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Use of the Ne-213 Organic Scintillator for the Reducti on of Compton Distribution from Gamma-Ray Spectra

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ABSTRACT

A method of reducing the Compton distribution from gamma-ray spectra recorded by NaI(Tl) detector using the NE-213 organic scintillator is presented. The similarity of the Compton distributions between both detectors may allow subtracting the NE-213 spectrum from the NaI(Tl) spectrum after making certain calibrations in energy, resolution and count rate at the Compton peak. The method is applied by using the ^{137}Cs and ^{60}Co gamma-ray standard sources. The "photopeak" spectra obtained showed that the Compton distribution may be highly reduced and the photopeaks are very well isolated.

1- Introduction

Gamma- rays interact with mater mainly by three interaction processes: photoelectric effect, Compton scattering and pair production. Most of the gamma-ray measurements depend on the photoelectric interaction. The appearance of Compton distribution, single and double escape peaks acts to complicate the spectra and may affect the qualitative and quantitative analysis of the full energy peaks. To simplify the spectra, the anti- Compton and pair spectrometers were suggested [1-3].The anti- Compton spectrometer generally consists of a central main detector (Ge or NaI(Tl)) surrounded by an efficient guard crystal (usually NaI(Tl) coupled to the related electronics. The role of the guard crystal is to regist the scattered gamma-rays from the central detector after the Compton scattering process. The spectrometer is electronically adjusted in a way that only full energy peaks are allowed to accumulate in the memory of the MCA. However, and in the actual operation of the spectrometer there still exists a fairly large remaining fraction of unsuppressed Compton distribution, besides the spectrometer is some that electronically complicated. [2].

On the other hand, one may seek an alternative method suitable for performing the suppression in a rather simple way. In this paper we suggest another method for the reduction of Compton distribution from gamma-ray spectra recorded by NaI(Tl) detectors. The method is based on the use of the liquid organic scintillator NE-213 to regist the Compton distribution using the gamma source and subtracting this from the whole spectrum recorded by the NaI(Tl) detector for the same source. Of course this is to be accomplished after making a series of calibration processes, keeping in mind that the NE-213 detector responds to both gamma-rays and fast neutrons. [4].

2- Theory

In the Compton scattering process, the incident gamma-ray photon with energy Eγ scatters from one of the outer or fairly free electrons of material. A part of the photon energy may be transferred to the electron and the photon is scattered with energy [4]:

$$E\gamma' = \frac{E\gamma}{1+(1-\cos\Theta)\,(E\gamma / m0\,c^2)} \quad \ldots (1)$$

Where Θ is the photon scattering angle with respect to the direction of its initial incidence. The recoil electron kinetic energy T is given by the difference between energy of the incident. and scattered photons as:[4].

$$T = \frac{(1-\cos\Theta)\,(E\gamma / m0\,c^2)}{1+(1-\cos\Theta)\,(E\gamma / m0\,c^2)}\, E\gamma \ldots\ldots\ldots (2)$$

The minimum energy of scattered photon occurs when $\Theta = \pi$ and corresponds to the maximum energy of recoil electron.

$$E\gamma'_{min} = \frac{E\gamma}{1+(2E\gamma / m_0 c^2)} \quad \ldots\ldots (3)$$

$$T_{max} = \frac{2E\gamma / m_0 c^2}{1+(2E\gamma / m_0 c^2)} E\gamma \quad \ldots\ldots (4)$$

While the maximum energy of scattered photon occurs when $\Theta = 0°$ and corresponds to the minimum electron recoil energy:

$E\gamma'_{max} = E\gamma$ ….. (5)

T min = 0 ……(6)

The maximum energy of recoil electron given by eq. (4) is called Compton edge energy and the distribution of recoil electron energies below this reaching zero is called Compton distribution.

The gamma-ray spectra recorded by Nal(Tl) detectors include full energy peaks and Compton distribution besides single and double escape peaks for incident photons with energies greater than the pair production threshold.

The NE-213 detector is a category of organic scintillators that responds to both fast neutrons and gamma-rays. Primarily the detector is used as a fast neutron detector. Even less efficient than Nal(Tl) detector it can also be used as a gamma-ray detector. The gamma-ray detection occurs mainly through the Compton scattering process. The probability of occurring of photoelectric effect is very little by this detector and is restricted to the low energy region. And the pair production process can be neglected for the energy range $E\gamma \leq 3MeV$ [5].

3- Experimental

In the present work two standard scintillation detectors are used, the 3"x3" Nal(Tl) inorganic scintillator (HARSHAW) and the 2"x2" NE-213 liquid organic scintillator (NUCLEAR ENTERPRISES). Each detector is connected to the data acquisition system for recording the gamma-ray spectra (Canberra DSA). The standard gamma-ray sources ^{137}Cs, ^{60}Co, and ^{22}Na are used in the measurements with their data given in Table (1).

Table 1: Data of the γ –sources used

Sources	T1/2 (γ)	Eγ (keV)	I γ	Activity (μ Ci)
^{137}Cs	30.14	661.64	84.6	0.714
^{60}Co	5.27	1173.23 1332.50	99.87 99.98	0.340
^{22}Na	2.60	511 1274.54	------- 99.94	0.0119

3-1 Determination of the Compton edge:

The Compton edge can be used for energy calibration and for the determination of detector linearity. The Compton edge is given by the relation [4].

$$Ec = \frac{2E^2\gamma}{0.511 + 2E\gamma} \quad \ldots\ldots (7)$$

where Eγ, is the photopeak energy and Ec is the Compton edge energy and all are in MeV units. Czirr et.al. [6] and Fowler et.al. [7] had determined the location of the Compton edge Ec as the point located at half height of the Compton peak E c.p in distribution. That is Ec is higher in energy than Ec.p. Other researchers had another determination, Flynn et.al. [8] and Knox and Miller [9] had referred that the point at half height of Compton peak is higher than the Compton edge by the factors 1.04 ± 0.01 and 1.117± 0.034 respectively. Accordingly, the Compton peak as determined by Knox and Miller is located below the Compton edge by 4.9 ± 1.7 percent. This latter determination is followed in the present study. The location of Ec.p is taken in the present study for calibration instead of half peak height where the location can be determined more accurately [10]. The location of Ec.p is taken to be equal to 0.95 percent from the location of Compton edge. Table (2) gives the gamma-ray energies of sources used in energy calibration and their Ec and Ec.p corresponding values.

Table 2: Energies of γ-rays Eγ, Compton edge Ec, and Compton peak Ec. p for the γ-sources used

Sources	Eγ(keV)	Ec (keV)	Ec.p(keV)
^{137}Cs	661.64	477.15	458.29
^{60}Co	1173.23 1332.50	963.42 1118.10	915.25 1062.20
^{22}Na	511 1274.54	340.67 1061.70	323.63 1008.62

3-2 Determination of the relationship between gamma-ray energy and channel number:

The gamma-ray sources ^{137}Cs, ^{60}Co and ^{22}Na are used to determine the relationship between photopeak energy and channel number of the MCA for the Nal(Tl) detector. The relation is linear except at low energy values, as shown in Fig. (1). For the same spectra another relation is plotted between Ec.p and channel number for the values given in Table (2). This relation is shown in Fig. (2) and has the same linearity behavior as for photopeaks. This determination of linearity is based upon what is available of gamma-ray sources. More accurate determination may be obtained with the availability of low energy gamma sources. For the determination of the relation of gamma-ray energy and channel number for the spectra recorded by NE-213 detector, the Ec.p energies, listed in Table (2) are used. The relation is plotted in Fig. (3) which also shows linearity except at low energy values.

3-3 Relationship between energy resolution and gamma-ray energy:

3-3-1 NaI(Tl) detector: The energy resolution of Nal(Tl) detectors is defined as[4]:

Energy Resolution = $(\Delta E / E) \times 100$ … (8)

Where ΔE is the FWHM of the photopeak with energy E.

Resolution is given as a percent number and for Nal(Tl) detectors defined at the 661 keV energy line emitted by ^{137}Cs source.

The more useful determination of the relationship between energy resolution and gamma-ray energy is that which can be compared with corresponding energy values using the NE-213 detector. The Gennie- 2000 analysis program [11,12] gives also a rough estimation of the FWHM of the Ec.p values. Although these values cannot be used as exact values for comparison as the Compton peaks are not classified as full energy peaks, but we used this rough estimation for a preliminary comparison with those of NE-213 detector. More accurate determination of energy resolution at the Compton peaks will be mentioned later.

3-3-2 NE-213 detector:

The same procedure used for NaI(Tl) detector mentioned above to evaluate the relation between resolution and Ec.p is repeated for NE-213 detector for the gamma-ray sources used .

It can be concluded that the resolution values of NE-213 detector are better (lower) than those of Nal(Tl) detector for the corresponding energy values. This may be partly attributed to the difference in volume between the two standard detectors used. The resolutions at Ec.p values of the ^{60}Co are excluded here due to the overlapping between these distributions.

3-4 Count rate at the Compton peak:

Another important factor to be determined between the Compton distributions recorded by Nal(TI) and NE-213 detectors is the count rate at the Compton peaks. The NE-213 is less efficient than Nal(TI) detector for gamma-ray measurements. Using the ^{137}Cs source, the spectrum is recorded by the Nal(TI) detector for a certain time. Then the gamma-ray background is subtracted from this spectrum till reaching a specified value of count rate at Ec.p of ^{137}Cs. Same procedure is repeated by using NE-213 (where background subtraction may include that of fast neutrons) till reaching same value of count rate of Nal(Tl) detector.

3-5 Unification of the calibrations of the NaI(TI) and NE-213 detectors:

3-5-1 Unification of Energy Calibration:

The two previous separate energy calibration curves of Nal(Tl) and NE-213 detectors can now be unified in one calibration curve for both them. The data points include both full energy peaks and Ec.p values of the standard sources used. The new unified relationship shows same linearity behavior as for the separate detectors. This calibration unification is important also in determining the threshold point of nonlinearity below which the spectra subtraction becomes unvalid.

3-5-2 Energy Resolution:

As we have seen from the previous preliminary measurements of the relationship between energy resolution and Ec.p Values for the two detectors used that resolution is generally lower for NE-213 detector than for Nal(TI) detector. Moreover we tended to make accurate calculation of resolution at the Ec.p of the 661 keV line.

We used the definition HWHM (half width at half maximum) which is more accurately suitable for Compton peak than the FWHM (full width at half maximum). The HWHM for Ec.p of the 661 keV is found to be equal to 9.7% and 8.5% for Nal(TI) and NE213 detectors respectively. However, the reaching of a common HWHM resolution value for the two detectors may be obtained through a suitable choice of the detectors volumes.

We may add another important point concerning resolution here. The precise inspection of the shapes of Compton peaks of the line shows that these are narrower and deeper in their leading edges for NE-213 detector than for Nal(TI) detector. This latter case might have affected the goodness of the final photopeak spectrum of ^{137}Cs. However, the inconsistency in energy resolution values and shapes of isolated Compton peaks between the detectors may be reduced or even overcomed through progress in manufacturing.

3-6 Reduction of Compton distribution:

After making the required calibrations in energy, resolution and count rate necessary to apply the present method in reducing the Compton distribution for gamma-ray spectra recorded by Nal(TI) detectors, we have applied the method for the gamma-ray spectra from the ^{137}Cs and ^{60}Co sources and as follows:

3-6-1 ^{137}Cs source:

The gamma – ray spectrum from the ^{137}Cs source as recorded by using the Nal(TI) detector is shown in Fig. (4). The Compton distribution spectrum of ^{137}Cs as recorded by the NE-213 detector for the some energy calibration and following the previously mentioned count rate considerations at the Compton peak is shown in Fig. (5).

On subtracting the NE-213 spectrum from that of NaI(TI) spectrum we obtained the ^{137}Cs photopeak spectrum shown in Fig. (6). It can be seen clearly that the Compton distribution is rather highly reduced and the 661 keV photopeak is well isolated.

3-6-2 ^{60}Co source:

Fig. (7). shows the ^{60}Co spectrum recorded by using the Nal(TI) detector. The Compton distribution as recorded by the NE-213 detector is given in Fig. (8) using the same energy calibration and keeping the same count rate at the Ec.p of both spectra. Compton distribution subtraction gave the photopeak spectrum of ^{60}Co shown in Fig. (9). In the last figure the Compton distribution is rather nearly completely reduced and the two photopeaks are excellently isolated.

4- Discussion

A method of Compton reduction from gamma-ray spectra recorded by Nal(TI) detector using NE-213 detector is suggested in this work. All measurements by the two detectors were made separately with out restricting these to a specified geometry. The main

idea in the present work is based on the similarity between the Compton distributions recorded by each of the detectors. Thus and after making the required calibration Compton distribution recorded by NE-213 detector may be subtracted from the whole gamma-ray spectrum recorded by Nal(TI). This is similar to the subtraction of background when using one nuclear detector.

As an application and in particular there may be a need to improve the quality of data in the measurements of environmental samples recorded by Nal(TI) detector[13].

Although we may regard the measurements and results obtained in this work as preliminary, but we may assure that these had initiated a method towards obtaing photopeaks isolated from the interferences of other phenomena, a thing spectrometry researchers may yearn for.

Besides the notes we have mentioned concerning the limitations of energy resolution, shape of Compton peaks and non linearity at low gamma energies we add here the possibility of appearance of photopeaks at low gamma energies in NE-213 spectrum.

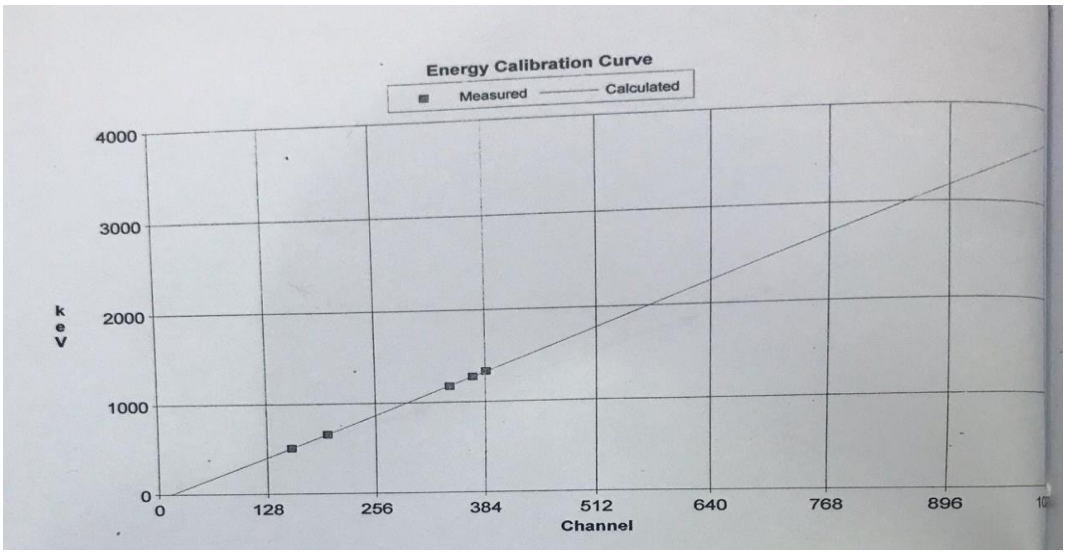

Fig. 1: Energy calibration curve of photo peaks for the 3"x 3" NaI(Tl) detector.

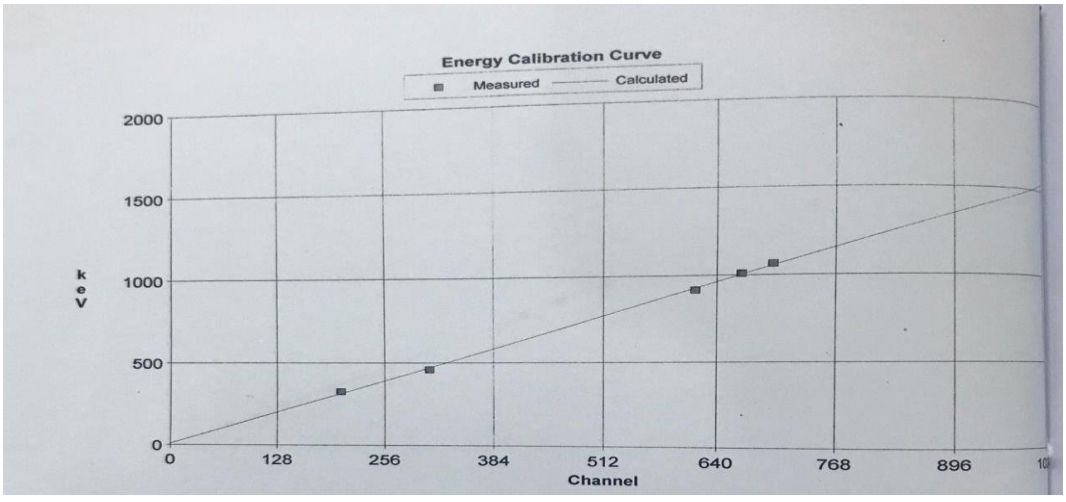

Fig. 2: Energy calibration curve of Compton peaks for the 3"x 3" NaI(Tl) detector.

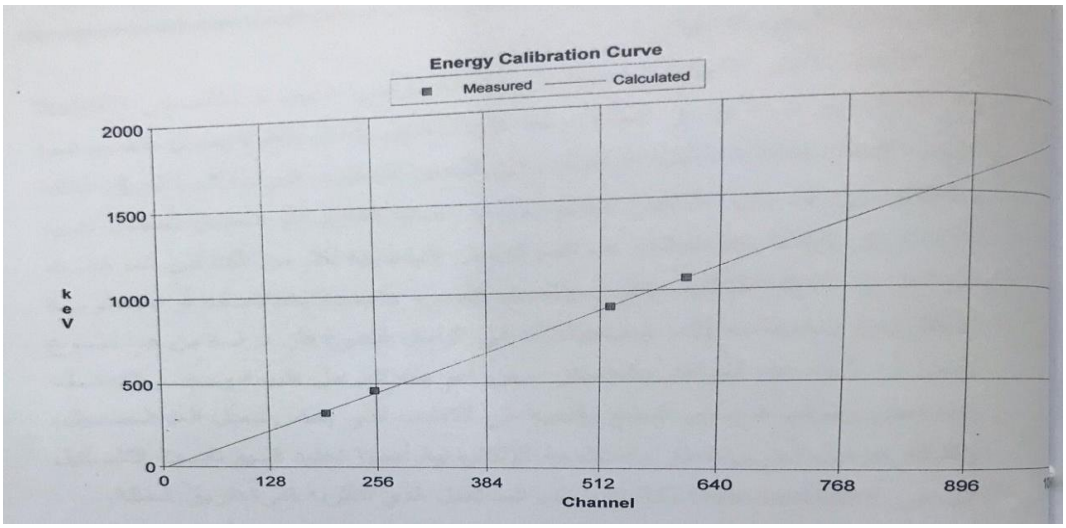

Fig. 3: Energy calibration curve of Compton peaks for the 2"x2" NE-213 detector.

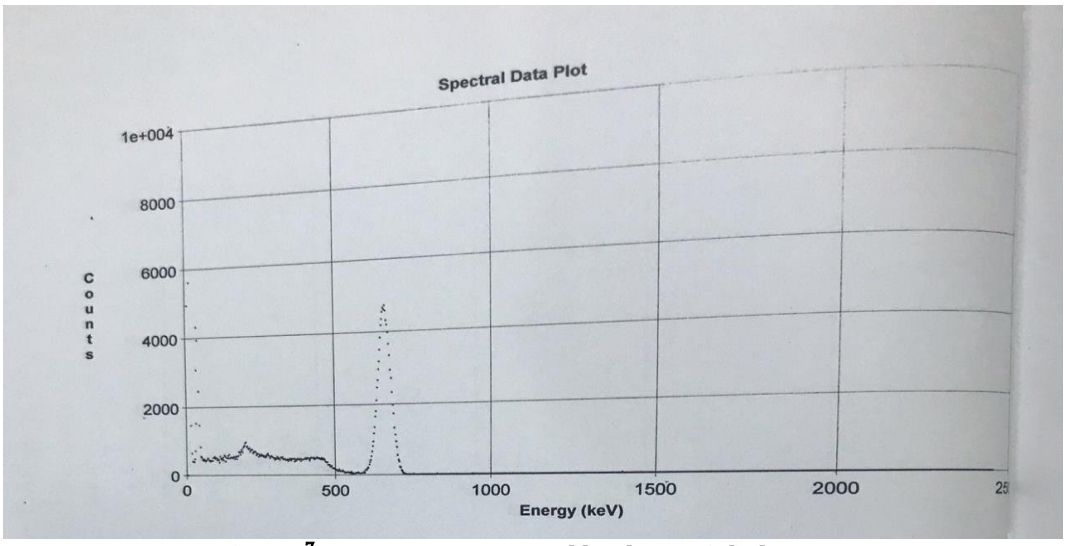

Fig.4: ^{137}Cs spectrum measured by the NaI(Tl) detector.

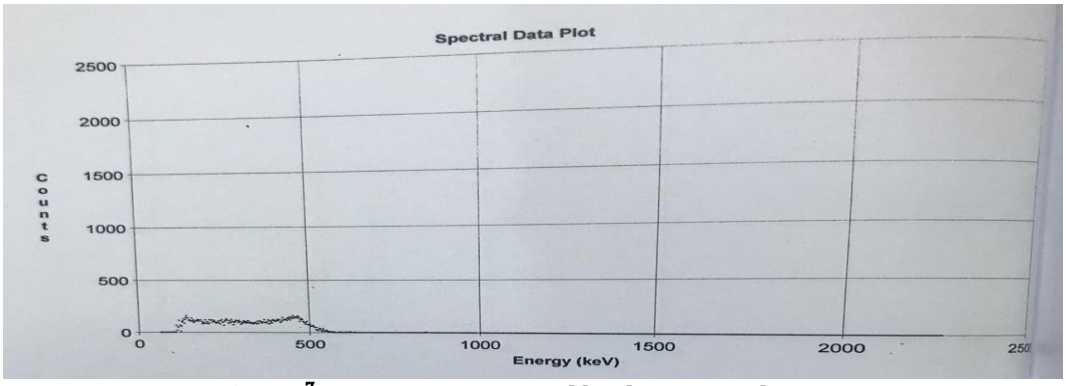

Fig.5: ^{137}Cs spectrum measured by the NE-213 detector.

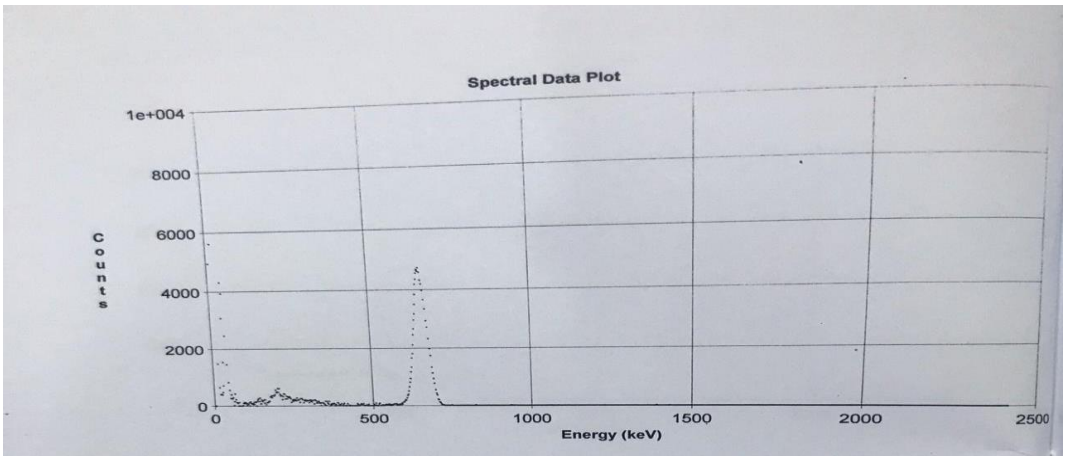

Fig. 6: ^{137}Cs spectrum of the NaI(Tl) detector after subtracting Compton distribution.

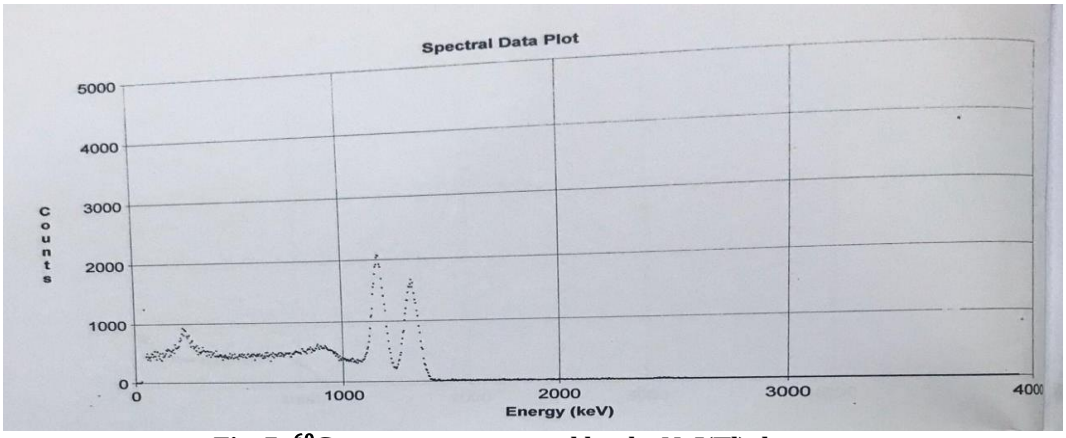

Fig. 7: ^{60}Co spectrum measured by the NaI(Tl) detector.

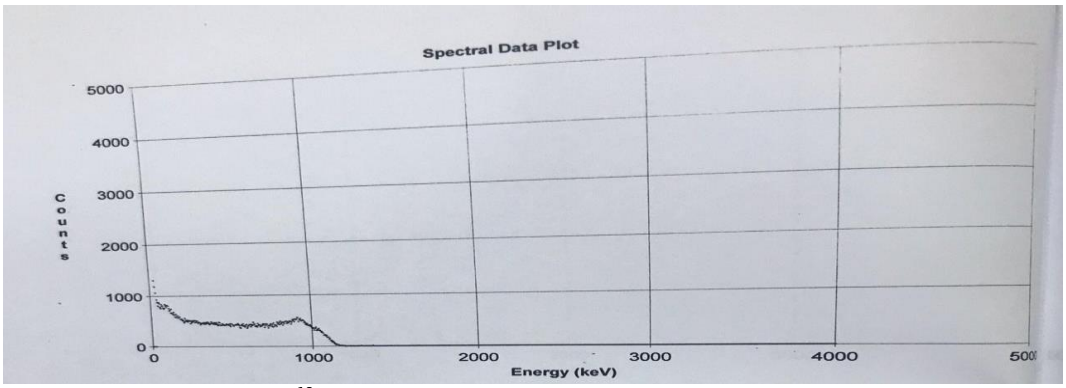

Fig. 8: ^{60}Co spectrum measured by the NE-213 detector.

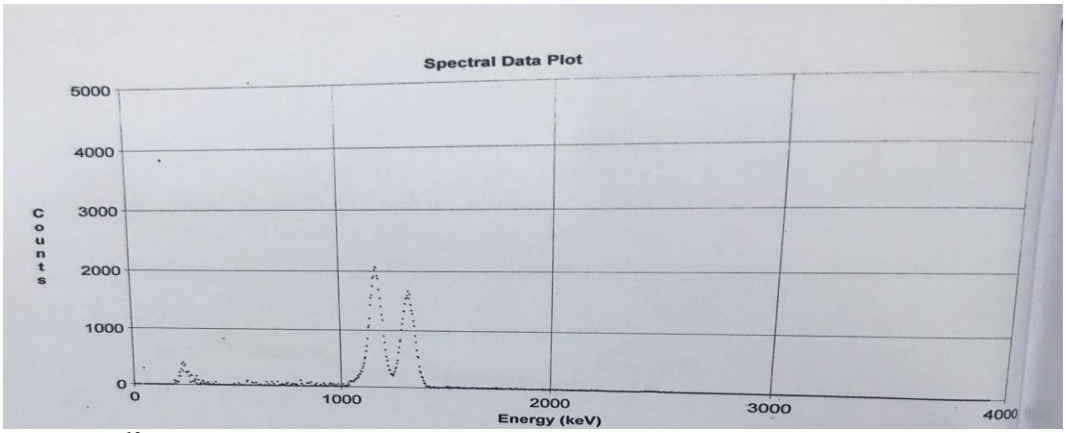

Fig. 9: ^{60}Co spectrum of the NaI(Tl) detector after subtracting Compton distribution.

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استخدام الوماض العضوي NE-213 لأختزال توزيع كومبتن من اطياف اشعة كاما

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الملخص

قدمت طريقة لأختزال توزيع كومبتن من اطياف اشعة كاما المسجلة بالكاشف Na(Tl) باستخدام الوماض العضوي NE-213. ان تشابه توزيعي كومبتن مابين الكاشفين يمكن ان يسمح بطرح طيف الكاشفNE-213 من طيف الكاشف Na(Tl) بعد اجراء معايرة معينة لكل من الطاقة، وتفريق الطاقة ومعدل العد عند قمة كومبتن. طبقت الطريقة باستخدام مصدري اشعة كاما القياسيين ^{137}Cs و ^{60}Co. ان اطياف القمة الضوئية التي تم الحصول عليها بينت ان توزيع كومبتن يمكن ان يخفض بصورة عالية وان القمم الضوئية قد عزت بصورة جيدة جداً.