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Effect of Partial Dependence of Photopeak Data on The Calculations of NaI(Tl) Detector Spectrum

Mahmoud Ahmad Elawi, Hafsa Taha Ahmad

Department of Physics, College of Education for Pure Sciences, Tikrit University, Tikrit, Iraq.

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Corresponding Author:

Name: Hafsa Taha Ahmad

E-mail: ammar_physics@yahoo.com

Tel:

ABSTRACT

Partial dependence of photopeak data of ɣ-ray energies is considering apart of peak channels after subtracting background (including Compton distribution) and obtaining symmetric Gaussian distribution, then considering this part to obtain other total data of peak. This was investigated by using NaI(Tl) detector with Eu-152, Ra-226 and Cs-137 point sources. For the isolated peaks of Eu-152, Gaussian shape is obtained, and the areas between $\pm\sigma$ and $\pm0.5\sigma$ were determined and efficiency is obtained. The calculated transformation to total data of peaks gave excellent agreement with the ordinary case. The overlap between the two peaks at 609.3 (Ra-226) and 661.6 keV (Cs-137) is studied with using σ values from data when sources are separated, and counts in peaks centroids. The data of each peak is "restored" and compared with that when sources are separated and gave a 98% agreement. Also the overlap between the two peaks at 1120 and 1238 keV (Ra-226) is studied with adopting the σ values from the shape calibration curve of Eu-152 and centroid counts in the same way as for the Ra-226 and Cs-137 case. The resultant peaks areas are compared with those obtained from efficiency calibration curve of Eu-152. However results here are of lower agreement.

1- Introduction

Among the three main interaction processes of gamma-rays with matter, namely the photoelectric absorption, Compton scattering and pair production, the photoelectric absorption is regarded as the more reliable method dealt with in analyzing gamma spectra recorded by both scintillation and germanium detectors. The photopeaks registered in the spectra result from total absorption of photon energy and can be represented by a known mathematical function. This allows making qualitative and quantitative analysis of samples with a relatively high accuracy if the photopeaks are isolated and well resolved. But generally the case is not such alike and it is expected to encounter complex spectra that may include peaks overlap for one isotope or different isotopes being in process.

The photopeaks may be superimposed on a Compton distribution and background of the surrounding laboratory materials or environment. Other contributions may include the effects resulting from pair production interaction. The background accompanying can be subtracted and eliminated from the whole spectrum by using the stripping function. The Compton distribution can also be reduced by using the anti-Compton spectrometer. In particular a relatively high reduction of Compton distribution from NaI(Tl) detector spectra may be achieved by stripping the same amount of data registered by the NE-213 organic scintillator[1].

The problem of overlapped peaks were studied in many researches breviously. A method is presented for computer analysis of ɣ-ray spectra from semiconductor detector systems. In which the researchers described a mathematical formalism for the representation of photopeaks and the continua in their vicinity which is applicable to analysis of spectra measured under widely varying conditions [2]. Based on the exponentially modified Gaussian (EMG) function, another approach is presented for the quantitation of a partially overlapped peak pair. This approach can be employed in a wide range of peak area ratio and asymmetry, provided that the relative valley between the two peaks is not greater than 55% [3].

The problem of the appropriate choice of the function that describes a chromatographic peak is examined in combination with the deconvolution of overlapped peaks by means of the non-linear least-squares method. It is shown that the majority of the functions proposed in the literature to describe chromatographic peaks are not suitable for this purpose. Only the polynomial modified Gaussian function can describe almost every peak but it is mathematically incorrect unless it is redefined properly [4]. A research described the results of a comparison of four peak function in describing real chromatographic peaks. They are the empirically transformed Gaussian, polynomial modified Gaussian, generalized exponentially modified Gaussian and hybrid function of Gaussian and truncated exponential function [5]. A nother method was developed to resolve overlapped peaks based on the mass conservation and the exponentially modified Gaussian (EMG) model [6].

A survey revealed that researchers still seem to encounter difficulties to cope with outliers. Detecting outliers by determining an interval spanning over the mean plus/minus three standard deviation remains a common practice. However, since both the mean and the standard deviation are particularly sensitive to outliers, this method is problematic. Researchers highlighted the disadvantages of this method and present the median absolute deviation, an alternative and more robust measure of dispersion that is easy to implement [7]. When processes or phenomena like background, Compton distribution and others in the spectra that affect the photopeak data are highly reduced, the remaining photopeak data is very near to be represented by a Gaussian function. In this work we investigate the case of isolated peaks and how to express the data by only the σ (standard deviation) and centroid counts only. And on the other hand how to make use of only the above tw o parameters in "restoring" the whole data of two overlapped peaks.

Theory2-

Due to the statistical nature of radioactive transmutation and the processes taking place in the detector, the spectral line corresponding to the total energy peak widens. The envelope curve of the peak can be approximated by a Gaussian curve[8]:

$$\mathbf{n}_{n} = \mathbf{n}_{o} \exp\left[\frac{-(n-n_o)^2}{2\sigma_{di}^2}\right] \text{……….(1)}$$

here $\mathbf{n}_n$ is the pulse count in the n-th channel ; n_o the channel corresponding to curve peak ; $\mathbf{n}_o$ the pulse count measured in the channel of the peak , i.e the maximum count ; σ is the standard deviation.

The peak area is[8]:

$\mathbf{n}_{\Sigma} = 1.064\ \mathbf{n}_o \Gamma$…… (2)

Γ is the full width at half-maximum FWHM and is equal to Γ = 2.354 σ. For the simple case when the total peak does not overlap other peaks in the ɣ-spectrum of the activated sample and the background below the peak can be regarded as linear, quantitative determination can be carried out simply by comparing the maximum $\mathbf{n}_o$ count or the $\mathbf{n}_{\Sigma}$ areas of the corresponding total energy peaks of the sample and the standard. The peak area method is suitable for manual calculation with a limited accuracy. Fig (1) shows atotal energy peak over a background that can be regarded as linear. If we consider the number of channels on both sides of peak maximum as p, the $\mathbf{n}_{\Sigma}$ peak area or the detected pulse number will be:

$$n_{\Sigma} = \sum_{i=n_o-p}^{n_o+p} \mathbf{n}_i - \frac{\mathbf{n}_{no-p} + \mathbf{n}_{no+p}}{2}(2p+1) \text{…….(3)}$$

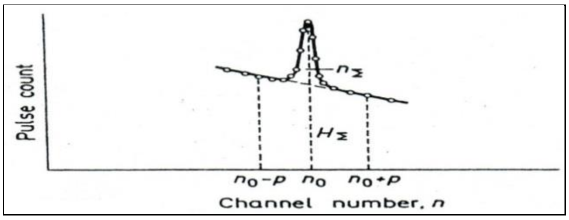

Fig (1) Determination of peak shape and linear background

3- Expermental

A 3"x3" NaI(Tl) detector is used in the measurements, with 3 point sources , namely Eu-152, Ra-226, and Cs-137.Spectra are collected using an integrated DSA system[9]. As shown in Fig (2) Coupled to PC. And data were analyzed using experimental setup Genie-2000 program [10,11]:

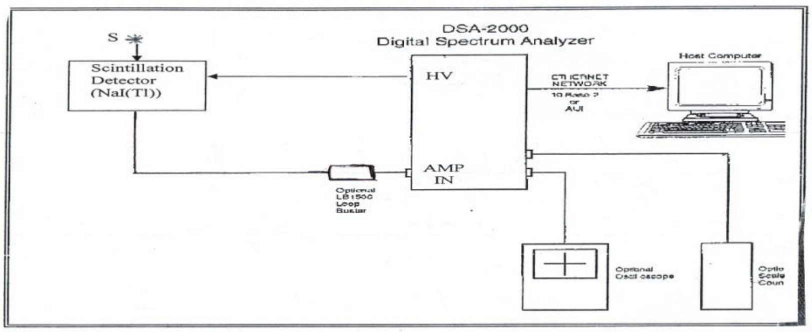

Fig (2) NaI(Tl) detector system

4- Results and Discussion

4-1- Measurements using Eu-152 source

A Eu-152 point source with activity 1.2 µCi is used in making a series of measurements for this part. Firstly the spectrum was accumulated for a sufficiently long time to insure obtaining good data. Results of running the Genie-2000 program revealed the photopeaks data that were then used in obtaining the full energy peak efficiency FEPE for the well resolved selected energies, this will be referred to as (A). Secondly the background was measured for the same time period and then subtracted from the first source spectrum using the stripping function , the resultant spectrum was used to evaluate FEPE, this will be referred to as (B). The third step was trying to "restore" the original data of each photopeak by determining the background (including Compton distribution) under it, which is proposed as linear for simplicity. The background here is higher at the left side than the right side of each photopeak. Subtracting background from the source spectrum peak data channel by channel reveals obtaining the Gaussian peak shape that was also tested by using a mathlab program to insure good fit. The last case is referred to as (C).
Results of FEPE calculations for the three cases A,B and C are presented in table (1) in (A) and (B) the results are nearly the same because the stripped background contributes little to the net data , and the main contribution comes from Compton distribution , and thus the results in (C) are somewhat different. However, better data may be obtained when using another function for both Compton and background other than the straight line. Moreover, if the Compton distribution could be subtracted separately as mentioned in the introduction above, the resultant data would be more satisfactory.

Table (1): Results of FEPE calculations for the cases A,B and C.

		FEPE		
Energy (keV)	Peak center (ch.)	A	B	C
121.7	62	$4.55\text{x}10^{-4}$	$4.55\text{x}10^{-4}$	$4.59\text{x}10^{-4}$
244.6	119	$4.04\text{x}10^{-4}$	$4.04\text{x}10^{-4}$	$3.98\text{x}10^{-4}$
344.2	168	$3.48\text{x}10^{-4}$	$3.48\text{x}10^{-4}$	$3.49\text{x}10^{-4}$
778.8	367	$1.49\text{x}10^{-4}$	$1.49\text{x}10^{-4}$	$1.47\text{x}10^{-4}$
964	452	$1.09\text{x}10^{-4}$	$1.09\text{x}10^{-4}$	$1.11\text{x}10^{-4}$

For each peak data that are obtained in A-C above, the Gaussian peaks data were then taken partially for the ranges ±σ and ±0.5σ where σ is the standard deviation. The area fraction for the range ±σ of the Gaussian distribution is 0.683 of the total area and 0.38 for the range ±0.5σ. However, the results of fractional percentage area their corresponding FEPE for the ±σ and ±0.5σ two ranges are presented in Tables (2) and (3). Where (NPA) net peak area (count/sec) and total area (Gross) (count/sec).

Table (2) data of NPA of Eu-152 photopeaks and NPA for ±σ and FEPE.

Energy (keV)	NPA count/sec	NPA(±σ) count/sec	±σ(%) area fraction count/sec	Efficiency (%)
121.7	1042234	670526	0.64	$2.95\text{x}10^{-4}$
244.6	239213	156394	0.65	$2.32\text{x}10^{-4}$
344.2	743296	524819	0.70	$2.47\text{x}10^{-4}$
778.8	152514	109518	0.71	$1.05\text{x}10^{-4}$
964	128835	90152	0.69	$0.77\text{x}10^{-4}$

Table (3) data of NPA of Eu-152 photopeaks and NPA for ±0.5σ and FEPE.

Energy (keV)	NPA count/sec	NPA (±0.5σ) count/sec	σ(%)0.5± area fraction count/sec	Efficiency (%)
121.7	1042234	436541	0.41	$1.88\text{x}10^{-4}$
244.6	239213	95928	0.40	$1.69\text{x}10^{-4}$
344.2	743296	314346	0.42	$1.39\text{x}10^{-4}$
778.8	152514	64659	0.42	$0.60\text{x}10^{-4}$
964	128835	50185	0.38	$0.44\text{x}10^{-4}$

The fractions differ slightly from their standard values in the distribution. Reasons may be attributed in part to approximating the counts in the boundary of channels. However precise accurate results may be obtained through using international channel shape programs and as referred in Ref [12]. The results of FEPE for the last two cases are of course lower than those obtained by using the whole peak data. Figs (3) and (4) show the efficiency curves for both.

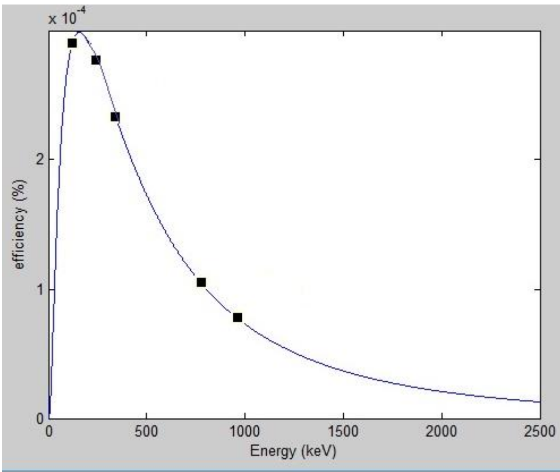

Fig (3) Eu-152 efficiency curve for the case ±σ

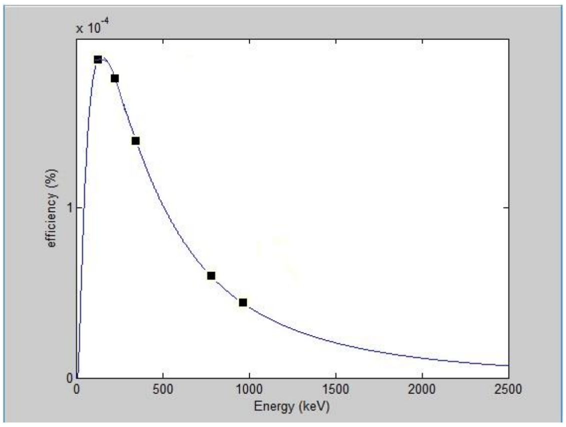

Fig (4) Eu-152 efficiency curve for the case (±0.5σ).

To obtain the whole peak FEPE is obtained by dividing the results by 0.683 and 0.38 respectively. Further more, these results may lead to obtain the whole peak data by knowing even if at least one channel as the centroid channel.

Study of the overlapping of the two photopeak at 609.3 and 661.6keV:4-2-

The cases investigated thus far for the Eu-152 source included well isolated and resolved photopeaks, these show that obtaining the data of a fraction of the Gaussian peak or even the centroid channel can reveal the whole area of the peak, but spectra in general may involve cases of complication that may include the overlap of two adjacent photopeaks that need to be treated. The two main parameters of the Gaussian peak necessary to obtain in formation like NPA for example , are the count in centroid channel $\mathbf{n_o}$ and σ or subsequently FWHM. We investigated the cases for the two overlapped photopeaks of 609.3 keV (Ra-226 source) and 661.6 keV (Cs-137 source), Fig (5) shows this part of the spectrum:

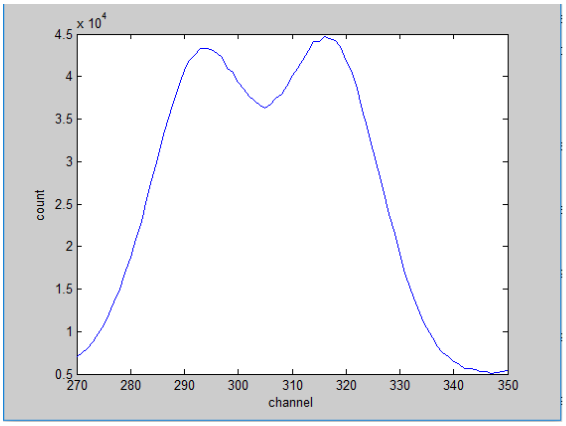

Fig (5) Part of spectrum of two energies 609 and 661 keV of Ra-226 and Cs-137 sources brought together.

Measurements at 5,10,15,20 and 25 cm from the detector face were carried out when the sources were separated or kept together and results are presented in Table (4).

Table (4) data of peaks at 609.3 and 661.6 keV when sources are brought together or seprated

Distance (cm)	NPA(Ra609keV) count/sec	NPA (Cs661keV) count/sec	NPA (Ra,Cs) count/sec
5	825014	914303	1680579
10	392362	421303	803637
15	226398	240638	466767
20	145064	153994	299792
25	100370	105198	205609

This aimed at testing the ratio of counting in each peak and to insure this keeps nearly constant. However, if the cases include two overlapped peaks of the same emitting isotope, their relative intensity I_γ keeps constant at different distances.

-Peaks overlapping at d = 5cm:4-2-1

The spectra of each of the two sources Cs-137 and Ra-226 were registered separately for equal times and data were tabulated in Table (5).

Table (5) data of peaks at 609.3 and 661.6 keV at d = 5 cm.

Energy (keV)	Total (Gross) Area count/sec	NPA count/sec
609.3	1108526	825014
661.6	943095	914303

Then the background (including Compton) were subtracted to obtain the Gaussian function. The obtained data are presented in Table (6).

Table (6) data of peaks at 609.3 and 661.6 keV after subtracting B.G and obtaining Gaussian shape.

Energy (keV)	NPA count/sec	FWHM (Ch.)	σ (Ch.)
609.3	834906	20.5	8.7
661.6	889748	22	9.3

To study the overlap between of the two peaks it is needed to know the values of σ and $\mathbf{n_o}$ for each of them. The values of σ may be obtained through a general shape (FWHM) versus energy calibration using a standard source. Here we made use of the σ values presented in Table (6). The values of n_o for each peak may be obtained through knowing the net count in centroid channel after determining the background. The background (including Compton) can be reduced and subtracted through using the Compton suppression techniques, and particularly very greatly reduced through using a proposed method of suppression via stripping the same spectrum registered by NE-213 detector [3]. However, here we adopted the net $\mathbf{n_o}$ count in both centroids after subtracting the background as represented by a straight line. Table (7) presents the data of the two "restored" peaks shapes.

Table (7) data of peaks at 609.3 and 661.6 keV after restoring the data using Gaussian function.

Energy (keV)	NPA count/sec	FWHM (Ch.)	(Ch.)σ
609.3	803280	20	8.4
661.6	902696	22	9.3

A comparison of the NPA for the isolated peaks in Table (6) and those "restored" after overlap Table (7) presents a relatively high degree of agreement. Same agreement is observed for the values of total NPA for the two isolated peaks, and the corresponding value after restoring. However, the inspection of the shape of the overlapped two peaks may show some questioning about a probable influence of the count rate of $\mathbf{n_o}$ values on each other. With taking this into account, we tried to repeat the calculations depending not only on the values of $\mathbf{n_o}$ but on the net count values of a selected channel on the left (leading) of the 609.3 keV peak and on right of the 661.6 keV peak, where the two values are far from being overlapped or interfered. The channel 257 (of 609.3 peak) and channel 330 (of 661.6 peak) are selected and by using eq (1) the data of each peak were restored. The last case revealed that $\mathbf{n_o}$ = 43473 counts where as the corresponding value obtained for the overlapping case and $\mathbf{n_o}$ = 43331 counts for the 609.3 keV. For the 661.6 keV the corresponding obtained values were $\mathbf{n_o}$ = 43013 and $\mathbf{n_o}$ = 44728; where excellent agreement is observed.

4-2-1- Peaks overlapping at d = 25 cm:

The procedure discussed in section -a for d = 5 cm is repeated for d=25cm. The obtained data are presented in the following tables (8,9,10) that correspond to the previous (5,6,7) tables for the d = 5 cm case.

Table (8) data of peaks at 609.3 and 661.6 keV at d = 25 cm.

Energy (keV)	Total (Gross) area count/sec	NPA count/sec
609.3	130262	100370
661.6	109317	105198

Table (9) data of peaks at 609.3 and 661.6 keV after subtracting B.G and obtaining Gaussian shape.

Energy (keV)	NPA count/sec	FWHM (Ch.)	(Ch.)σ
609.3	102194	21	8.9
661.6	106940	21.5	9.13

Table (10) data of peaks at 609.3 and 661.6 keV after the restoring data using Gaussian function.

Energy (keV)	NPA count/sec	FWHM (Ch.)	(Ch.)σ
609.3	111010	20.5	8.7
661.6	109006	21.5	9.13

The comparisons between the different cases of the two peaks when isolated and their "restored" data after being overlapped, give also very good agreements as obtained in the case for d = 5 cm.

4-3- Study of the overlapping between the photopeaks at 1120 and 1238 keV of Ra-226 source:

It is an interesting matter to complete and support the calculations presented in the previous section of the two energies at 609.3 and 661.6 keV by studying the overlap of the two peaks for the two adjacent energies emitted by the same source. The energies 1120 and 1238 keV emitted by Ra-226 source are shown to be at channels 519 and 571 respectively as registeard in the data. The analyzing programs give their data as separated. However, we try here to in- vestigate their overlapping and obtain the data requested and compare between the cases as for the Ra-226 and Cs-137 case. The background is determined for both peaks and subtracted to obtain $\mathbf{n_o}$ values. The σ values are obtained from the shape vs energy (FWHM calibration) curve obtained by using Eu-152 source. Using eq (1) we "restored" the data of the two photopeaks and checked these by using matlab program. The NPA under the 1120 keV peak was 219434 and the NPA after restoring data with using eq (1) was 195398 besides the NPA obtained by using the Eu-152 efficiency curve was 175688. The agreement is very good taking into consideration the problem of background subtraction. For the 1238 keV peak, the NPA was 61952 and NPA after restoring data using eq (1) was 58245 besides the NPA obtained with the aid of Eu-152 efficiency calibration curve was 143213. The main two parameters need to "restore" peak data are the standard deviation and net count in centroid. For Ra-226 and Cs-137 sources together these gave excellent results as because we used σ values for the same sources when separated. For the overlap between 1120 and 1238 keV the σ values were used from Eu-152 calibration source, this gave lower agreement. However both results need to be confirmed by using high resolution Ge-detector.

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تأثير الاعتماد الجزئي لبيانات القمة الضوئية على حسابات طيف الكاشف NaI(Tl)

محمود أحمد عليوي ، حفصة طه أحمد

قسم الفيزياء ، كلية التربية للعلوم الصرفة ، جامعة تكريت ، تكريت ،العراق

الملخص

الاعتماد الجزئي لبيانات القمة الضوئية لطاقات أشعة كاما هو اعتبار جزء من قنوات القمة بعد طرح الخلفية الاشعاعية (بضمنها توزيع كومبتن) والحصول على توزيع كاوس المتناظر، ثم اعتماد هذا الجزء للحصول على البيانات الكلية الأخرى للقمة. درس هذا باستخدام الكاشف NaI(Tl) ومصادر Eu-152 و Ra-226 و Cs-137 النقطية. ولحالة القمم المعزولة للمصدر Eu-152 تم الحصول على الشكل الكاوسي وحددت المساحات ما بين $\pm\sigma$ و $\pm 0.5\sigma$ ومن ثم كفاءة الكاشف. ان التحويل للبيانات الكلية للقمة قد اعطى توافقا ممتازا مع الحالة الاعتيادية للطيف. درس التلاحم ما بين القمتين للطاقتين 609.3 keV (لمصدر Ra-226) و 661.6 keV (لمصدر Cs-137) باستعمال قيم σ من البيانات لحالة المصدرين وهما منفصلان، ومقدار صافي العد بمركزي القمتين. ان بيانات كل قمة قد "استرجعت" وقورنت مع تلك لحالة المصدرين وهما مفصولان واعطت توفقا بدرجة 98%. ودرس أيضا التلاحم ما بين القمتين عند الطاقتين 1120 keV و 1238keV للمصدر Ra-226، بتبني قيم σ من منحنى معايرة شكل القمة للمصدر Eu-152 والعد في مركزي القمتين بطريقة مشابهة لحالة المصدرين Ra-226 و Cs-137. ان المساحات الناتجة للقمم قورنت قيمها مع تلك المستحصلة من منحنى الكفاءة للمصدر Eu-152، وكانت النتائج هنا بدرجة توافق اقل.