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# IMPROVED NON-DESTRUCTIVEEXPERIMENTAL ARRAY FOR POINT AND CYLINDRICAL SOURCES ASSAY

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## Abstract

This work aims mainly at development and improvement of the performance of thecylindrical (standard nuclear material -SNM)and point sources (radioactive $^{137}Cs$) assay. New geometries and arrays of detectorswere installed and investigated to reduce the unwanted noises and interactions. Two different detectors arrays design are optimized and presented with respect to the analyzed nuclear material samples. The arrays consistof threeSodium Iodide (NaI)detectors; one of them is in annular perpendicular position and the others are guardssurrounding the mainHyper Pure Germanium Detector (HPGe).An enhanced Peak-Compton (P/C) ratioswere obtained and discussed.

**Paper contents:**



**Key words:** New array. Nondestructive Assay (NDA), Standard Nuclear Material (SNM), HPGe, NaI

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**References**

[1] Badran H.M., T. Sharshar, An experimental method for the optimization of anti-Compton spectrometer, Nuclear Instruments and Methods in Physics Research A 435 (1999) 423-432.

[2] Charles J. Hellier, Hand book of Nondestructive evaluation.

[3] Darwish Al-Azmi, Simplified slow anti-coincidence circuit for Compton suppression systems, Applied Radiation and Isotopes 66 (2008) 1108–1116.

[4] Glenn E Knoll, Radiation Detection and Measurement.

[5] Hyun-Je Cho, Yong-Sam Chung, Young-Jin Kim, Study on prompt gamma-ray spectrometer using Compton suppression system, Nuclear Instruments and Methods in Physics Research B 229 (2005) 499–507.

[6] Iskander F. Y., S.landsberger, S.D.Warren, Determination of 137 Cs in soil samples by low-level Compton suppression gamma-counting, Journal of radioanalytical and nuclear chemistry, Vol.244,No.1(2000)159-163.

[7] MAUERHOFER E., Improvement in the Counting Statistics and in the Limit of Detection with Compton Suppression Spectrometers a Contribution to Instrumental Neutron Activation Analysis, Appl. Radiat. lsot. Vol. 47, No. 7, pp. 649-658, (1996).

[8] Non-Destructive Assay: Instruments and Techniques forAgency Safeguards, IAEA BULLETIN-VOL.19, NO.5.

## 1. Introduction

The distinctive techniques must be provided in the development and selection of instruments for nuclear materials measurements for safeguards purposes. These include: portability, ease of checking and repair, accurate calibration using physical standards and calibration sources [8].

Non-destructive assay instruments are common techniques for the identification and measurement of nuclear materials. The nondestructive assay techniques are direct, fast and easy to execute. They are more preferred rather than chemical destructive testing because of slow and need more exact sampling. These techniques can be classified as passive or active depending on how the response is obtained. In the passive mode, the radiations from the natural radioactive decay of the isotopes of interest are monitored. In the active mode, the delayed neutrons/prompt neutrons or gamma rays from the samples irradiated by the neutrons are monitored [2].

This paper concerned to improve passive nondestructive assay techniqueby studying gamma ray spectroscopyand its applicationson special nuclear materials and point source analysis. The Compton Effect is studied to enhance performance and detection of the main photopeaks.

The signals of γ-rays emittedby low-activity radionuclides and the signals of γ –rayswith weak emission rates are obscured at low andmedium energy in the γ-spectrum by the Comptoncontinuum. The Compton background arises fromthe incident photon energyowing to the escape of Compton scattered γ –raysfrom the germanium detector so that, many gamma-rays entering the germanium detector will not deposit their full energy, leading to a large Compton continuum [5-6-7].

Theanti-Compton-shield can be made of NaI(TI) or BGO(bismuth germanate) crystals. During the last 30 yr,different arrangements of Compton suppression spectrometers with the source position inside oroutside the anti-Compton-shield have been developedfor applications in neutron activation analysis [7].

## 2. Factors Affecting the performance improvement

An analytical approach is taken in this paper to describe the factors determining the improvements inthe counting statistics obtained for γ -ray measurements with new design array.
In gamma-ray spectrometry measurements, some of the photons which emitted from the sample are scattered within the radiation detector itself depositing part of their energy within the detector and escape. This leads to the generation of so-called Comptonassociatedbackground representing incomplete energy deposition of the incident photons, which leads to thedistortion of the obtained spectrum from the actual energy distribution. Because the escaping energy is a photon, it is possible tocollect that energy with another detector. This is typicallydone with a larger detector made of a less expensive material such as plastic or NaI surrounding the maindetector, and is known as a surrounding shield ‘‘guard’’. By correlating events in the main detector and the surrounding shield detector [3].

The used detectors are calibrated so that, photon energy equivalent to the same channels in all the detectors as we can and run all the detectors in the same live time to correlate the events in all detectors.
On the other hand, the data acquisition part of Comptonsuppression systems adds more complication beside therequirements for the specific detector geometry in order toachieve improved spectral information. The anti-coincidence instrumental arrangement between the two detectors requires timing analysis of the signals. Fast timing measurements are desired in such timing analysis for accurate action. With fast timing measurements, an additional circuit (beside the ordinary energy circuit) is used to study the time correlation between the two signalsfrom both detectors. It is known that the work with instruments employed for timingmeasurements is timeconsuming,particularly for the system setup.

The reduction in Compton continuum is measuredby the Compton suppression coefficient defined as;

$$F = (P/C)_{suppressed}/(P/C)_{Unsuppressed} \quad (1)$$

Where*P*/*C* is the ratio of the net photopeak area tothe area of an equal spectral width in the Comptoncontinuum below, but not including, the Comptonedge.

In orderto reduce the contribution of the scattered gamma-rays, the Ge detector can be surrounded byan inorganic scintillator detector. This is alsoshielded against neutron- and gamma-radiationbackground, which improves the signal-to-backgroundratio [5].

Because of the random nature of radioactive decay, there is alwayssome probability that a true event will be lost because it occurs too quickly following a precedingevent. These "dead time losses" can become rather severe when high counting ratesare encountered, and any accurate counting measurements made under these conditionsmust include some correction for these losses.

$n$= true interaction rate

$m$= recorded count rate

$\tau$= system dead time

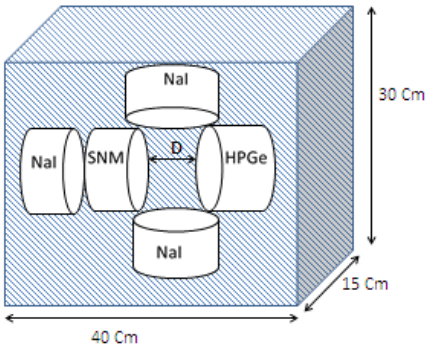
We would like to obtain an expression for the true interaction rate $n$ as a function of the measured rate $m$and the system dead time $T$, so that appropriate correctionscan be made to measured data to account for the dead time losses [4].

(2) $$n = \frac{m}{1-m\tau}$$

## 3. Experimental arrangement:

The annulus detector is positioned with alignment with the HPGedetector.The guard detectors placed at both sides of annual detectors, SNM and Ge detector as shown in the figures (1) and (2). The annulus NaIdetector is dimensioned as 3x3 inch contained in a thin aluminum holder. One of The guard detectors dimensioned as 3x3 inch and other 2x2 inch. 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). Compton scattered photons from the HPGe detector are captured by the surrounding NaI(TI) detectors, registering a coincidence hit.

These coincident events are rejected from the output spectrum, reducing the Compton continuum.



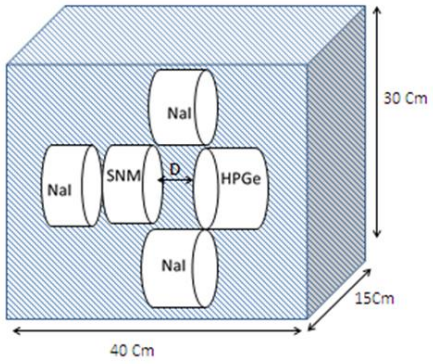




Fig (1).Showsthat array design detectorsFig(2). Shows that array design detectors
1with SNM2with SNM

TheSNM sources arein the form of compact powder in Aluminum cans (Cylindrical Source) with chemical composition $U_3O_8$and different enrichment (ratio of U-235)where $^{235}U$ contains many energy lines as shown in table(1).The radioactive source $^{137}Cs$ with activity 5 µCi (Point Source) which is surrounded by plastic cover. The data of the used samples are presented as shown in table (2).

**Table (1) shows the energy lines and specific activity of $^{235}U$**

| Source | Energyline (keV) | Specific activity Per gram per second (disintegration / s) |
|---|---|---|
| $^{235}U$ | 143.8 | $7.8\times 10^3$ |
| $^{235}U$ | 163.4 | $3.7\times 10^3$ |
| $^{235}U$ | 185.7 | $4.3\times 10^4$ |
| $^{235}U$ | 202.1 | $8.0\times 10^2$ |
| $^{235}U$ | 205.3 | $4\times 103$ |

Where the energy line 185.7 represents the signature of $^{235}U$, it is specialist in this paper

**Table (2) shows the Dataof the used cylindrical (SNM) and $^{137}Cs$ point sourcessample**

| Used Samples | Shape | Chemical Composition | Enrichment | Activity |
|---|---|---|---|---|
| [a]Depleted Uranium | Cylindrical Source | $U_3O_8$ | 0.31% | |
| [a]Natural Uranium | Cylindrical Source | $U_3O_8$ | 0.71% | |
| [a]Enriched Uranium | Cylindrical Source | $U_3O_8$ | 2.95% | |
| [b]Radioactive Source | Point Source | $^{137}Cs$ | | 5 µCi. |

[a] USA–National Bureau of Standards, Standard Reference Material 969, NBS-USA (1985);
[b] Certified Standard point sources [Eckert & Ziegler, California-USA (2006); with total uncertainty ±3.0%].
All the used sources are measured in Key Measurement Point (E) in Material Balance Area ( ET-Z) which subjected to Egyptian nuclear safeguards.

For Low Cs-137 concentrations, the signal to noise ratio improves to reduce significantly the error on the photopeak. The radioactive source $^{137}Cs$ is point source and presented in front of Ge- detector with different distance between them (D) as shown in fig.(3). The used arrays are installed with different guard detector positions, one array in which the Al-cap of guard detectors parallel to the Al-cap of Ge detector as shown in the fig.(4) and the other in which the Al-cap ofguard detectors in front of the Al-cap of Ge detector as shown in the fig.(5).

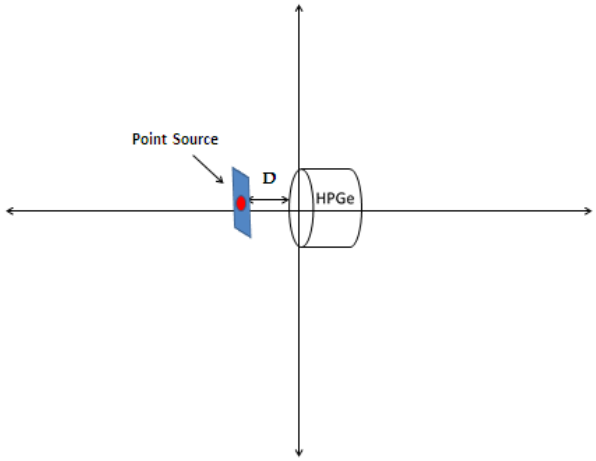



**Fig.(3) show the point source position with respect to the Ge detector**

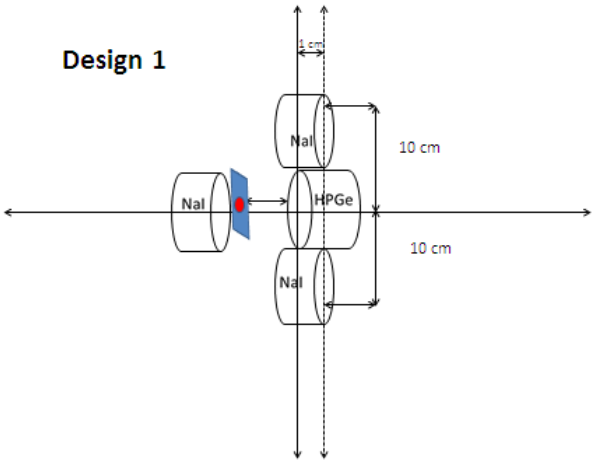



**Fig.(4) show the detailed dimensions of design 1 in case of point source measurement**

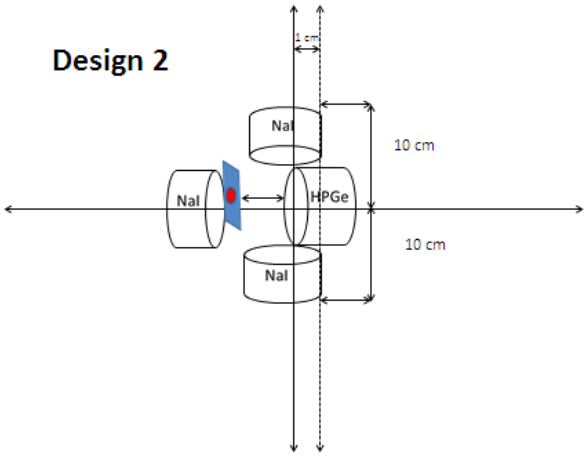



Fig.(5) show the detailed dimensions of design 2 in case of point source measurement

The SNMs are positioned as in the same of point source as shown in the figs. (6),(7) and (8). The live photos are taken to describe the set up in details as shown in fig.(9)

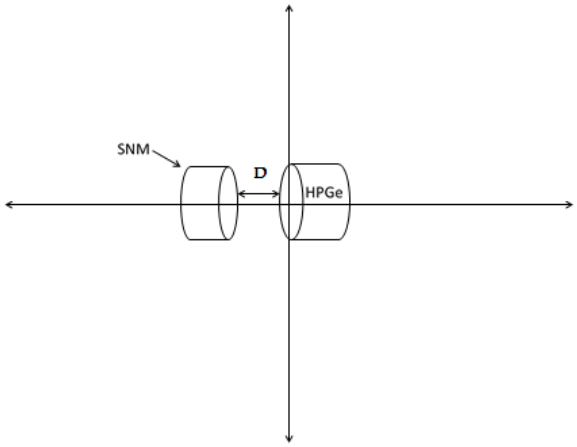



Fig.(6) show the SNM position with respect to the Ge detector

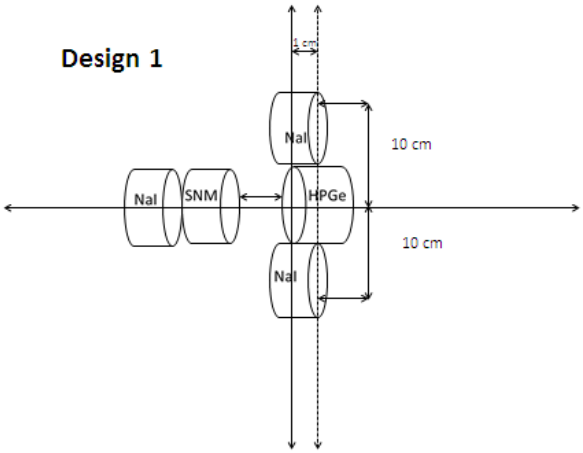



Fig.(7) show the detailed dimensions of design 1 in case of SNM measurement

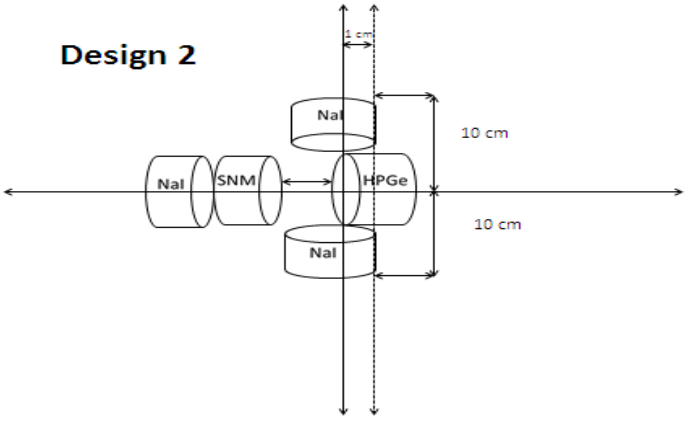



Fig.(8) show the detailed dimensions of design 1 in case of SNM measurement

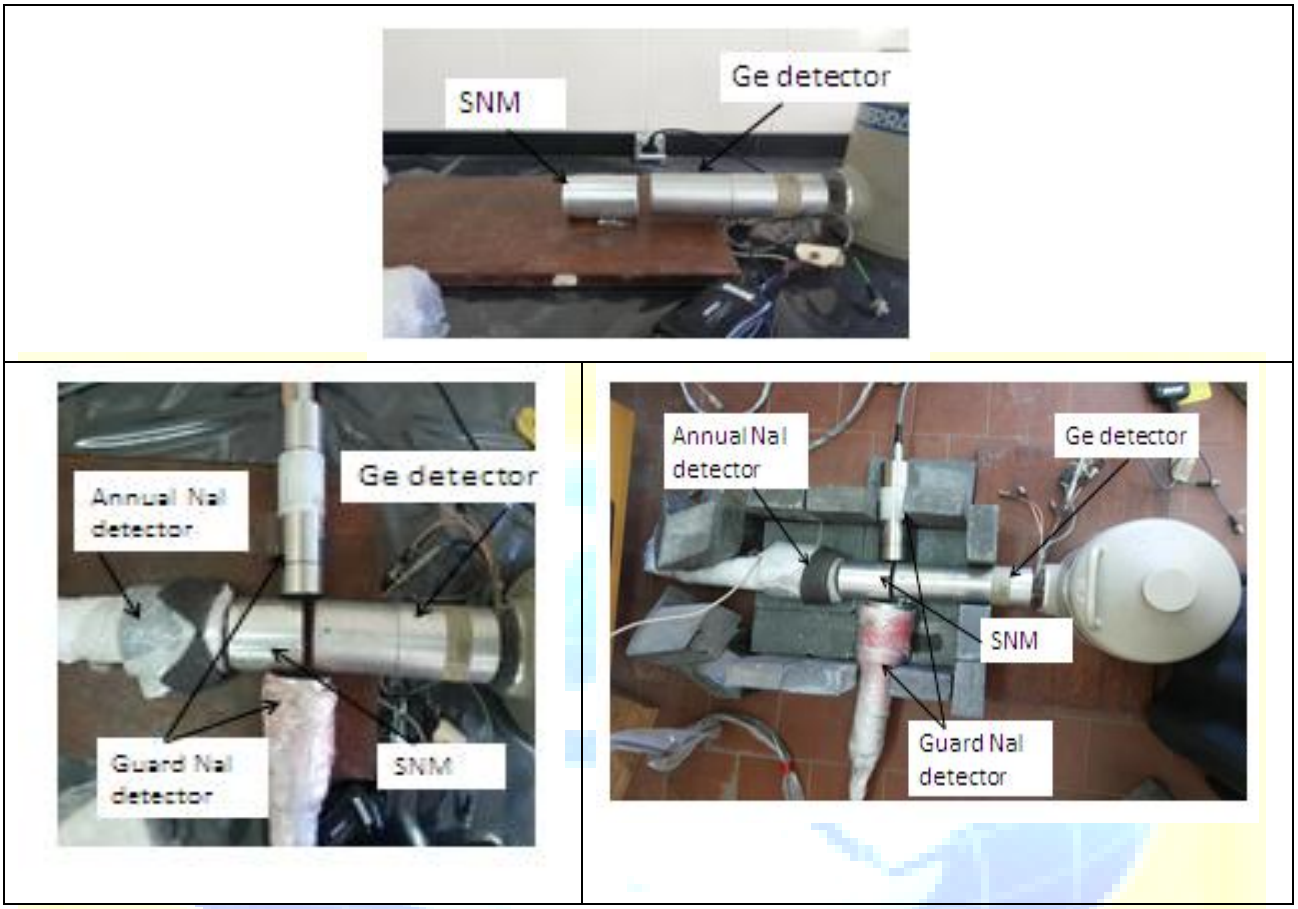




Fig.(9) Photorealisticfor the array inside and outside the shield

Where the guard detectors placed in the alignment with the Ge detector and shift 1 cm towards it to be in the active volume of it.

## 4. Results

Each photopeak has its corresponding Compton distribution due to Compton scattering of the incident γ-ray in the detector and the surrounding materials. The reduction of the Compton continuum makes the identification of low-intensity peaks possible and improves the uncertainty of the measured activities [1].

The experiments were executed at different distance between the Ge-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 Ge detector in each case.

In The first experiment, the radioactive source 137Cs with activity 5µCi is used in the presence of single Ge detector. The photopeak is taken the energy range 650-670 KeVmarked by ROI (Region Of Interest) in MAESTRO software. The net area of photopeak at energyline 661.7 KeV registered in live time 900 S in each distance. The same experiment repeated with marked another area (Compton continuum) which takes the energy range 430-460 KeV to estimate P\C ratio. These steps repeated in each distance to obtain P\C ratio in each one.

The above procedures were executed in each array where the Ge detector surrounded by NaI detectors which operated with WINSPEC softwarein the same time of Ge detector to determine P\C ratio outside and inside the shield and compare the results with each other as shown in the fig.(10).

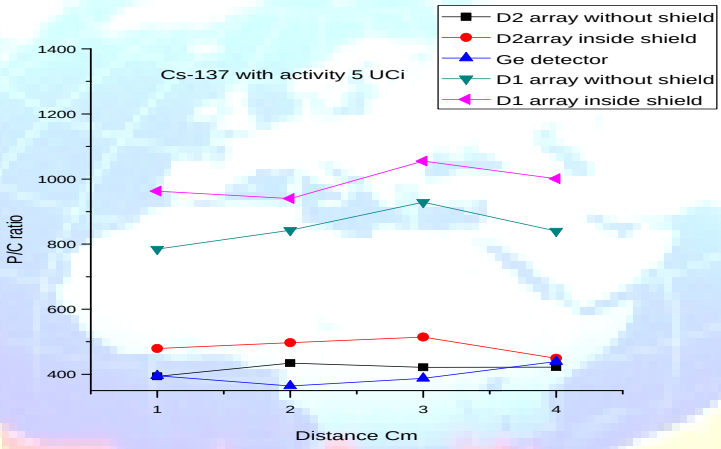



Fig.(10):Represents P\C ratio versus the distance between the Ge detector and the point source in all the cases

SNMs with different enrichment are used in each array with changing the distance between the detector and the sample with the same procedures. The net area of energy line 185.7KeV of 235U is registered in live time 900 S. the energy range of photopeak 185.7 KeVis taken from 178KeV to 197 KeV. The results are compared with the result of using single Ge-detector as shown in the figs.(11),(12),(13) and (14).

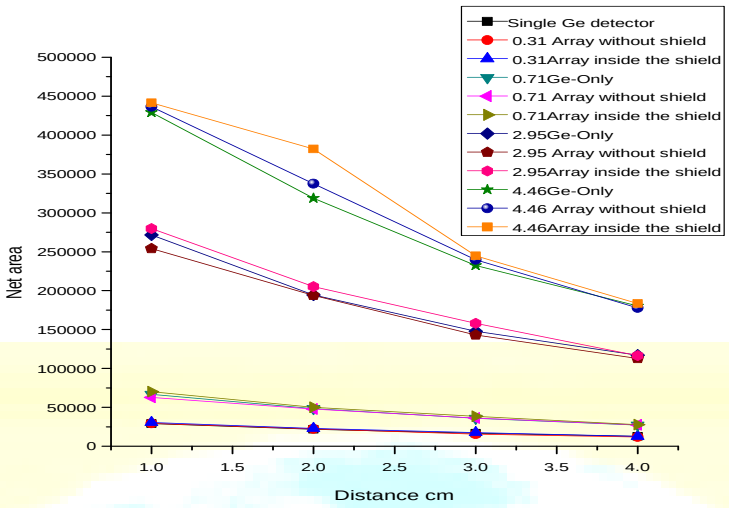



Fig.(11): Representsnet area versus the distance between the Ge detector and the SNM in all the casesfor the first design number 1.

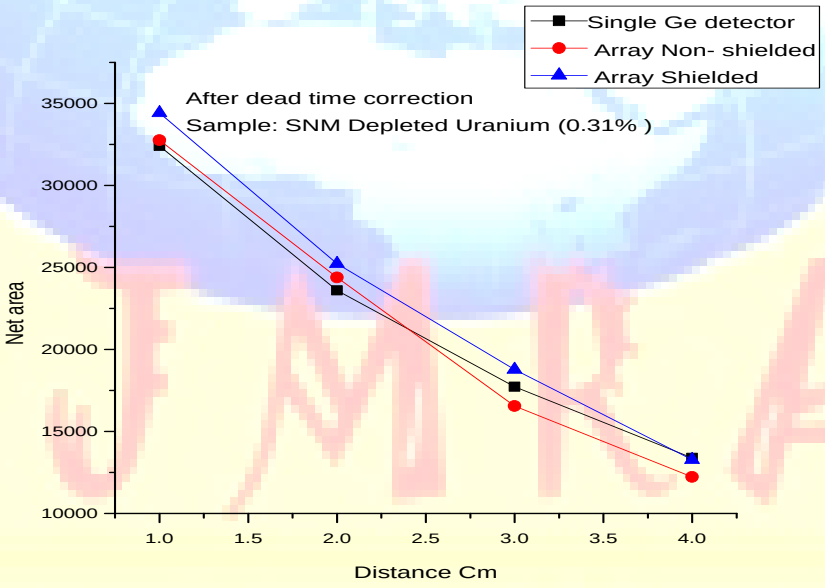



Fig.(12):Represents net area versus the distance between the Ge detector and the SNM (Depleted Uranium) in Design 1

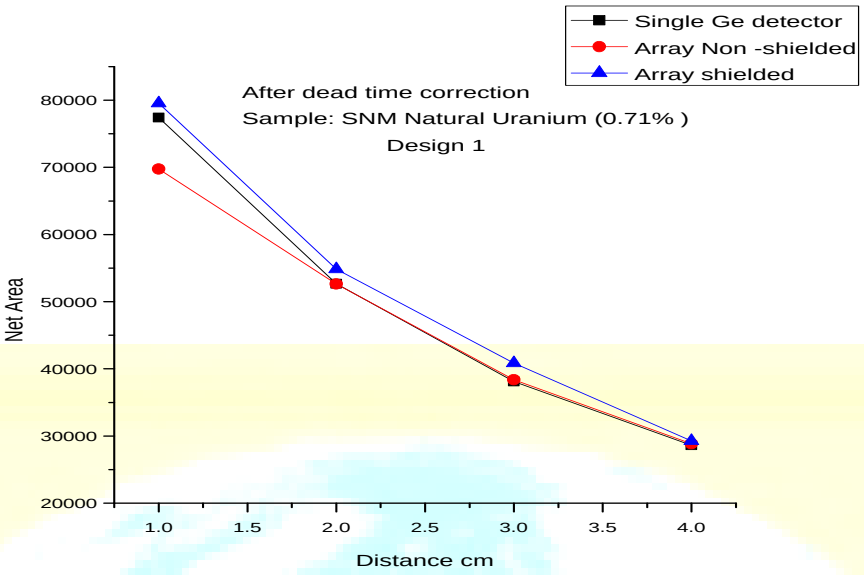



Fig.(13):Represents net area versus the distance between the Ge detector and the SNM (Natural Uranium) in design 1

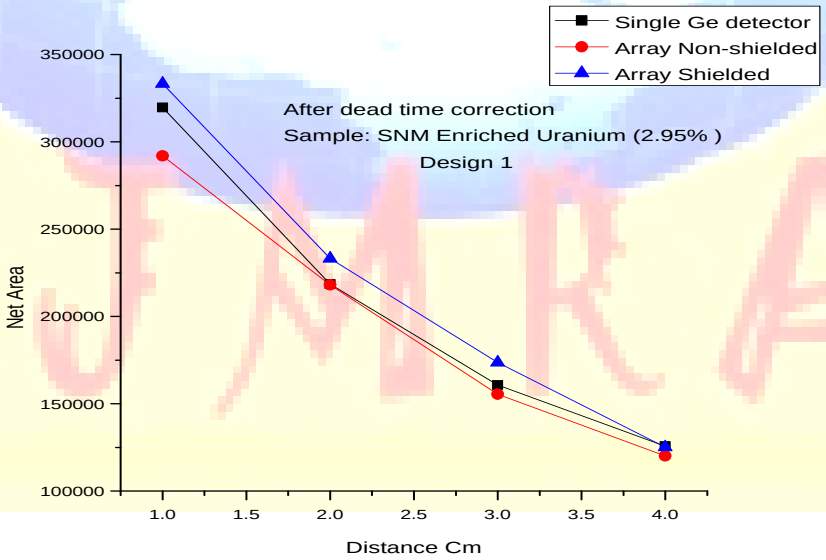



Fig.(14): Represents net area versus the distance between the Ge detector and the SNM (Enriched Uranium) in design 1

## 5. Conclusion

The problem of using anaccurate and sensitive technique for nuclear materials assay is essential forviable research and development. The optimized new design shows enhancement of theresults obtained in this work. It wasproved that the design number 2 gives the best P/C ratio results especiallyin the case of shielded arrays including point or cylindrical SNM sourcesof different enrichment percentages (%E).