a,*], H.C. Jain[a], A.S. Medhi[a], S. Chattopadhyay[b], S. Bhattacharya[b], A. Goswami[b]

[a] *Nuclear Reactions Group, Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400005, India*
[b] *Saha Institute of Nuclear Physics, 1/AF Bidhan Nagar, Calcutta 700064, India*

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Abstract

The resolution, efficiency and summing characteristics of a clover detector obtained from Eurisys Mesures, France, have been studied in the singles and the add-back mode. The results of the measurements using ^{152}Eu and ^{60}Co sources are presented in this paper.

1. Introduction

The development of high-resolution HPGe detectors provided a big boost to nuclear spectroscopic studies in the early seventies. These detectors, with a typical volume of ~110 cc, have very high energy resolutions for detection of γ-rays (~2 keV at 1.33 MeV photon energy), but have a limitation in terms of relatively low photopeak efficiency. This requires the use of a large number of detectors for acquiring large statistics in an experiment which gives rise to a large Compton background in a γ-ray spectrum. This led to the development of Bismuth Germenate Oxide (BGO) anti-Compton shields to reduce the Compton background. These have been used in various combinations to form large arrays of HPGe detectors [1]. However, the ever increasing interest in acquiring larger statistics in various nuclear spectroscopic experiments required the development of higher efficiency detectors without deterioration in energy resolution or the timing characteristics. The higher the efficiency required larger is the size of HPGe single crystals. There has been difficulty in growing larger crystals. Moreover, the larger crystals will necessarily have poorer timing characteristics since there will be a larger time spread or jitter in the transit/collection time of electron–hole pairs produced in the large volume of the crystal. In addition, a large-volume detector will have a large Doppler broadening effect which deteriorates energy resolution. These problems have been addressed in recent years through the development of composite detectors like the clover, cluster and segmented detectors. These detectors consist of several HPGe crystals (four for clover and seven for cluster) placed side by side in the same enclosure. Each one of these crystals behaves as a separate detector with an independent output. These outputs can be externally added through hardware electronics or through software to give an energy output which will look like the output of a single large detector. The timing characteristics of the added spectrum will, however, be similar to that of each individual (small size) detector. We have recently acquired and tested a clover detector from Eurisys Mesures, France. Clover detectors are being

* Corresponding author. E-mail: pkjoshi@tifrvax.tifr.res.in.

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used in the detector array EUROGAM Phase II [2]. However, there is no systematic report on the characteristics of this detector. It was, therefore decided to report on the energy resolution, efficiency and summing characteristics of this detector as a function of γ-ray energy obtained from ^{60}Co and ^{152}Eu sources in the present paper.

2. Experimental set up for the clover detector

The clover detector, purchased from Eurisys Mesures, France, consists of four closely-packed n-type hyperpure germanium crystals. The geometry of the crystals inside the vacuum chamber is shown in Fig. 1. Each of these crystals, 50 mm diameter and 70 mm long, has a tapering at the front faces, leaving a total volume of 470 cm^3, which is nearly 89% of the initial volume. The front face of these crystals is shown in Fig. 1. A common high voltage supply provides positive bias of +2500 V (max) to the inner side of the crystal with p-type contact in all the four crystals. The detector was placed on a horizontal stand custom made to support the detector and the liquid N_2 dewar. The HPGe crystals were maintained at liquid N_2 temperature by pressure filling the dewar every 24 h. The LED display glows and automatically cuts off the bias from the detector in the event of detector warm up.

The outputs from the pre-amplifiers of each of the four detectors were amplified using the TENNELEC amplifier TC244. The differentiating and integrating time constants of 6 μs were used for the measurements. The timing signals from all the four pre-amplifiers were shaped using timing filter amplifiers and constant fraction discriminators. These outputs were fed to an octal constant fraction discriminator (ORTEC CF2000). The multiplicity output of this unit was fed to a discriminator to obtain a master pulse consisting of 1-, 2-, 3-, or 4-fold events. The data gated with the master-pulse generated above were recorded in list mode using a CAMAC-based data acquisition system with ORTEC ADCs (ORTEC AD415). The gains of the amplifiers were adjusted to obtain an energy calibration ~0.5 keV/channel for each of the four detectors.

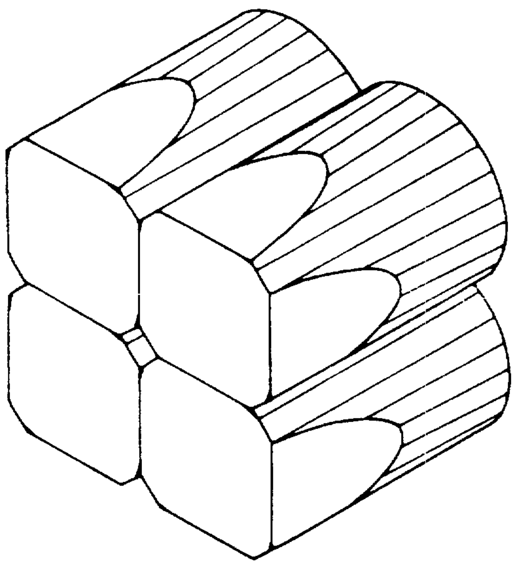

Fig. 1. Geometrical arrangement of HPGe crystals in a clover detector.

3. Measurements

The γ-ray spectra were obtained in list mode using ^{60}Co and ^{152}Eu radioactive sources placed at a distance of 25 cm from the front face of the vacuum chamber of the clover detector. A total of about 1.12×10^5 events were collected with ^{60}Co and 5.9×10^4 events were collected with the ^{152}Eu source.

4. Data analysis

The singles projections for each of the four detectors were obtained from the list-mode data. These projections were used to obtain parameters for matching the gains for each of the four detectors to precisely 0.5 keV/channel. The gain matched data for all the four detectors were rewritten in list mode and used for all subsequent analysis. The singles projections obtained for each of the four detectors from the gain matched data for the ^{152}Eu source are shown in Fig. 2. It is seen that the energy difference for all γ-ray peaks between 122 to 1408 keV is less than 0.25 keV for all the four detectors.

It is seen and also expected that the Compton background in each of the above spectra will be more than

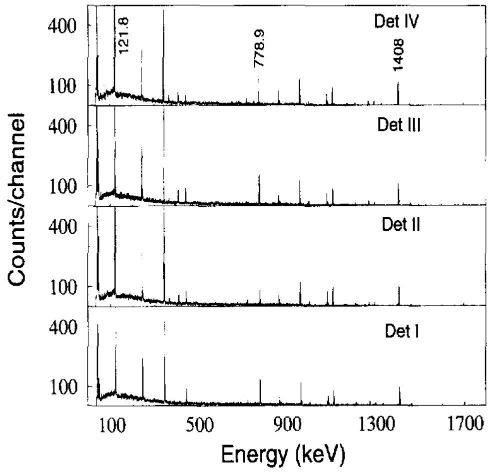

Fig. 2. Projections for each of the four detectors using ^{152}Eu source. The data were gain matched.

the Compton background in each detector if there was only one crystal in the vacuum chamber. This increase in the Compton background is due to Compton scattering from any one crystal to the second, third or even fourth crystal. In this situation, some fraction of γ-rays lose their full energy as Compton events in two or more detectors. These events can be recovered into the photopeak by adding the outputs of all the four detectors. The photopeak intensity in this add mode will, therefore, increase by more than a factor of four. The gain matched data was, therefore, sorted in the following manner:

1. The first set consisted of events where only one of the four recorded a γ-ray. This is called single firing.
2. The second set consisted of events where two of the four detectors had fired. This will consist of events where a single γ-ray loses energy in two of the four detectors through Compton scattering and photo absorption. It can also be that two different γ-rays lose energy in each of the two crystals through Compton scattering or photo absorption.
3. In the third set, three of the four detectors are fired simultaneously.
4. Finally, all the four detectors are fired simultaneously.

The analysis of ^{152}Eu data showed that there were a total of 79.4% events with only one firing, 18.2% events with two firings, 2.2% events with three firings and only 0.14% events where all the four detectors had fired. The γ-ray spectra were generated from 2-, 3- and 4-fold events by adding the energies detected in each of the detectors. Several Compton events belonging to the group, where the total γ-energy is lost in two or more detectors, will move to the photopeak as a result of the above addition. This gives rise to a higher photopeak efficiency where all spectra obtained above are added together. The centroids and resolution for several γ energies in ^{152}Eu for 1-fold spectrum and for the spectrum obtained by adding all (1+2+3+4)-fold events are shown in Table 1. The centroids for all peaks are the same within 0.25 keV and the energy resolution worsens by a maximum of 0.3 keV at the highest energy. Thus, one expects a small worsening of energy resolution in the add-back mode. This is shown in Fig. 3, which compares the 964 and 1408 keV γ-peaks obtained in add-back mode and from the 1-fold events only. The relative intensities of the 1-fold events and (1+2+3+4)-fold events for each of the photopeak are shown in Table 2. The last column in Table 2 shows the ratio of the total photopeak efficiency of the clover detector in the add-back mode to the average efficiency of each single crystal in the clover detector as a function of the γ-ray energy. This is also shown in Fig. 4. The solid line in Fig. 4 represents a fit with a second-order polynomial in energy. It is seen that there is maximum contribution of higher-fold events at the highest energy i.e. 1408 keV where the area under the photopeak increases by a factor of about 1.5 in add-back mode compared to the 1-fold spectrum. Thus, it is seen that the efficiency of the clover detector in the add-back mode is 6 times that of the average efficiency of each individual detector at 1408 keV.

The list-mode data collected with the ^{60}Co was also gain matched. The spectra were generated by adding only 1-fold events and also by adding all of 1–4-fold events in all the detectors. The energy resolution and peak/total ratio for the 1173.2 and 1332.5 keV γ-rays for singles mode, add-mode with 1-fold events and add-back mode for 1–4-fold events are given in Table 3. It is seen that the energy resolution is worsened by about 0.3 keV in the add-back mode, but peak/total, where 'total' includes photopeak plus Compton events, ratio improves from 0.10 to 0.18. As discussed earlier, the improvement in peak/total ratio

Table 1
Positions for photopeaks from 1-fold and (1 + 2 + 3 + 4)-fold firings

Engergy (keV)	Add mode			
	1-fold		(1 + 2 + 3 + 4)-fold	
	Centroid channel no.	Resolution (keV)	Centroid channel no.	Resolution (keV)
121.8	243.70(6)	1.78(2)	243.94(6)	1.73(2)
244.7	489.36(3)	1.66(2)	489.42(4)	1.73(2)
344.3	688.50(2)	1.64(1)	688.48(2)	1.71(1)
443.97	887.73(4)	1.70(2)	887.79(6)	1.82(2)
411.11	822.11(6)	1.84(3)	822.18(8)	1.91(3)
778.9	1558.19(4)	1.85(2)	1558.00(8)	2.08(3)
867.4	1735.31(7)	1.98(3)	1735.15(7)	2.15(3)
964.1	1928.38(5)	2.04(2)	1928.14(5)	2.22(2)
1085.92	2171.81(8)	2.14(3)	2171.77(6)	2.32(3)
1112.10	2224.29(6)	2.24(2)	2224.23(6)	2.45(2)
1408.07	2815.08(4)	2.35(1)	2815.27(3)	2.68(1)

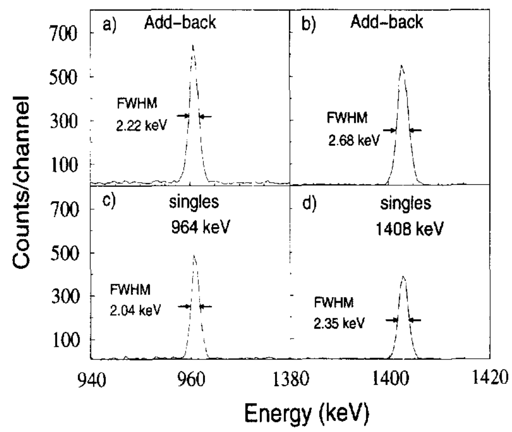

Fig. 3. The 964 and 1408 keV γ-peaks from ^{152}Eu source obtained in (a, b) add-back mode and (c, d) singles (add) mode.

is the result of some of the Compton events in two or more detectors adding up to give a photopeak energy. The improvement in the peak/Compton background in the add-back mode is quite clearly seen in Fig. 5. It is also seen that the maximum addition of Compton events takes place from the low-energy region. Therefore, the reduction in the Compton background is more evident in the low-energy region (< 500 keV).

In the process of addition of n-fold events, it is possible that one of the detectors detects a photopeak and

Table 2
The average photopeak area for a single detector ($A_{\rm sing}^{\rm avg}$), the photopeak areas in the add-back mode ($\sum_{i=1,4}A_i$), and the ratio of photopeak efficiency for clover detector in add-back mode ($\sum_{i=1,4}\varepsilon_i$) and average efficiency ($\varepsilon_{\rm sing}^{\rm avg}$) for a single detector, as a function of energy

Energy (keV)	Photopeak area		$\sum_{i=1,4}\varepsilon_i/\varepsilon_{\rm sing}^{\rm avg}$ [a]
	$A_{\rm sing}^{\rm avg}$	$\sum_{i=1,4}A_i$	
121.8	3277 ± 33	13219 ± 129	4.03 ± 0.06
244.7	828 ± 18	3574 ± 75	4.31 ± 0.13
344.3	1686 ± 22	8093 ± 98	4.80 ± 0.08
443.97	225 ± 10	1122 ± 44	4.98 ± 0.28
411.11	173 ± 10	867 ± 44	5.02 ± 0.39
778.9	517 ± 13	2838 ± 60	5.48 ± 0.18
867.4	215 ± 9	1188 ± 41	5.52 ± 0.30
964.1	498 ± 12	2821 ± 57	5.68 ± 0.17
1085.92	250 ± 9	1439 ± 47	5.76 ± 0.26
1112.10	378 ± 10	2208 ± 50	5.84 ± 0.20
1173.2[b]	5319 ± 38	31745 ± 183	5.97 ± 0.05
1332.5[b]	4912 ± 35	29843 ± 175	6.08 ± 0.06
1408.07	483 ± 11	2984 ± 56	6.16 ± 0.18

[a] Same as ratios of areas in columns 3 and 2.
[b] ^{60}Co data.

the other detects a Compton event. Addition of such an event results in a Compton event in the higher-energy region. However, if both the detectors record photopeaks, the addition gives rise to a sum peak. The sum peaks obtained from the addition of 1173.2 and

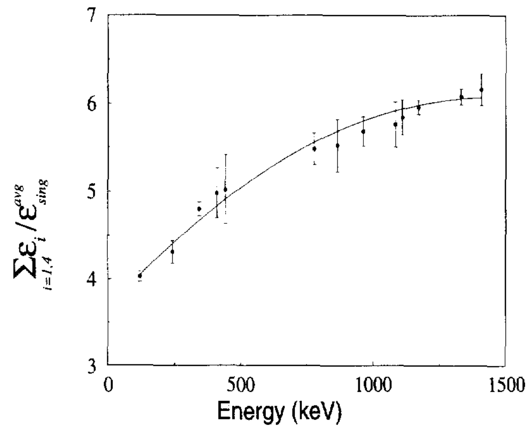

Fig. 4. Ratio of the photopeak efficiency of the clover detector in add-back mode, to the average efficiency of a single detector.

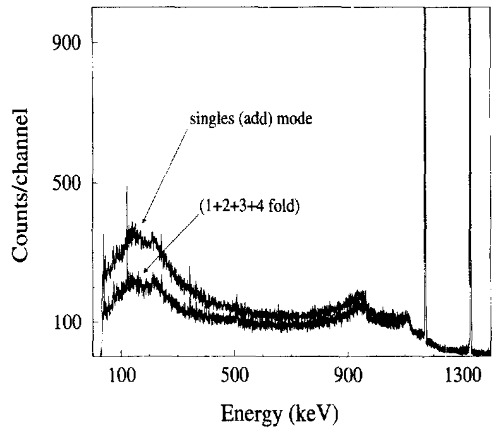

Fig. 5. Comparison of the Compton background in ^{60}Co data, spectrum in add-back mode and in singles (add) mode.

Table 3
Resolution and peak/total fraction for ^{60}Co data

Detector #	Resolution		Peak/total Fraction
	1173.2 keV	1332.5 keV	
1	2.11	2.20	0.100
2	2.07	2.10	0.103
3	1.98	2.11	0.106
4	1.99	2.09	0.102
1-fold	2.11	2.22	0.102
(1 + 2 + 3 + 4)-fold	2.31	2.43	0.176

1332.5 keV γ-rays from ^{60}Co are seen in Fig. 6. The 2346.4 and 2665.0 keV peaks are obtained from random summing of two 1173.2 keV and two 1332.5 keV γ-rays, respectively. The stronger 2505.7 keV peak is obtained from the summing of coincident 1173.2 and 1332.5 keV γ-rays. The relative intensities of the sum peaks are shown in Table 4. It shows nearly 0.7% intensity in sum peaks, compared to singles intensities. The summing effects could, however, be larger for shorter source to detector distances, stronger sources and higher gamma-ray multiplicities.

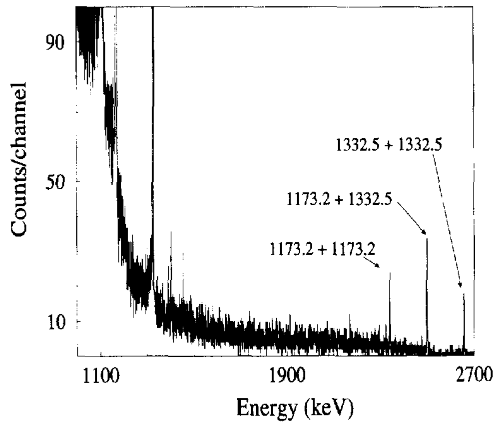

Fig. 6. Summing effect of photopeaks in the add-back mode.

Table 4
Summing effects in clover detector

E_γ (keV)	Area
1173.2	31 685 ± 380
1332.5	29 655 ± 385
2346.4	112 ± 12
2665.0	212 ± 13
2505.7	95 ± 9

5. Conclusions

The test results show that clover detector, when used in the add-back mode gives better peak/Compton ratio, thus increasing the photopeak efficiency, especially at higher energies. The Compton background in the low-energy region is reduced and summing effects of photopeaks are negligible at source to detector distance used in the present studies. Resolutions are slightly poorer compared to a single HPGe detector.

Acknowledgements

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