Enhancement of Peak to Compton Ratio (P/C) using a New Array Design for Safeguards Applications

R.A. El-Tayebany[1], A.A.Hamed[1], A.Abdelsalam[2],W. Osman[2], Sayed El-Mongy[1]

1 Egyptian Nuclear and Radiological Regulatory Authority(ENRRA), Cairo, Egypt

2 Physics Department, Faculty of Science, Cairo University, Cairo, Egypt

Abstract

This paper focuses on installation of a new geometry and array of detectors to investigate reduction and suppression of unwanted noises and background to enhance P/C ratio. This objective is positively affecting the accuracy of safeguarded nuclear materials assay. The new array consists of three sodium iodide (NaI) detectors; one of them is in annular perpendicular position and the others are guards surrounding the main Hyper Pure Germanium Detector (HpGe). The optimum configuration for the array was selected to maximize P/C ratio and minimize the noises and Compton continuum that produced at higher-energy gamma-rays. The enhancement of the Peak-Compton (P/C) ratios was investigated using the radioactive source ^{137}Cs. It was observed that the new array configuration enhanced the P/C ratios compared to single HPGe detector in range 387.6±6.12 to 1001.12±7.4. The design was also investigated and applied on standard nuclear materials (SNM) at the photo peak 185.7 KeV of ^{235}U. The system gave great value in the net area for photo peak 185.7 KeV for investigated SNMs samples.Since, The maximum difference was found to be 17.6%. The results are given, discussed and interpreted.

Key words: New array design, HPGe, NaI, (P/C) Ratio, Standard Nuclear Materials (SNM),

1. Introduction

In gamma-ray spectrometry measurements, the predominant mode of photon interaction depends on the energy of the incident photons and the atomic number of the target material. some of thephotons from the sample are scattered within the radiation detector itselfdepositing part of their energy within the detector andescape. This leads to the generation of Comptoncontinuum associatedbackground representing incomplete energydeposition of the incident photons, which leads to thedistortion of the obtained spectrum from the actual energydistribution [1,5].

Gamma spectrometry with high-purity germanium (HPGe) detectors is routinely used for the Non- Destructive assay techniques (NDA). Improvements to the NDA can be achieved by minimizing theCompton continuum, through the use of array of detectors.The Compton continuum is primarily generated byphotons which undergo one or two scatterings within the detectorbefore escaping, depositing only a fraction of their total energy.These events may obscure low intensity full energy peaks[4].

The precision of gamma spectrometry is partly related to the efficiency calibration of the detector system. The detector efficiency is usually much less than 100% on account of the loss of gammaraysthrough interactions either within the sample itself, thedetector or other

inactive regions (e.g. detector packaging, electrical contacts, and semiconductor dead layer). Gamma spectrometry calibration for accurateactivity measurements requires knowledge of the efficiency forspecific source and detector configurations [3,4].

The non-destructive identification of nuclear material samples can be achieved using different gamma spectrometry techniques for accurate verification of NMs. However, the sensitivity of Gamma spectroscopy is dependent on many factors. This includes the resolution and efficiency of the detector, and the amount of background radiation seen. The Compton continuum (which arises due to the incomplete energy deposition of a Compton scattered γ decay in the crystal) also obscures lower energy decays, reducing the observed Peak to Count (P/C) ratio for these transitions. Many radionuclides of interest fall into this category, and methods employed to improve the low-energy performance of γ-spectroscopy systems.

2. System description

2.1 Sources and detectors assembly Design

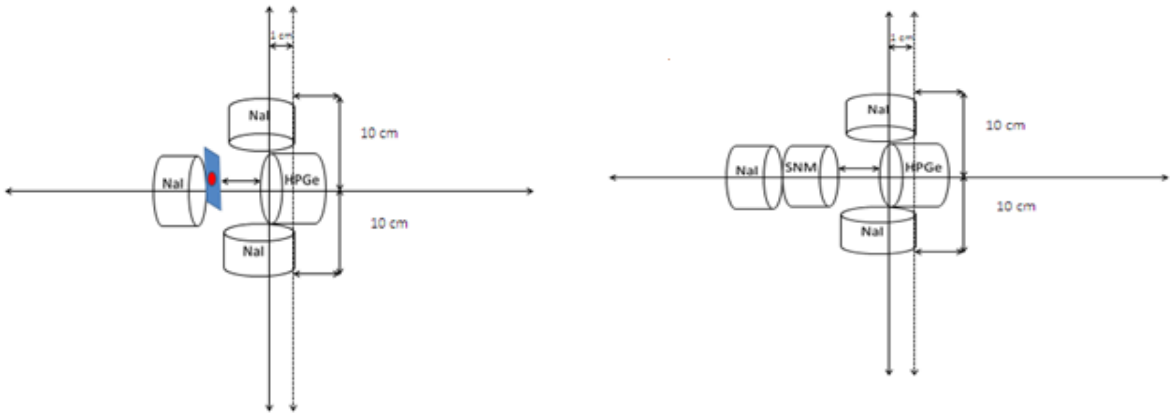
In the first part, The experiments were carried out at different distance between the HpGe-detector and the sample at 1,2,3 and 4 cm since, the guard detectors kept with fixed position close to the active volume of HpGe detector in each case. In The first experiment, the radioactive source ^{137}Cs with activity of 5μCi **(Certified Standard point sources [Eckert & Ziegler, California-USA (2006); with total uncertainty ±3.0%])** was used in the presence of single HpGe detector alone. The photo peak was collected in the energy range 650-670 KeV marked by ROI (Region of Interest) in MAESTRO software. The net area of photo peak at the energy line 661.7 KeV was registered in live time of 900 sec. in each distance. The same experiment was repeated with marked another area (Compton continuum) which is in the energy ranges 430-460 KeV to estimate P\C ratio. These steps were repeated at each source-to-detector distance to calculate the P\C ratios.

The above procedures were executed for certain array where the HpGe detector surrounded by two NaI guard detectors and one annual,as shown in figure (1),which are operated with WINSPEC software in the same time of HpGe detector to determine P\C ratio outside and inside the shield and compare the results. The detectors specifications are displayed in table (1).

Table (1).The used Detector Specifications

	HPGe	NaI (Annual)	NaI (Guard)	NaI (Guard)
Crystal size	Planardetector active area = 500 mm^2	3"×3"	3"×3"	2"×2"
Operating Voltage	-2500 V	-740 V	- 820 V	+620 V
Manufacturing Data	(Canberra; model GL0515R),	Ortec and based on a Mini Multi Channel Analyzer model (MCA-166) with a NaI (Tl) detector model (12S12-3.VD.PA.003) and serial number (2518.05.09). As provided by the manufacturer, the detector has a NaI(Tl) crystal with dimensions (76.2 x76.2 mm) and an Aluminum housing of 1mm.		Crismatec with crystal type: 8 ss2/2G-XTAm, PM: 9266 B.

The setup is placed in lead shield with length 40cm, width 30cm and height 15 cm to protect against environmental radiation (e.g. cosmic rays, building materials radiation).



(a) (b)

Fig.(1) Experimental configuration for array detectors set up: (a) using radioactive ^{137} Cs, (b) using SNM.

In the second part, the array design was investigated by using set of SNMs with different enrichment (Depleted uranium, Natural uranium and Enriched uranium). They were compact powder in U_3O_8 chemical composition as shown in table (2).

Table (2). The Data of used Cylindrical SNMs Samples.

Samples	Shape	Chemical Composition	Enrichment (%)
[1] **Depleted Uranium**	Cylindrical Source	U_3O_8	0.31
[1] **Natural Uranium**	Cylindrical Source	U_3O_8	0.71
[1] **Enriched Uranium**	Cylindrical Source	U_3O_8	4.46

[1] USA–National Bureau of Standards, Standard Reference Material 969, NBS-USA (1985);
* The total mass of each sample is 200.1 g and the total mass of Uranium in each sample is 169.681 g [7].

3. Results and Discussion

3.1 Results of array configuration with ^{137}Cs source:

Several key peaks of the gamma ray spectra were analyzed to demonstrate the effectiveness of the use of detectors array. The radioactive source ^{137}Cs with activity 5µCi is used in the presence of single HpGe detector alone. The photo peak is taken the energy range 650-670 KeV marked by ROI (Region of Interest) in MAESTRO software. The net area of photo peak

at energy line 661.7 KeV registered in live time 900 sec. in each source-to-detector distance. The same experiments are repeated with marked another area (Compton continuum) which takes the energy range 430-460 KeV to estimate P\C ratio. These steps are repeated in each distance to obtain the corresponding P\C ratio in each one.The results are depicted in the figure (2).

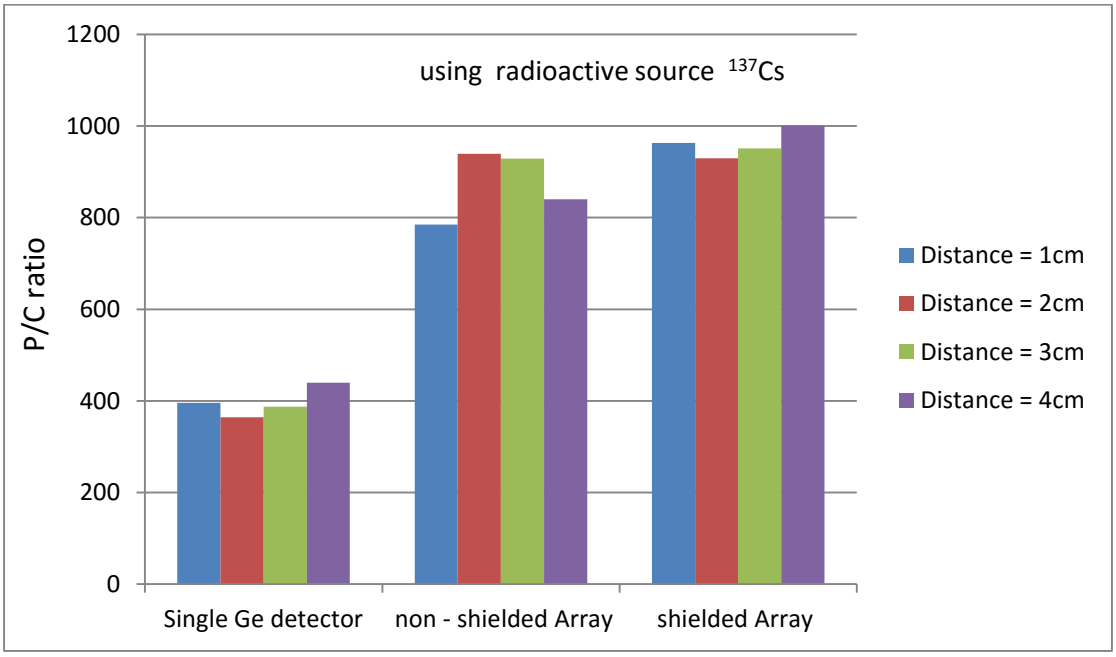


Fig.(2): The experimental results for P\C ratio with different distance between the HpGe detector and the radioactive point source ^{137}Cs in all the conditions.

It can be clearly seen from the above mentioned results that the highest P/C ratio value belongs to the shielded array design detector where the P/C value lies in range 929.16±10.12 to 1001.12±7.4. These results give good indication for the shielded design array detectors to be the best configuration for using SNMs with different enrichment percentage.

3.2 Results of detectors array configuration with SNMs samples:

It is necessary to understand the physical explanation for the detector array set up that contains HpGe detector which is surrounded by two guard detectors and one annular, usually NaI. The HpGe and NaI detectors are operated in anti-coincidence mode. The photons that are escaped from HpGe detector are interacted and deposited within the NaI detectors to form Compton continuum that can be subtracted from the spectrum to reduce the un interested background [6].

To investigate and validate the new array of detectors, the SNMs are used with different enrichment. The net area of photo peak at energy line 185.7 KeV is measured at different distances of the sample from the HpGe detector as shown in figures (3), (4), and(5).

The net area of energy line 185.7KeV of ^{235}U is registered in live time 900 S. the energy range of photo peak 185.7 KeV is taken from 178 KeV to 197 KeV. The results are compared with the result obtained using single HpGe-detector in the experimental results. To obtain the relative difference of two values is their absolute difference divided by the average of the two

numbers [8]. Suppose that the net area for photopeak at energy line 661.7 KeV using single Ge detector is X_1, and the net area for that photopeak using detector array design is X_2.
The percentage difference between the two values is:

$$Difference\ (\%) = \frac{|x_2 - x_1|}{\frac{|x_2 + x_1|}{2}} \times 100$$

Figures (3) demonstrates that the highest net area for photo peak 185.7 KeV, using enriched Uranium (4.46%), was in shielded array where the difference between using single HPGe detector and shielded array was 17.54 %.

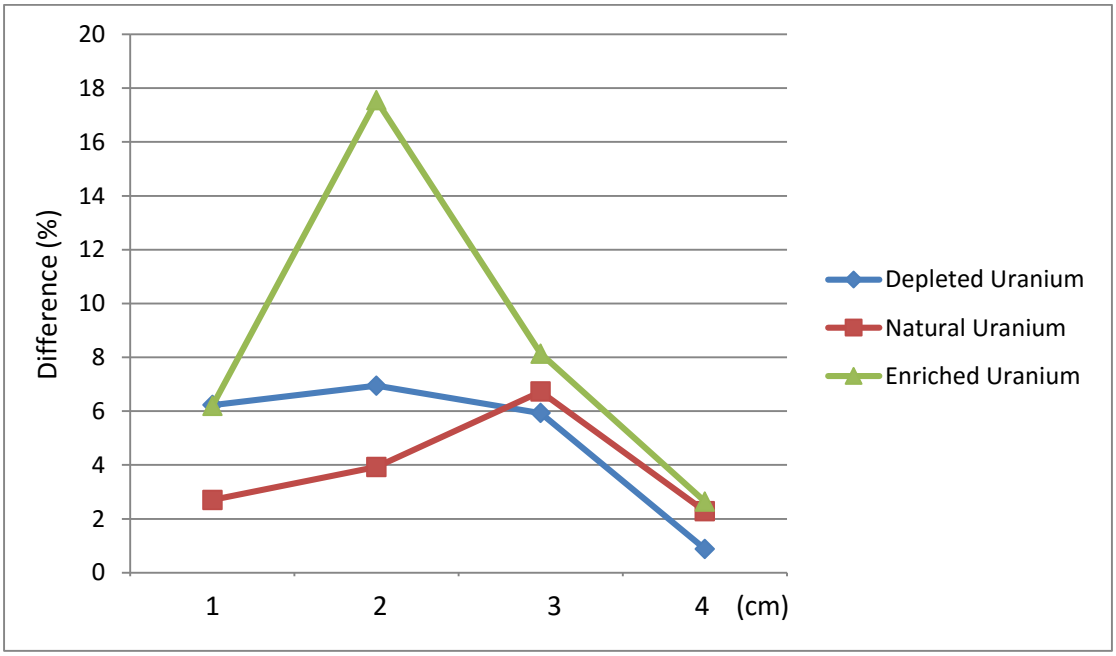


Fig.(3): differences(%), between net area of 185.7 KeV using single HpGe detector and shielded array detectors design, versus the distance for all used SNMs samples.

Consequently, the detailed results should be represented and explained to show the variation of net area as in Figure(4) which describes the effect of shilded array detectors on the net area comparable with the remain cases. It gave large values of net area for photopeak at 185.7 KeV ussing depleted uranium saple at all distance with respect to the other cases.

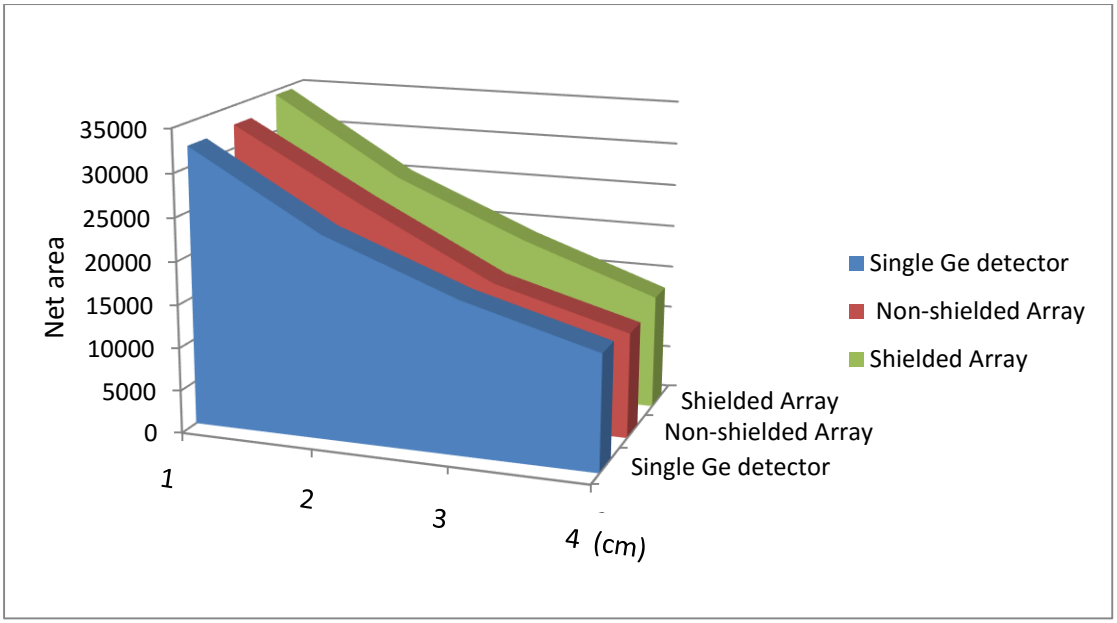


Fig.(4): Net area at energy line 185.7 KeV versus the distance between the HpGe detector and the SNM (Depleted Uranium) in all conditions.

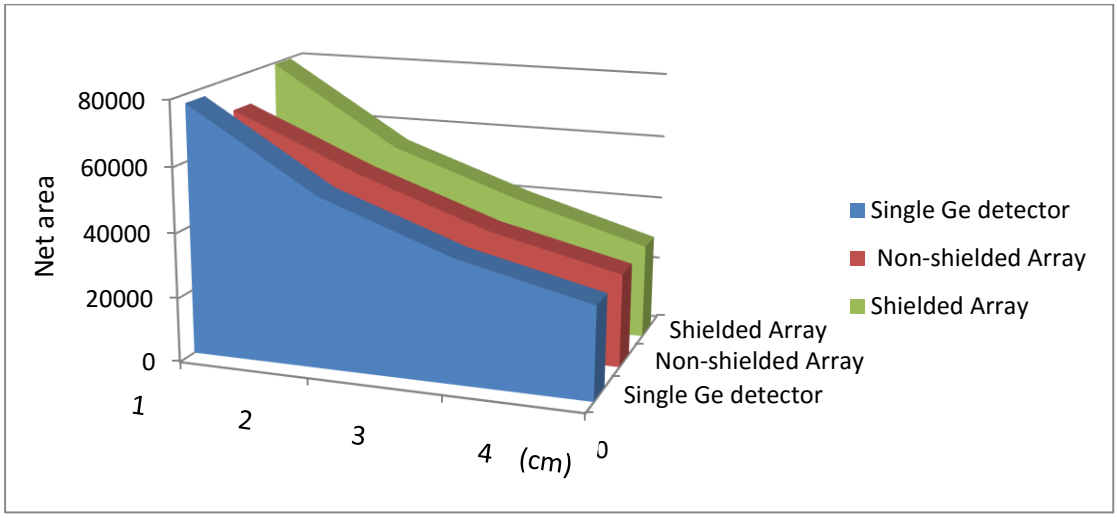


Fig.(5): Net area at energy line 185.7 KeV versus the distance between the HpGe detector and the SNM (Natural Uranium) in all conditions.

It is obvious that, figure (5) shows that the difference in Net area for photo peak 185.7 KeV, using natural Uranium (0.71%), was from 2.29% to 6.73% but, it ranges from 2.64% to 17.55% for using enriched Uranium (4.46%) as shown in figure (6).

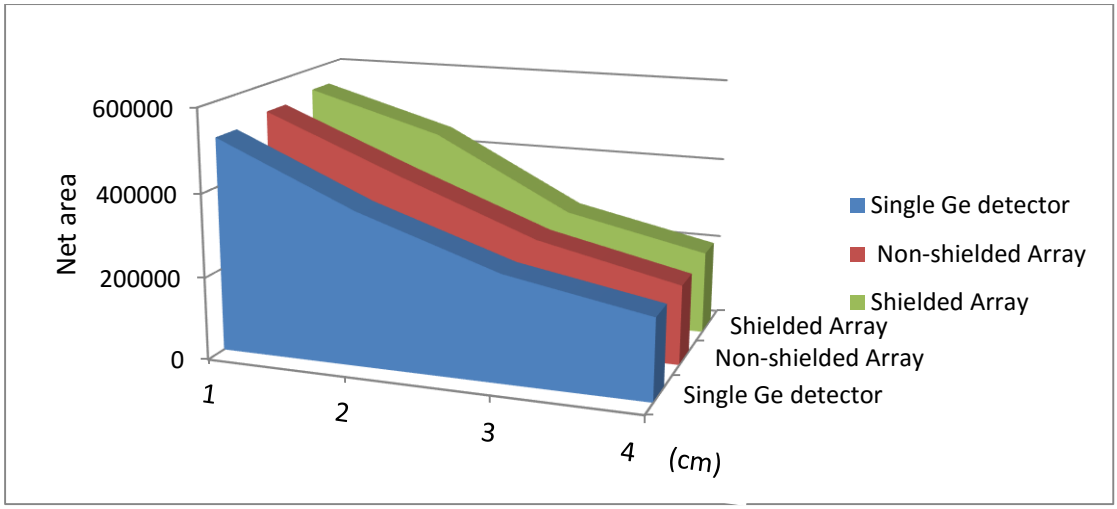


Fig.(6) Net area at energy line 185.7 KeV versus the distance between the HpGe detector and the SNM (Enriched Uranium) in all conditions.

The above results gave clear vision for employing the system to improve the performance of nuclear safeguards measurments. In order to generalize the usage of array detector design, the point source was utilized, represented in ^{137}Cs, which is considered as small volum. As well as, bulck samples (SNMs), which are considered as large volums with various enrichment.

4. Conclusions

This work aims at the investigation and improvement of detection accuracy for several safeguards key elements using new detectors assembly. The experimental work showed that the P/C values were enhanced using the array detectors design with respect to single HPGe usage only from 387.6±6.12 to 1001.12±7.4. This result indicates and proves that the proposed new detectors array design achieved the target. The system is quite capable for the assay of small amounts and depleted nuclear materials and radioactive source with relatively high accuracy and enhanced P/C ratios. The system gives great value in the net area for photo peak 185.7 KeV for investigated SNMs samples.Since, The difference ranges from 0.91% to 17.55%. The designed system is being developed to be comparable with the commercial Compton suppression systems.

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