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M.E.Medhat[1], M.A.Ali[1], Z.Awaad[2]

A NEW EXPRESSION FOR THE FULL ENERGY PEAK EFFICIENCY OF A HIGH PURE GERMANIUM DETECTOR

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[1] Experimental Nuclear Physics Department, Nuclear Research Centre, Cairo, Egypt
[2] Physics Department, Faculty of Science, Zagazig University, Zagazig, Egypt

INTRODUCTION

In the field of neutron activation analysis and gamma ray spectroscopy need the accurate knowledge of the efficiency of the detection system for the source-detector geometry. There are two ways for this geometry; the fixed source-detector geometry and the variable source-detector geometry. In the case of fixed Source detector geometry, the efficiency (eff) depends only on the gamma ray energy (E). However, the gamma ray energies produced by neutron activation analysis are in the range of 20-4000 KeV. Since there are not sufficient gamma-ray standard sources to cover this wide range, the most convenient method for the determination of the efficiency within this energy range is by interpolation [1-3]. This method involves choosing standard sources with known emission probabilities and well resolved gamma energy peaks within the energy range. Using these standard sources the full energy peak efficiency of the detection system was experimentally measured. A theoretical curve was then fitted to the experimental data, which the efficiency at any energy within the range can be obtained by calculations. In the case of variable source detector geometry, the full energy peak efficiency of the detection system does not depend only the energy of the gamma ray line but also the distance between the source and the detector. Thus by using the fixed source-detector geometry approach, experimental measurements were made at different source-detector distances. The measured efficiencies are plotted on the same graph and a family of curves is obtained, each curve represents a different distance from the detector surface. Due to inflexibility and difficulties encountered in experimental detector calibration, the interest for computational techniques has increased during the last years. Based on different principles, models and assumptions. In the field of neutron activation analysis and gamma-ray spectroscopy, there are some software packages used to adopt this approach[4,5]. Others adopt a purely theoretical approach for obtaining the full energy peak efficiency by making use of the mechanisms involved in the interaction of electromagnetic radiation with the matter together with the detector characteristics and specifications [3]. Others adopt Monte Carlo to calculate the efficiencies [2,3,6]. Numerous papers can found in the literature [7-12]. This work aims a single analytical functions for the full energy peak efficiency in terms of gamma ray energy and the source-detector distance instead of series of analytical functions for different distances.

PRINCIPLE OF THE CALCULATION METHOD

The full energy peak efficiency (eff) of a high pure germanium (HPGe) detector may be expressed in the form of a polynomial with respect to the gamma-ray energy (E) as [13,14]:

$$\ln(eff) = \sum_{i=0}^{n} k_i (\ln(E))^i \qquad (1)$$

where k_i are the coefficients of the polynomial and are different at source-to-detector distance d. These coefficients k_i, may be obtained for each distance by fitting Eq.1 to the experimental measured efficiency values for that particular distance.
Assuming the coefficients, k_i can be expressed in a polynomial form involving d, then we may write:

$$k_i = \sum_{j=0}^{m} k_{ij} d^j \qquad (2)$$

where k_{ij} are the coefficients of the polynomial. These coefficients k_{ij}, may also obtained by fitting the graphs of k_i versus distances d with Eq 2. Thus by combining Eq 1 and Eq 2, a general equation for the efficiency may be expressed as:

$$\ln(eff)=\sum_{i=0}^{n}\sum_{j=0}^{m}k_{ij}d^{j}(\ln(E))^{i} \qquad (3)$$

Hence from the constants k_{ij}, the full energy peak efficiency may be obtained for a wide range of gamma-ray energies and for a various distances from the source-to-detector. Experimentally, the full energy peak efficiency for a particular sample-to detector geometry is obtained by measuring the net counts under the photopeak energy of interest and using the formula:

$$eff=\frac{N(E)}{A_{std}I_{r}(E)C_{ABS}C_{SEA}} \qquad (4)$$

where N(E) is the net activity (count/second) under the photopeak, A_{std} is the activity of the standard source, $I_r((E)$ is the emission probability per decay for the particular gamma transition, C_{ABS} and C_{SEA} are the respective correction factors for self-absorption and summing effect.

EXPERIMENTAL TEST OF THE APPLICABILITY OF THE METHOD

In this work a high pure germanium detector with relative efficiency 25 % and 1.9 KeV energy resolution for the 1332.5 KeV line of Co^{60} was used. The detector was housed in a lead cylinder of thickness 5cm to reduce the effect of the back ground as low as possible. The other associated electronics consisted of an H.V model ORTEC 660 and an amplifier of type TC-243 TENNELEC. The electronics was configured to observe gamma rays in the range ~30 to 2000 KeV. Pulse computer analyzer (PCAIII) card is used in the measurements. Point standard sources of known activities, supplied by the International Atomic Energy Authority (IAEA), provided the necessary gamma-ray energies for the measurement. The specification of these sources is given in Table 1. The sources were placed at different distances from the surface of the detector such that the vertical axis through the centre of the source and normal to the plane of the source coincided with that of the detector. The sources were counted for 2000 second at distances 5,10,15,20,25,30 cm. By using Eq.4 the full energy peak efficiency values were calculated and are displayed as dots in Fig1.

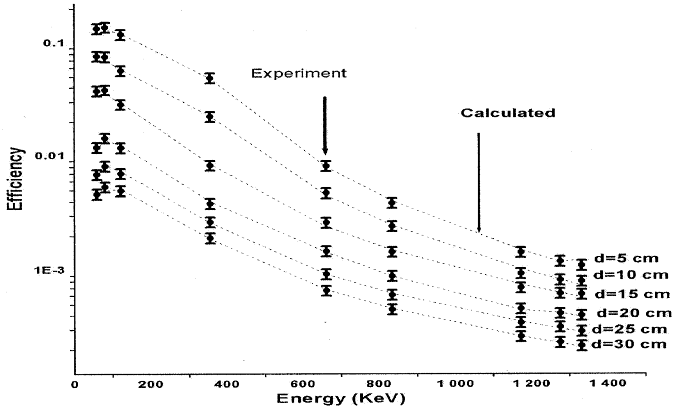

Fig1. Comparison of the experimental and calculated efficiencies of a HPGe detector at different source-detector distances.

Table 1: *Specification of the IAEA standard sources used for the measurements.*

Standard Source	**Energy(KeV)**	**Branching ratio %**	**Half-life**	**Activity μ Ci**	**Date of calibration**
Am^{241}	59.5	35.70	432.21 y	10	5-25-94
Co^{57}	122.1	85.20	270.0 d	2.33	4-26-95
Ba^{133}	356.0 81.0	62.10 33.8	10.7y	0.77	10-3-94
Cs^{137}	661.7	85.21	30.17 y	0.88	1-17-95
Mn^{54}	834.8	99.98	312.12 y	1.53	5-2-95
Co^{60}	1173.2 1332.5	99.90 99.98	5.27 d	0.98	10-4-94
Na^{24}	1275.5	100	2.6y	0.93	10-3-94

RESULTS

Determination of the coefficients, k_l

To obtain the coefficients $K_{i,}$ the experimental measured efficiency for the different d-position was fitted with a theoretical function. Since it was not possible to cover the full energy range of 59.5-1332.2 KeV with a single polynomial, the range was divided into two portions, a lower energy portion with E≤ 356 KeV and a higher energy portion with E>356 KeV. A theoretical fit was then applied to each portion separately. For the lower energy portion a second order polynomial in E could fit the experimental data:

$$eff = \sum_{i=0}^{2} k_i E^i \tag{5}$$

where k_i are the coefficients of the polynomial.

For the higher energy portion a first order polynomial in ln(eff) was used to fit the experimental data:

$$\ln(eff) = k_0 + k_1 \ln(E) \tag{6}$$

The k_i values obtained from the fit for the different d positions are shown in table 2. The solid lines in Fig.1 are the calculated curves to the experimental data for different d values.

Determination of the coefficients k_{ij}

To obtain the coefficients k_{ij}, graphs of the coefficient k_i versus d, for the two separated portions. The results of the fit showed that for the two portions a fourth order polynomial function in terms of d could fit the data; i.e.:

$$k_i = \sum_{j=0}^{4} k_{ij} d^j \tag{7}$$

The values of the coefficients k_{ij} are shown in Table 3

Table 2: *Coefficients of energy polynomial k_i*

Sample to detector distance (d), cm	Coefficients of energy Polynomial k_i				
	E≤ 356 KeV			E>356KeV	
	$K_0\times10^{-2}$	$k_1\times10^{-4}$	$k_2\times10^{-7}$	k_0	k_1
5	15.14	-2.23	-1.82	14.05	-2.90
10	10.27	-4.33	5.81	11.38	-2.58
15	4.98	-1.91	5.81	7.14	-2.02
20	1.24	0.12	-1.03	4.83	-1.76
25	0.68	0.12	-0.67	3.89	-1.67
30	0.41	0.12	-0.60	3.44	-1.65

Table 3: *Coefficients of k_{ij} corresponding to each of the energy coefficient k_l*

Coefficients of energy polynomial k_i	Coefficients of the d Polynomial k_{ij} , E≤ 356 KeV				
	k_{io}	k_{i1}	k_{i2}	k_{i3}	k_{i4}
k_0	0.138	0.013	-0.002×10^{-2}	1.192×10^{-4}	-1.615×10^{-6}
k_1	0.001	-4.952×10^{-4}	-7.93×10^{-8}	2.518×10^{-9}	-2.763×10^{-11}
k_2	-3.363×10^{-6}	9.707×10^{-7}	-7.935×10^{-8}	2.518×10^{-9}	-2.763×10^{-11}

Coefficients of energy Polynomial k_i	Coefficients of the d- Polynomial kij , E> 356				
	k_{io}	k_{i1}	k_{i2}	k_{i3}	k_{i4}
k_0	10.65934	1.73261	-0.26124	0.01092	-1.4691E-4
k_1	-2.36215	-0.26062	0.0376	-0.00158	2.12893E-5

A generalized expression for the efficiency as a function of distance and energy

From the theoretical fit to the experimental data, the following expression were for the efficiency of the detector from the energy of 59.5 ≤E≤1332.2KeV and for a source to detector distance of the range of 5≤ d≤ 30:

$$eff = \sum_{i=0}^{1}\sum_{j=0}^{4} k_{ij} d^j E^i \qquad \text{For E} \leq 356 \text{ KeV} \qquad (8)$$

$$\ln(eff) = \sum_{j=0}^{4} k_{0j} d^j + (\sum_{j=0}^{4} k_{1j} d^j \qquad \text{For E} > 356 \text{ KeV} \qquad (9)$$

Thus by combination Eqs 8 and 9, a general analytical function was obtained for calculating the efficiency as a function of both distance and energy. Table 4 shows the experimental efficiencies and the values obtained using Eqs 8 and 9. It can be seen that the calculated efficiencies agree very well with the experimental values. The calculated efficiencies are shown as dotted lines in Fig 1.

Table 4: *Comparison of the experimental and calculated efficiencies.*

		Detector efficiency (eff × 10^{-2})				
Energy (KeV)	Exp. d=5 cm	Calc.	devation %	Exp. d=10 cm	Calc.	devation %
59.5	13.590	13.756	1,22	7.653	7.902	3.24
81.0	13.790	13.223	-0,04	7.559	7.151	-5.44
122.1	11.920	12.155	0,02	5.687	5.853	2.92
356.0	4.895	4.852	-0,01	2.229	2.249	0.89
661.7	0.818	0.800	-0,02	0.475	0.453	-4.58
834,8	0.390	0.407	0,04	0.244	0.248	1.84
1173.2	0.144	0.151	0,05	0.0991	0.1032	4.17
1275.5	0.1200	0.1189	-0,01	0.0827	0.0831	0.47
1332.5	0.1300	0.1247	-0,04	0.0773	0.0742	-4.05

		Detector efficiency (eff × 10^{-2})				
Energy (KeV)	Exp. d=15 cm	Calc.	devation %	Exp. d=20 cm	Calc.	devation %
59.5	3.754	3.915	4.28	1.188	1.144	-3.72
81.0	3.833	3.567	-6.94	1.438	1.379	-4.08
122.1	2.848	2.955	3.77	1.18	1.244	5.42
356.0	0.828	0.848	2.41	0.385	0.400	4.10
661.7	0..262	0.241	-7.93	0.147	0.144	-1.76
834,8	0.1450	0.1505	3.79	0.0893	0.0892	-0.12
1173.2	0.0735	0.0755	2.74	0.0459	0.0450	-2.06
1275.5	0.0629	0.0637	1.31	0.0418	0.0423	1.08
1332.5	0.0618	0.0583	-5.71	0.0401	0.0391	-2.60

		Detector efficiency (eff × 10^{-2})				
Energy (KeV)	Exp. d=25 cm	Calc.	devation, %	Exp. d=30 cm	Calc.	devation, %
59.5	0.688	0.663	-3.50	0.463	0.485	4.83
81.0	0.814	0.839	3.132	0.536	0.500	-6.69
122.1	0.702	0.733	4.415	0.498	0.512	2.95
356.0	0.265	0.261	-1.24	0.192	0.188	-1.61
661.7	0.0927	0.0926	-0.12	0.0660	0.0678	1.95
834,8	0.0609	0.0627	2.88	0.0453	0.0462	2.02
1173.2	0.0347	0.0355	2.26	0.0262	0.0263	0.49
1275.5	0.0317	0.0308	-2.78	0.0232	0.0229	-1.29
1332.5	0.0290	0.0287	-1.03	0.0216	0.0213	-1.47

CONCLUSION

The result of the measurements showed that the efficiency of HPGe detector might be expressed as a function of both of gamma ray energy of the radioactive sample and the vertical distance from the detector surface. It is clear from Eqs 8 and 9 that the calculated efficiencies agree very well with the experimental values.

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Мидхат М.Э., Али М.А., Аваад З. E6-2001-123
Новое выражение полной энергетической максимальной
эффективности высокочистого германиевого детектора

Представлена эмпирическая формула, которая описывает эффективность полного поглощения в фотопике в зависимости от энергии гамма-излучения E и от расстояния d между детектором и источником (т.е. эффективность есть функция (d,E)). Эта формула была получена для высокочистого германиевого детектора (HPGe), при этом применялись разные стандартные источники. Сравнение рассчитанных величин эффективности и экспериментально измеренных в интервалах энергии от 59,5 до 1332,2 кэВ при расстояниях между детектором и источником от 5 до 30 см показало, что рассчитанные величины согласуются с экспериментальными.

Работа выполнена в Центре ядерных исследований (Каир, Египет) и в Лаборатории ядерных реакций им. Г.Н.Флерова ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2001

Medhat M.E., Ali M.A., Awaad Z. E6-2001-123
A New Expression for the Full Energy Peak Efficiency
of a High Pure Germanium Detector

An empirical expression for the full energy photo-peak efficiency in terms of gamma-ray energy (E) and the vertical distance from the detector surface (d) (i.e. efficiency = function (d,E)) has been obtained for a high pure germanium detector (HPGe) using different standard sources. Comparison of the calculated efficiencies and the experimentally measured values for the energy range from 59.5–1332.2 keV and a source-to-detector distance of 5–30 cm showed that the theoretical values agree with the experiment.

The investigation has been performed at the Nuclear Research Centre (Cairo, Egypt) and at the Flerov Laboratory of Nuclear Reactions, JINR.

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