IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 11, Issue 6 Ser. I (Nov. – Dec. 2019), PP 58-66
www.iosrjournals.org

Test performance of Gamma Spectrometry Co-Axial High Purity Germanium detectors in Universiti Teknologi Malaysia.

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Abstract:*The utilization and prolonged working of two gamma spectrometry (GS1 and GS2) in nuclear laboratories, UTM, causing one to questioning its performance. To achievethe higher quality outcomes of gamma spectrometry system. Itsperformance specifications should verify against the warranted values offered by the manufacturer. High purity germanium (HPGe) detectors is the most distinguished radiation measurement instrument that produced excellent energy resolution. The aims of this studyis to determine the working condition and compare the performances of two gamma spectrometry systems. The GS1 consist of n-type closed end coaxial HPGe detector GC 2018 model and GS2 consist of p-type closed end coaxial HPGe detector of GEM25-76-LB-C model. The test performance specifications such as resolution, peak shapes, peak-to-Compton ratio, figure of merit, and dead time for both spectrometry systems are measured using American ANSI/IEEE 325-1996 standard procedure.Four (4) standard source ^{60}Co, ^{152}Eu, ^{133}Ba, and ^{137}Cs were used. It covered energies range from (4.3 keV-3194.9) keV. The source-to-detector distance is set 25 cm to avoid the summing coincident gamma ray. The relative efficiency measured improve by 0.2% and 4% for GS1 and GS2 respectively. Peak-to-Compton ratio of both detectors improved by factor of 4.Dead time found to be less than 1% at 25 cm compared to 12 cm. From the results, GS1 has higher resolution compared to GS2 detector. Based on the results obtained, it can be concluded that the performance of two coaxial HPGe detectors in nuclear laboratories, (UTM) are in good working condition.Thisrevealed propercontrol and maintenance of the two detectors.*

Keywords*:HPGe detectors; resolution, peak shape, peak-to-Compton ratio, relative efficiency, dead time.*

Date of Submission:13-11-2019 Date of Acceptance:27-11-2019

I. Introduction

Of late, high purity germanium (HPGe) detector marked the most distinguished gold standard for excellent higher resolution. It predominantly become a solution to unresolved complex peak in sodium iodide (NaI) detector [1], [2]. HPGe standout the most champion non-destructive method that used for identification and quantification of unknown radionuclides gamma-ray energy[3]. Undoubtedly, gamma spectrometry is credited technique used to perform measurements of collected radionuclides samples from industries, environmental and nuclear waste management [4]. The quality results of gamma spectrometry mainly dependent on the knowledge of the detector efficiency [5]. Today, the global demand of Hygge detector increases because of it great sensing to tracking all gamma-rays interaction in the detector. Majority of the recent literature focusing on resolution and counting efficiency of the detector[6]–[8]

Most of the factors affecting theresolution and efficiency of the detector are insufficient of charges collection during gamma ray interaction with matter. This would leadthe formation of low energy tail[9]. Present of defects due to generation/recombination state for charge carriers will cause high dislocation in the crystal. This will increase leakage current of the system and reduce sensitivity of the working detector [10]. Likewise, electrical cooling with constant temperature should be monitored, because increase in temperature gradient (e.g. coaxial detector above 130 K), yield energy resolution degradation [11]. Efficiency decreases exponentially when dead layer thickness increases specifically at low energy level [12], [13]. These will cause the failure of the outcome performance of gamma spectrometry system, especially when it is engaging working for a prolonged period of time.

It is believable that ANSI/IEEE-325, 1996 standard test procedure becomes a unique procedure in which both user and manufacturer agreed, especially on what parameters should be measure and how to measure it. Both are specified in the standard, in order to have a valid record of measurement for future reference. The parameter specifications such as resolution, peak-to-Compton ratio and relative efficiency, yield a better indication of good working gamma-ray spectrometry. The main focus of HPGe detector is to covert gamma ray

into electrical pulse which can be used suitable signal processing to achieve a desirable application. Despite the importance of these specifications few work have been published by examining some specific parameters stated in ANSI/IEEE std 325, 1996 [14]–[17].

II. Methodology

A ^{60}Cosealed traceable standard source of 1 μCi activity was used. It is calibrated on1st January, 2007 by IAEA, USA. The current activity was calculated on the basis of ^{60}Co decay rate. GS1 HPGe detector characterized as Canberra product (GC 2018 model) and GS2 detector is anOrtec product (GEM25-25-76-LB-C).The two HPGe detectors, haverelative efficiency 20% and 25%, energy resolution 1.8 keV and 1.85 keV, built-in preamplifier, is operated under high supplied voltage 3.0 kV and 4.0 kV respectively. Before counting, the source was mounted 25 cm axially from end cap of the detector using sample holder, at least thousands of counts were accumulated in the photopeak [18]. Both gamma-ray spectrometry was irradiated accordingly.The shaping time was adjusted to 4 μs and 6 μs for GS2 and GS1 respectively. Data was equipped with a multichannel analyzer 16 K (16384 channel) and analyzed using origin 7.0 software. However, rectangular block and cylindrical container lead was used for shieldedto minimized external background radiation. Background was subtracted to obtain net count area.The dead time will be measure for 12 cm and 25 cm from the end cap of the detector respectively.Furthermore, in order to measure the rate of counting detected by the detector crystal, ^{152}Eu, ^{137}Cs and ^{133}Ba standard source will be use to obtain energy and efficiency calibration curve.

Testing parameters

In this study, there are four (4) main testing parameters to verify which consist energy resolution, peak shape, peak-to-Compton ratio and relative efficiency.Decay rate of ^{60}Co is a negative beta particle (β^{-1}) by emitting gamma ray which led to cascade two energy gammas 1173.2 keV about (99.88%) and 1332.5 keV (99.98%) for β_1 probability emission. Usually gamma radiation is released in excited statede-excited (parent nuclide) and drop to the ground state (daughter) to form nickel (^{60}Ni) as shown Figure 1. ^{60}Co unstable is reached stability when disintegrates to ground state to form of nickel (^{60}Ni) accompanies β^- and $\bar{\nu}$ as shown in Equation 1.

$$^{60}\text{Co} \rightarrow {}^{60}\text{Ni} + {}^{0}_{-1}\beta + \bar{\nu} \quad (2.1)$$

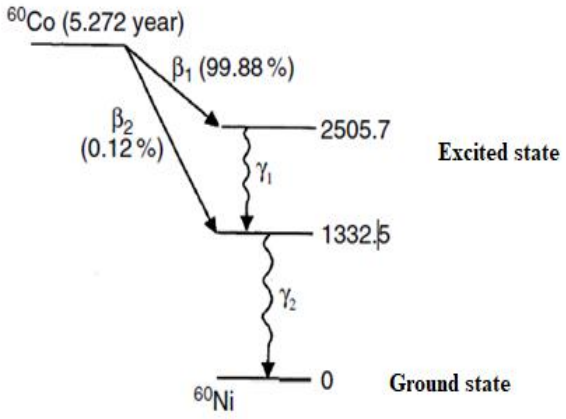


Figure 1A typical ^{60}Co decay scheme [19].

Resolution of an instruments tells us how well two close line energies (wavelength) can be resolved[20]. Figure 2 displayed two peaksenergies at1173.5 keV and 1332.5 keV for ^{60}Co respectively.

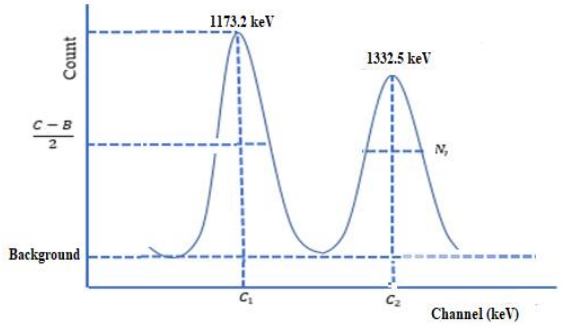


Figure 2A typical spectrum photo peak for ^{60}Co resolution using linear interpolation.

Thus, resolution can be computed manually using interpolation methodin equation2.2

$$\text{FWHM} = \frac{\Delta E}{C_2 - C_1 + 1} \times N_r \ \text{(keV)} \quad (2.2)$$

where $\Delta E = E_2 - E_1$is the difference between E_2 (1332.5 keV) and E_1 (1173.2 keV) known as Conversion factor. C_1 and C_2 are the peak position in terms of channel for 1332.5 keV and 1173.2 keV respectively. Nr be the width of the reference peak in term of channel number. Where, one is the uncertainty channel count. Background count, gross area, count number, channel number was recorded from multichannel analyzer (MCA) at the same live time.

In many common solid detectors, peak shape play an important role by carries information regards to peak shape discrimination system (PSD) [21]. Furthermore, one way to described the worsening of tail for a specific detector is to quote full width at one-tenth maximum (FWTM) and full width fifty maximum (FWFM).FWFM is very close in height to continuum background [9]. The ratio of tenth maxima should be ≤ 1.9 and ratio of fifty ≤ 2.8 respectively.

In this standard the relative efficiency can be express in equation (2.3)

$$\text{Related efficiency} = \frac{\text{Net Area Activity}}{\text{Activity} \times \text{live time} \times (1.2 \times 10^{-3})} \times 100\% \quad (2.3)$$

The value (1.2×10^{-3}) often use in relative efficiency to compare the absolute efficiency of the detector at 1332.5 keV, ^{60}Co to that of a 3 in x 3 in NaI scintillation detector at 25 cm source-detector geometry. In addition, absolute efficiency will be measured base on appropriate dead time correction, net area, emission probability of the source and present activity of the source [22], [23].

Peak-to-Compton ratio is an analogy to signal-to-noise ratio. This can be achieved by accumulated at least ten (10) thousand counts in the photopeak. A loss in peak-to-Compton ratio might displayed unhappy energy resolution on the system [14]. Compton background may increase due to absorbing material in the vicinity either by detector itself, by source, present of ^{40}K from concrete wall. Comptonregion was measured within a range 1040 keV-1096 keV. This can be determine using the equation (2.4)

$$\text{Peak-to-Compton ratio} = \frac{\text{(Highest peak count at 1332.5 keV)}}{\text{(Average counts per channel between 1040 keV to 1096 keV)}} \quad \text{.....(2.4)}$$

Physical measurement such as detector design, geometrical shape, high voltage, operating temperature and pressure are highly contributing to the ballistic effect of dead time[24]. In this work, dead time was measured against resolution for each gamma-ray detector. Mainly, Multichannel analyzer (MCA) system displayed dead time in percentage as in Equation 2.5

$$\text{Dead Time } (\tau) = {}^{(RT - LT)}/_{RT} \times 100\% \quad (2.5)$$

Where, RT = real time and LT = live time of the counting system.

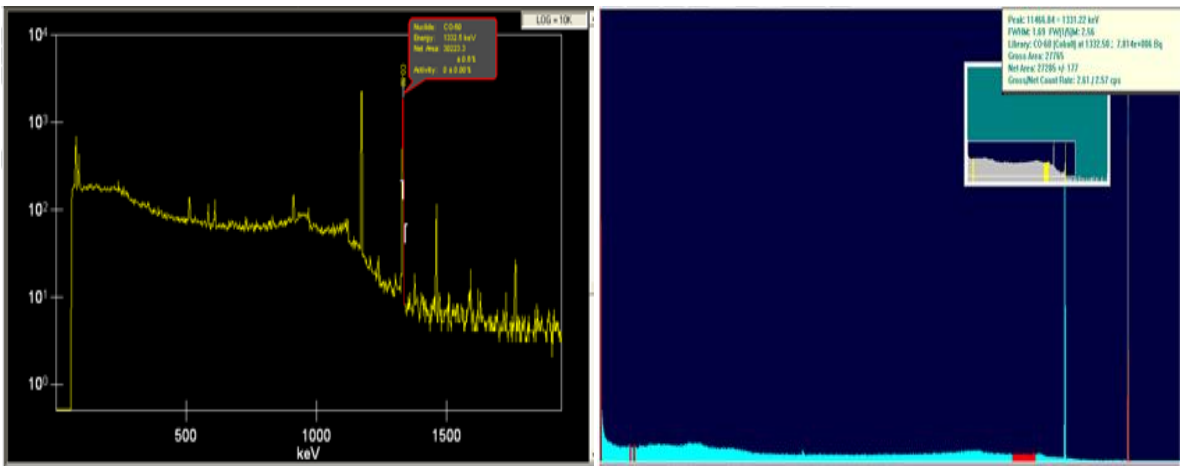
III. Results and Discussion

GS1 was manufactured by Canberra industry and installed since, 2006 in UTM. While GS2 manufactured by Ortec industries and installed 2015. The time was adjusted so that, net peak area uncertainty found below 1%. The sample running at 77 K and was subjected to gamma-ray spectral analysis counted for 18000 seconds real time. In each GS1 and GR2 detectors suitable region of interest (ROI) and logarithm scale was selected utilizing Genie-2000 software version v.3.2 and Gamma Vision automatic software respectively. At least more than twenty thousand (20,000) counts were accumulated in 1332.5 keV. The collected spectrum

for both detector as shown in Figure 3(a) and (b). Afterwards, the values FWHM, FWTM and FWFM were measured. Likewise, the result obtained using linear interpolation method (manually) in GS1 and GS2 are very closed to automatic acquisition softwares, which indicates the good working of the two software. Hence, all the specification results are summarized and presented in Table 1.

Table 1 Summarized Specifications measured using software (M*), linear interpolation method (M**) and compared to warranted(W*) values certified by the manufacturer for each gamma-ray spectrometry.

	GS1			GS2			Acceptable value in practical
Specifications	W*	M*	M**	W*	M*	M**	
FWHM at 1332.5 keV	1.8	1.809	1.89	1.85	1.69	1.85	1.7-2.7 n-type 1.7-2.5 p-type
Peak Shape FWTM/FWHM	1.75	1.83	1.75	1.9	1.88	1.76	≤ 1.9 (value for Gaussian peak, 1.82)
Peak Shape FWFM/FWHM	-	-	2.44	2.6	2.56	2.44	≤ 2.5 (Gaussian, 2.38) for n-type and ≤ 2.8 (Gaussian 2.38) for p-type.
Relative efficiency at 1332.5 keV (%)	20	20.2	-	25	29	-	Not Specified
Peak-to-Compton Ratio	50:1	54:1	-	56:1	60:1	-	>50



(a) (b)

Figure 3A typical spectrum of ^{60}Co point source collected from (a) GS1 using Genie 2000 software and GS2 using Gamma vision producing less than of dead time 1%

From the results, itis indicating that n-type GS1 has high resolution of 1.8 keV as compared to p-type GS2 of 1.69 keV. Even when calculated manually using interpolation method, the resolution found to be 1.89 keV and 1.85 keVrespectively. This is because n-type has a thin window that suit for low energy measurement [24].

Calculation for GS1 using interpolation method.

Half of the total counts (FWHM) $=\frac{C-B}{2}=\frac{1689}{2}$ = 845 counts

$$C_2 - C_1 + 1 = 11231 - 9888 + 1 = 1344 \text{ keV}$$

Left average (Channel) $=\frac{11223+11224}{2}$ = 112223.5 keV

Right average (Channel) = 11239+ 11240/2 = 11239.5 keV

$$N_r = (11239.5 - 11223.5) \text{ keV}$$

$$N_r = 16.0 \text{ keV}$$

From equation (2.1) we have

$$\text{FWHM} = \frac{159\ Kev}{(11231-9888+1)\text{ keV}} \times 16 \text{ keV}$$

FWHM = 1.89 ~ 1.9 keV.

Similarly, for tenth of the total counts (FWTM)$=\frac{C-B}{10}=\frac{1689}{10}$ = 169 counts

Left average (channel) = 11217.5 keV

Right average (Channel) = 11245.5 keV

$$N_r = 28.0 \text{ keV}$$

$$\therefore \text{FWTM} = \frac{159 \text{ keV}}{(11231-9888+1)\text{ keV}} \times 28 \text{ keV} = 3.3125 \text{ keV}$$

FWTM = 3.31 keV

Also, for fifty of the total counts (FWFM)$=\frac{C-B}{50}=\frac{1689}{50}$ = 34 counts

$$N_r = 39.0 \text{ keV}$$

$$\therefore \text{FWFM} = \frac{159 \text{ keV}}{(11231-9888+1)\text{keV}} \times 39 \text{ keV} = 4.613 \text{ keV}.$$

However, peak-to-Compton ratio and counting efficiency is higher in GS2 as compared to GS1.Result, GS2 is well proper shielded rounded with heavy cylindrical lead and set 3 m away from the wall to avoid vicinity background presentas compared to GS1. This also, proves that the smaller the detector will yield higher resolution and low detection counting efficiency. Meanwhile, perfect gaussian peak obtained in GS1 as shown in Figure 4. This revealed that skew factors are found within a limit 1.0 in GS1 and 1.03 and 1.07 for GS2 which tend to be wider onit basepeak. Similarly, for quotient fifty maxima obtained to be 1.0.

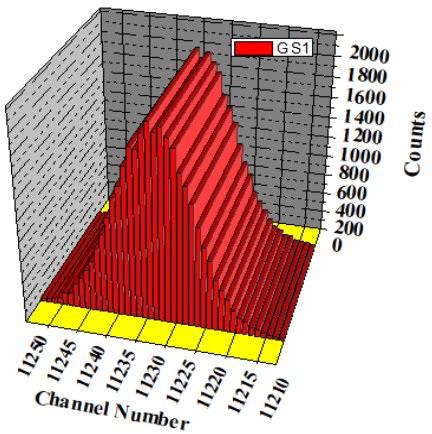


Figure 4A typical perfect gaussian peak for 1332.5 keV for n-type HPGe detector

Figure of Merit (FoM)

Today, choice of gamma -ray detector depend on figure of merit (FoM). This is easy calculated, since the relative efficiency (η_{rel}), peak-to-Compton ratio (p/c)and resolution (Δ) of the two detectors was measured. Thus, Figure of merit can be obtained using Equation 3.1.

$$\text{Figure of Merit (FoM)} = \eta_{rel}\left[\frac{p/c}{\Delta}\right]^{\frac{1}{2}} \quad (3.1)$$

Energy calibration of different gamma-ray energy source are illustrated in Figure 5. Where black colors represent data for GS1 and red indicates data for GS2. GS2 show a linearity of Y = 8.425X + 4.5807 and GS2 with Y = 5.0042X + 3.9524 linearity. The statistical correlation coefficient is found to be 1 for each data measured at GS1 and GS2. This shows a good relationship with the channel count. The linearity indicates their better efficient in detecting gamma rays.

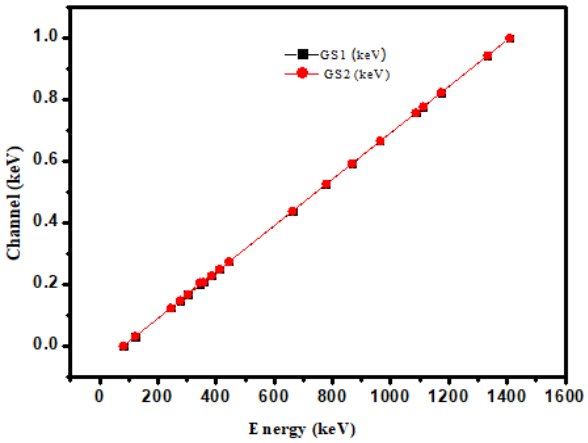


Figure 5 Energy calibration curve for GS1 and GS2

It is clearly described how useful HPGe detector is for separating two adjacent energy peaks can be slightly distinguished. Figure 6 which described how energy resolution varies with different emitted gamma-ray. The result obtained shows a good resolution with linear correlation 0.9996 for GS1 and 0.9959 for GS2 detectors. While the values 0.0008, 0.0007 and 0.7283, 0.8808described the slopes and intercepts for GS1 and GS2.this shows the linearity of this measurement.

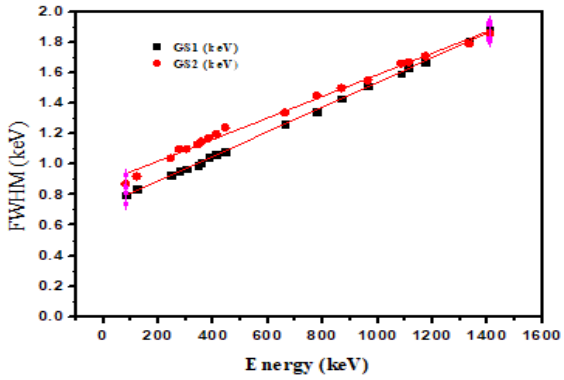


Figure 6 Variation of energy resolution with different gamma-ray energy at 25 cm analyzed by Genie 2000 and Gamma Vision

Usually, efficiency of the detector increases as the source is placed near very closed to the surface of the crystal, but this may cause summing coincident or pileup loss effects. It can be observed from the efficiency curve in Figure 7. The efficiency started increase at 81.0 keV of ^{133}Ba source and eventually decreases at 121.8 keV of ^{152}Eu as a result in increases in gamma-ray energy. This implies that the efficiency is maximum at low energy and decreases exponentially at higher emitted gamma-ray[25].It could be observed that GS2 has higher efficient as compared to GS1.This is becauseGS2 has lesser background in the detector. The corrected dead time was recorded during live time when different energies subjected to two gamma-ray as shown in Table 2.

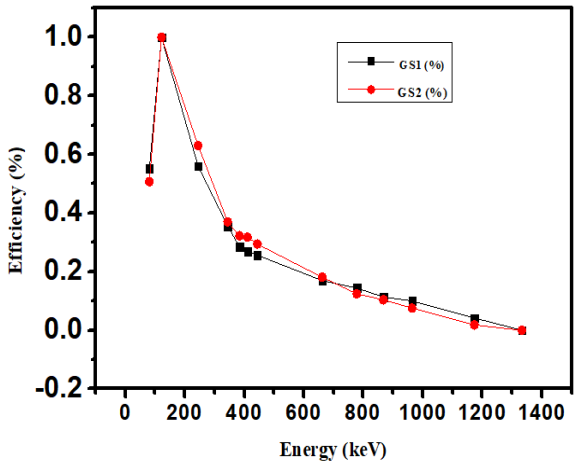


Figure 7 The variation of the absolute efficiency curve with energy for GS1 and GS2 at 25 cm.

The effect of dead time was recorded at 25 cm and 12 cm as indicates in Table 2. The result shows that the effect of time lost was found lessened at 25 cm compared to 12 cm. This because the far the distance of the source from detector the less the summing coincident of emitted gamma ray [26]. The closer the source the higher the efficiency [7].

Table 2. Shows relationship of dead time at 25 cm and 12 cm source detector distance for 1800 second live time.

		n-type detector, GS1		p-type detector, GS2	
Source	Energy (keV)	Dead time at 25 cm (%)	Dead time at 12 cm (%)	Dead time at 25 cm (%)	Dead time at 12 cm (%)
^{152}Eu	121.8	0.8	2.9	1.95	3.91
^{133}Ba	302.8	0.32	1.4	0.9	1.86
^{137}Cs	661.7	0.22	0.71	0.86	1.42
^{60}Co	1332.5	0.15	0.42	0.64	1.71

Figure 8 and Figure 9 show variation of gamma ray energy with dead time at 25 cm and 12 cm for GS1 and GS2. However, the resolution of the two detectors by selecting different gamma ray energy such as ^{60}Co of 1332.5 keV, ^{137}Cs of 661.7 keV, ^{152}Eu of 121.7 keV, and ^{133}Ba of 302.8 keV peaks respectively.

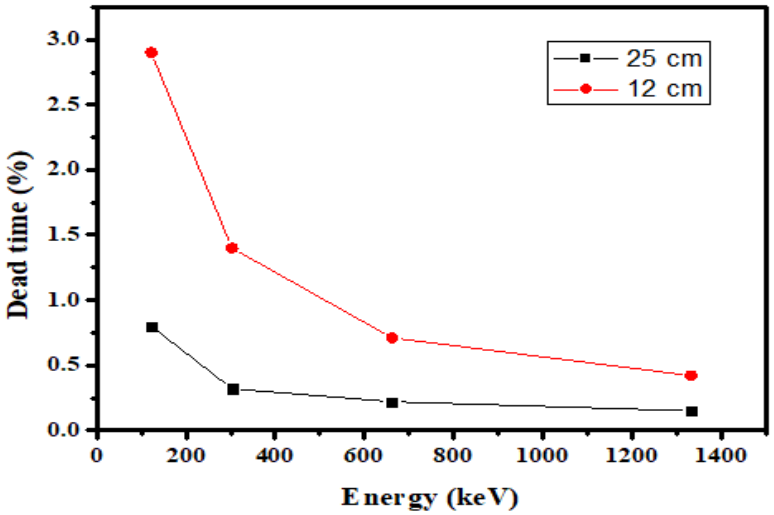


Figure 8Relationship of gamma ray energy with dead time at 25 cm and 12 cm for GS1.

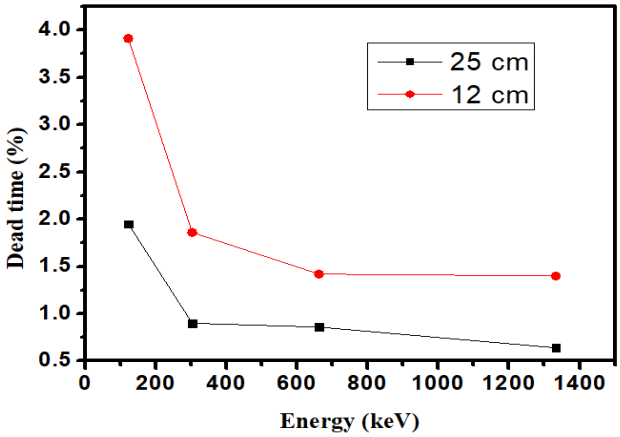


Figure9 Relationship of gamma ray energy with dead time at 25 cm and 12 cm for GS2.

IV. Conclusions

The quality control of two gamma-ray spectrometry was studies. The performance verification in the proficiency tests using ANSI/IEEE 325-1996, was compared and validated. The specifications parameters are fallen in a specified acceptable limit. The result shows that GS1 has 1.8 keV better resolution as compared with GS2 of 1.69 keV. While the result obtained using linear interpolation method show good working of Genie 2000 and gamma vision automatic softwares. There is improvement in relative efficiency about 0.2% for GS1 and 4% for GS2. Likewise, in Peak-to-Compton ratio improvement by 4 for each detector was obtained. Meanwhile, peak-to-Compton ratio and counting efficiency is higher in GS2 as compared to GS1. This indicates that the larger the detector, the less resolution. While, the smaller the detector, the higher resolution and less count efficiency. efficient However, gaussian perfect was obtained for GS1. GS2 has increment of 0.03%. Consequently, due to counting error of the detector. This was adjusted by pole zero amplifier. likewise, dead time was measured for fast signal respond. The test result shows that at 25 cm the dead time is less than 1%. This described the stability dead time of the two-gamma spectrometry. Specifications parameters measured namely Resolution, relative efficiency, peak shape and peak-to-Compton ratio shows a good agreement with the warranted value specified by theirmanufacturer. Based on the result obtained the two gamma-ray spectrometry in nuclear laboratories Universiti Teknologi Malaysia are operating in a good working condition.

Acknowledgement

The authors would like to express their sincere thanks to the technical staff in nuclear laboratories Universiti of Teknologi Malaysia for their cordial assistance in performance this research.

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IOSR Journal of Applied Physics (IOSR-JAP) is UGC approved Journal with Sl. No. 5010, Journal no. 49054.

Abubakar Usman "Test performance of Gamma Spectrometry Co-Axial High Purity Germanium detectors in Universiti Teknologi Malaysia." IOSR Journal of Applied Physics (IOSR-JAP) , vol. 11, no. 6, 2019, pp. 58-66.