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## Determination of Fano Factor and Pre-amplifier Noise from the Measurement of Energy Resolution of a HPGe Detector

(Penentuan Faktor Fano dan Hingar Pra-penguat melalui Pengukuran Resolusi Tenaga Pengesan HPGe)

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### ABSTRACT

A HPGe detector and  $\gamma$ -ray multinuclide standard solution were used to get several data pairs of photon energy  $E$  and detector's energy resolution  $FWHM$ . A series of graph of  $FWHM^2$  versus  $E$  was plotted to determine the detector's Fano factor and pre-amplifier noise, which yielded the mean values of  $0.123 \pm 0.003$  and  $(7.448 \pm 0.011) \times 10^{-1}$  keV, respectively. The Fano factor value agrees within 95% confident interval with the mostly quoted value of 0.13 for semiconductor detectors. The obtained preamplifier noise is in agreement with typical manufacturer's specification.

**Keywords:** Fano factor; FWHM; gamma-ray spectrometry; pre-amplifier noise

### ABSTRAK

Satu pengesan HPGe dan cecair multinuklid piawai sinar- $\gamma$  telah digunakan bagi mendapatkan beberapa pasangan data tenaga foton  $E$  dan resolusi tenaga pengesan  $FWHM$ . Satu siri graf  $FWHM^2$  melawan  $E$  telah diplotkan bagi menentukan nilai faktor Fano dan hingar pra-penguat bagi pengesan, yang memperoleh nilai purata masing-masing  $0.123 \pm 0.003$  dan  $(7.448 \pm 0.011) \times 10^{-1}$  keV. Nilai faktor Fano ini bersetuju (pada sela keyakinan 95%) dengan nilai yang kerap dilaporkan bagi pengesan semikonduktor iaitu 0.13. Nilai hingar pra-penguat yang diperolehi sama dengan spesifikasi pembekal.

**Kata kunci:** Faktor Fano; FWHM; hingar pra-penguat; spektrometer sinar gama

### INTRODUCTION

For a semiconductor detector such as  $\gamma$ -ray spectrometer, the energy resolution  $FWHM$  (denoted by  $R$ ) is important as it measures the detector's ability to distinguish the closely-spaced lines. In a measuring system,  $FWHM$  is actually the overall  $R$ , i.e.

$$R_{\text{overall}} = FWHM. \quad (1)$$

This  $R_{\text{overall}}$  is affected by some factors including  $R_{\text{statistical}}$  (statistical fluctuation in the process of charge collection) and  $R_{\text{noise}}$  (the preamplifier noise in the process of output signal from the detector) (Eichholz & Poston 1979; Mann et al. 1980).  $R_{\text{overall}}$  can be expressed mathematically as the quadrature sum of  $R_{\text{statistical}}$  and  $R_{\text{noise}}$ , i.e.

$$R_{\text{overall}}^2 = R_{\text{statistical}}^2 + R_{\text{noise}}^2. \quad (2)$$

The value of  $R_{\text{statistical}}$  in (2) can be calculated from

$$R_{\text{statistical}}^2 = \left( K \sqrt{\epsilon FE} \right)^2. \quad (3)$$

where  $K$  is the conversion from the standard deviation to the peak width ( $FWHM$ ) for a Gaussian shaped peak (= 2.35);  $\epsilon$  is the mean energy deposited per ion pair formed ( $= 2.9 \times 10^{-3}$  keV/ion pair);  $E$  is the energy (in keV) where

the  $FWHM$  is obtained; and  $F$  is the Fano factor (=0.13) (Alig et al. 1980; Eichholz & Poston 1979; Samat & Evans 1990). Using these three numerical values of  $K$ ,  $\epsilon$  and  $F$  in (3), the  $R_{\text{statistical}}$  as a function of  $E$  (of the  $FWHM$ ) is given by

$$R_{\text{statistical}}^2 = 2.082 \times 10^{-3} E \text{ keV}^2 \quad (4)$$

In the experimental situation, (1) and (3) are more of practical value because they contain the two measurable  $FWHM$  and  $E$  quantities, respectively, in comparison with (2). The latter now can be represented by

$$(FWHM)^2 = (K^2 \epsilon F) E + R_{\text{noise}}^2 \quad (5)$$

Note that the form of (5) is similar to a straight line equation of  $y = mx + c$ ; where  $y = (FWHM)^2 \text{ keV}^2$ ,  $x = E \text{ keV}$ ,  $m$  (gradient) =  $K^2 \epsilon F \text{ keV}$  and  $c$  (intercept) =  $R_{\text{noise}}^2$ . If  $\Delta m$  is the uncertainty in  $m$ , the Fano factor and its uncertainty may be calculated (Priharti et al. 2013; Samat & Evans 1992) from

$$F \pm \Delta F = m / K^2 \epsilon \pm \Delta m / K^2 \epsilon. \quad (6)$$

Consequently, if  $\Delta c$  is the uncertainty in  $c$ , the  $R_{\text{noise}}$  and its uncertainty may be calculated from

$$R_{noise} \pm \Delta R_{noise} = \sqrt{c \pm \Delta c^2/4c}. \quad (7)$$

The purpose of the present work was to determine experimentally this Fano factor  $F$  of a HPGe detector and compared it with the well documented value of 0.13. The pre-amplifier noise  $R_{noise}$  will also be determined.

#### MATERIALS AND METHODS

The experiments were carried-out at the Nuclear Science Laboratory in Universiti Kebangsaan Malaysia, using a Canberra HPGe detector (model GC3018 with a diameter of 59 mm and a length of 50 mm), connected to MCA card (Accuspec B) and Genie-2000 analysis software. The detector's  $FWHM$  and relative efficiency are 1.8 keV (at 1.33 keV  $^{60}\text{Co}$ ) and 30% (at the same energy peak), respectively. A  $\gamma$ -ray multinuclide standard solution (Ecker & Ziegler, California) which emits 13 energies from 11 radionuclides was used. A measurement time of 43200 s (12 h) was chosen. During the experiment however only seven peaks (energies) were detected. They are 46.18 keV ( $^{210}\text{Pb}$ ), 59.46 keV ( $^{241}\text{Am}$ ), 88.29 keV ( $^{109}\text{Cd}$ ), 122.51 keV ( $^{57}\text{Co}$ ), 662.18 keV ( $^{137}\text{Cs}$ ), 1173.35 ( $^{60}\text{Co}$ ) and 1332.50 keV ( $^{60}\text{Co}$ ). Therefore, seven experimental data pairs of  $(x, y) = (E, FWHM^2)$  were obtained from one set of experiment.

In this work, ten sets of  $(x, y)$  data pairs were acquired. It is for the purpose of checking the reproducibility of the system in yielding the results. To get the values of  $m \pm \Delta m$  and  $c \pm \Delta c$  from the straight-line equation, the present work has developed the Excel program based on the least square method (Samat & Evans 1991). This program is also capable of evaluating the goodness-of-fit test by yielding the value of  $\chi^2$  calculated. For this  $\chi^2$  calculation, the program requires the input of the uncertainty in the  $FWHM$ . This was made possible by calculating the standard error of estimate derived from the value of  $\Delta m$  and  $\Delta c$  (Lind 1996).

#### RESULTS AND DISCUSSION

Table 1 shows the ten data sets together with their determined values of Fano factor  $F$ , pre-amplifier noise  $R_{noise}$  and the goodness-of-fit of the straight-line graphs  $\chi_{cal}^2$ . All these values were obtained from the graph of  $(FWHM)^2$  versus  $E$ . As an example, for the first set of data pairs, this is shown by the solid line of Figure 1. This solid line equation was yielded by the Excel program, with  $m$  and  $c$  values (shown in the graph) and  $\chi_{cal}^2$  (only shown in Table 1); whereas broken line equation was obtained from (4). The  $F$  and  $R_{noise}$  values were then calculated from the graph gradient  $m$  (6), from the graph intercept at the  $y$ -axis  $c$  (7) of the solid line, respectively.

The accuracy of the determined values ( $F$  and  $R_{noise}$ ) depends of the goodness-of-fit of the solid line to the experimental data. This is indicated by the  $\chi_{cal}^2$  value in Table 1. It is obvious that the fitting of the line to the data is good, as for the ten data sets, all graphs satisfy the condition set-up by the  $\chi^2$  statistics for 5 d.o.f. Therefore the values of  $m$  and  $c$  that were yielded by the program are accurate.

For all the ten data sets in Table 1, it can be seen that the range values of  $F$  and  $R_{noise}$  are 0.120 to 0.126 and 7.264 to 7.912, respectively. When the mean value was calculated, the  $F$  value ( $0.123 \pm 0.003$ ) is in agreement within 95% confident interval and differs only slightly by 5.01% with the mostly quoted value of 0.13 for semiconductor detectors. Comparison of this value with other previously reported values is given in Table 2. On the other hand, the  $R_{noise}$  ( $7.448 \pm 0.011$ )  $\times 10^{-1}$  keV is in agreement with typical manufacturer's specification.

It can also be seen in Figure 1 that the two lines (solid and broken) are parallel within 95% confidence interval of the experimental error, which concludes that there is a constant  $R_{noise}$  ( $(7.448 \pm 0.011) \times 10^{-1}$  keV). This noise is probably caused by the defect in electronic performance of semiconductor detector such as from the power supply,

TABLE 1. The Fano factor and the pre-amplifier noise for ten sets of data pairs

Set	Fano factor			Pre-amplifier noise ( $\times 10^{-1}$ keV)		$\chi_{cal}^2$ (5)
	$m \pm \Delta m$ ( $\times 10^{-3}$ keV) <sup>(1)</sup>	$F \pm \Delta F$ <sup>(2)</sup>	$\Delta\sigma\%$ <sup>(3)</sup>	$c \pm \Delta c$ <sup>(1)</sup>	$R_{noise} \pm \Delta R_{noise}$ <sup>(4)</sup>	
1	2.014 $\pm$ 0.053	0.126 $\pm$ 0.003	-3.27	5.553 $\pm$ 0.383	7.452 $\pm$ 0.007	5.45
2	1.983 $\pm$ 0.036	0.124 $\pm$ 0.002	-4.75	5.725 $\pm$ 0.262	7.566 $\pm$ 0.003	5.46
3	2.022 $\pm$ 0.051	0.126 $\pm$ 0.003	-2.88	5.997 $\pm$ 0.367	7.744 $\pm$ 0.006	4.72
4	1.981 $\pm$ 0.044	0.124 $\pm$ 0.003	-4.85	5.916 $\pm$ 0.314	7.692 $\pm$ 0.004	4.92
5	1.963 $\pm$ 0.073	0.123 $\pm$ 0.005	-5.71	5.276 $\pm$ 0.529	7.264 $\pm$ 0.013	5.34
6	1.915 $\pm$ 0.051	0.120 $\pm$ 0.003	-8.02	6.260 $\pm$ 0.370	7.912 $\pm$ 0.005	4.38
7	1.941 $\pm$ 0.044	0.121 $\pm$ 0.003	-6.77	5.495 $\pm$ 0.314	7.413 $\pm$ 0.004	4.63
8	1.963 $\pm$ 0.073	0.123 $\pm$ 0.005	-5.71	5.276 $\pm$ 0.524	7.264 $\pm$ 0.013	5.42
9	2.018 $\pm$ 0.131	0.126 $\pm$ 0.005	-3.09	4.672 $\pm$ 0.943	6.835 $\pm$ 0.048	5.00
10	1.976 $\pm$ 0.066	0.123 $\pm$ 0.003	-5.08	5.426 $\pm$ 0.471	7.336 $\pm$ 0.010	4.73
	Mean	0.123 $\pm$ 0.003	-5.01		7.448 $\pm$ 0.011	

<sup>(1)</sup> Obtained from the graph via the Excel program

<sup>(2)</sup> Using (6)

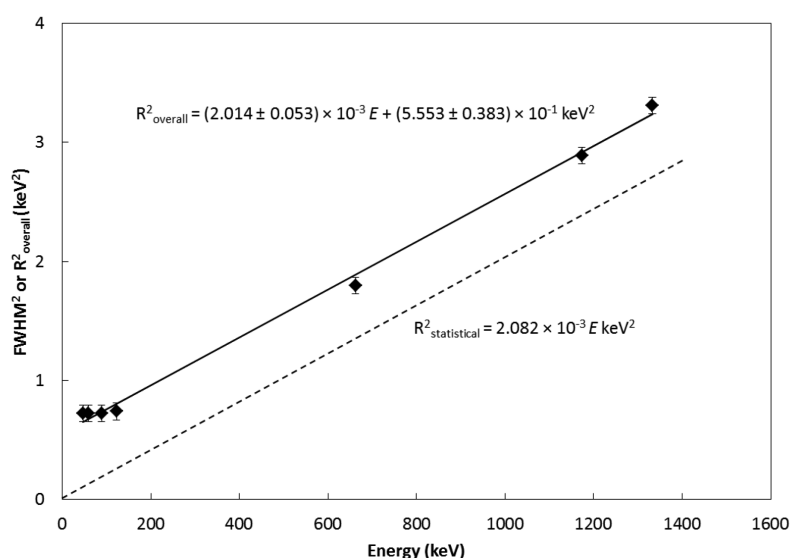
<sup>(3)</sup> By taking 0.13 as the standard value

<sup>(4)</sup> Using (7)

<sup>(5)</sup> For d.o.f. = 5, the  $\chi_{cal}^2$  satisfy the condition of  $\chi_{0.75}^2 \leq \chi_{cal}^2 \leq \chi_{0.25}^2 = 6.63 \leq \chi_{cal}^2 \leq 2.67$

TABLE 2. Fano factors for germanium (Ge) reported by literatures

Fano factor	References
0.060	Strokan (1971); Zullinger & Aitken (1970)
0.059 – 0.083	Papp et al. (2004)
0.080	Pehl & Goulding (1970)
0.112	Croft & Bond (1991)
0.117	Luca et al. (2006)
0.129	Bilger (1967)
0.130	Eichholz & Poston (1979), Alig et al. (1980), Samat & Evans (1990)
0.132	Sher & Pate (1969)
0.123 ± 0.003	Present work

FIGURE 1. FWHM<sup>2</sup> or ( $R^2_{overall}$ ) versus gamma-ray energy  $E$  for a HPGe detector for the first data set

effect of thermal in the detector and direct current in semiconductor crystal. Note that this value is lower than the previously reported value by Samat and Evans (1990) ( $R_{noise} = 1.09 \pm 0.04 \times 10^{-1}$  keV). This progress is perhaps due to the recent technology improvement in the electronic components of a semiconductor detector.

#### CONCLUSION

The Fano factor and pre-amplifier noise for HPGe gamma spectrometer has been experimentally determined and both values are in agreement with the published results.

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