Source-Detector Distance Dependence of Energy Resolution for NaI (Tl) Scintillation Gamma Ray Spectrometer

Nay Aung Kyi[1], Win Win Thein[2], Omma Sein[3], Mu Mu Kyaw[4]

Abstract

As the nuclear radiation has started to be used in a variety of different fields, it is important to be protected from it, and thus the radiation measurement becomes vital. The quality of the performance of a detection system used for the energy measurements is important. Two important performance parameters are the resolution and efficiency. The energy spectrum of a radiation source depends on the type and energy of the incident particle, the type of the detector and the details of the counting geometry. In this paper the energy resolution of a $1.5''\times2''$ NaI (Tl) detector had been measured for photon energies of 60 keV, 662 keV, 1173 keV and 1332 keV and its variation with the source-detector distance was investigated. The energy resolution of a detector system is obtained from the peak full width at one-half of the maximum height (FWHM) of a single peak as a function of detector-source distance. It was found that the energy resolution has decreased with the increasing distance.

Keywords: NaI (Tl) detector, nuclear radiation, energy resolution, FWHM

INTRODUCTION

As the nuclear radiation is getting used in a variety of different fields such as health physics, industry, energy and environmental application, radiation measurement becomes important. The quality of the performance of a detection system used for energy measurements is also important. It is characterized by the width of the pulse-height distribution, obtained with particles of the same energy. The energy spectrum of a radiation source depends on the type and energy of the incident particle and the type of the detector. An important aspect of an energy spectrum is the ability to distinguish gamma rays with slightly different energy. This is the so-called energy resolution, which is defined as the full width at half maximum (FWHM) of the photo peak at a certain energy. In this paper, the energy resolution of a $1.5''\times 2''$ NaI (Tl) detector has been measured for photon energies of 60 keV, 662 keV, 1173 keV and 1332 keV and its variation with the source-detector distance was investigated.

Experimental Methods and Calculations

For the gamma ray spectrometry, the energy resolution is an important parameter to be determined. The energy resolution of the NaI (Tl) detector has been determined experimentally at 60 keV, 662 keV, 1173 keV and 1332 keV energies obtained from ^{241}Am, ^{137}Cs and ^{60}Co radioactive isotopes.

The gamma ray spectrometry consists of $1.5''\times 2''$ NaI (Tl) detectors and it is connected to 4000-channel Multichannel Analyzer (MCA). The spectrum obtained from MCA

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is analysed by using the Measure-4 software obtained from PHYWE. Experimental set up of scintillation gamma detector has been displayed in Figure (1). Photograph of the radioactive sources used to obtain energies has been displayed in Figure (2). The three different radiation sources (^{241}Am, ^{137}Cs and ^{60}Co) that give 60 keV, 662 keV, 1173 keV, and 1332 keV. These gamma ray energies were placed at five different distances (0.5 cm, 2 cm, 4 cm, 6 cm and 8 cm) from the face of a detector and the measurement has been performed for each source. Each measurement has been done for a period of 300 sec. In Table (1) the present activity and half-life of the radioactive sources are given and nuclear decay data of the radioactive sources are tabulated in Table (2). Typical gamma spectrum for ^{241}Am, ^{137}Cs and ^{60}Co sources taken with the NaI (Tl) detector is given in Figure (3), (4) and (5).

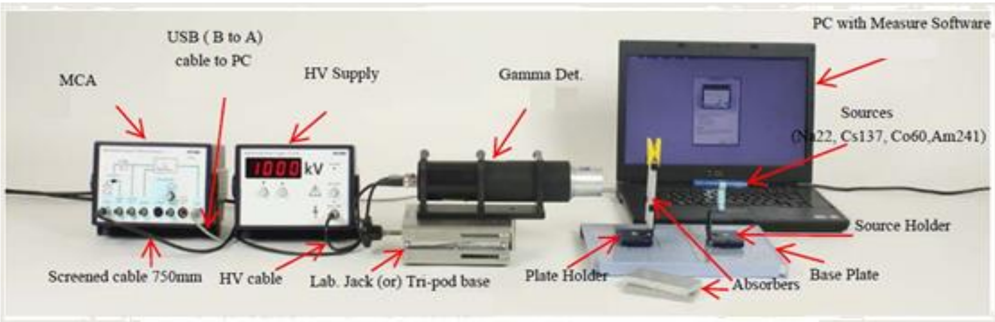

Figure (1) Experimental set up of Scintillation Gamma Detector

Figure (2) Photograph of the Radioactive Sources Used to Obtain Energies

Table (1) The Present Activity and Half-life of the Radioactive Sources Used to Obtain Energies

Nuclide	Original Activity (µCi)	Present Activity (µCi)	Half- life (years)
^{241}Am	2	1.995	432.20
^{137}Cs	5	4.839	30.10
^{60}Co	1	0.830	5.27

Table (2) Nuclear Decay Data of the Radioactive Sources Used to Obtain Energies

Parent nucleus	Decay mode	Daughter nucleus	Gamma-ray Energies (keV)	Gamma-ray Emission probabilities (%)
^{241}Am	α	Np-237	60	35.92
^{137}Cs	β^{-}	Ba-137	662	85.10
^{60}Co	β^{-}	Ni-60	1173 1332	99.85 99.98

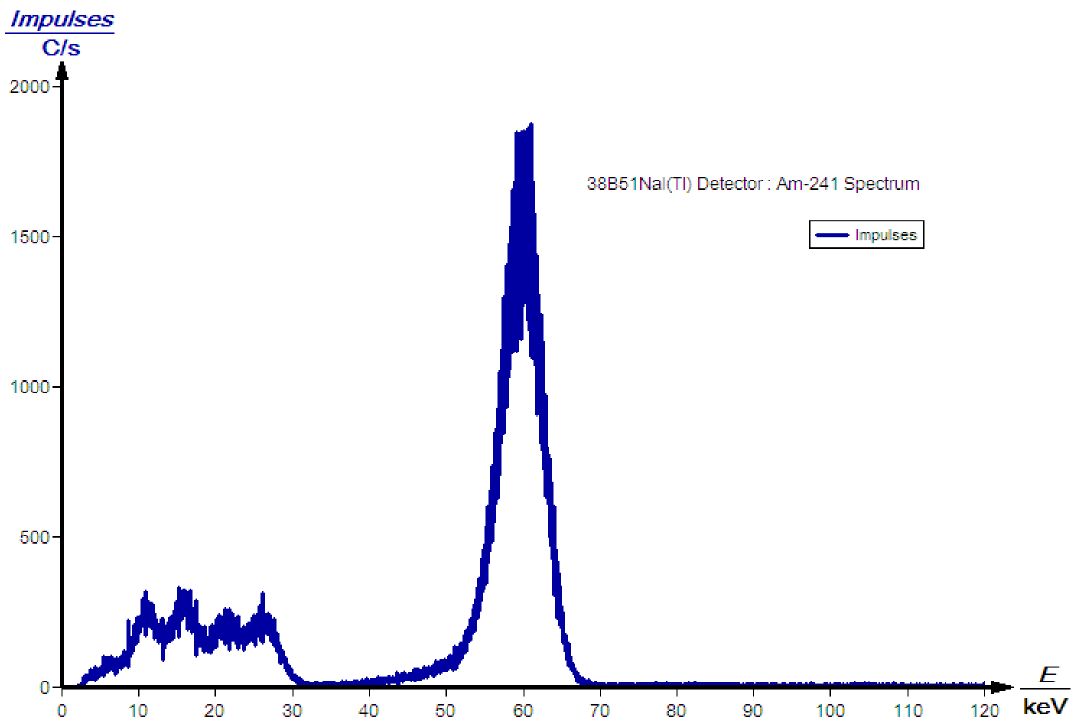

Figure (3) Gamma Ray Spectrum Obtained from ^{241}Am Source for 2 cm Distance

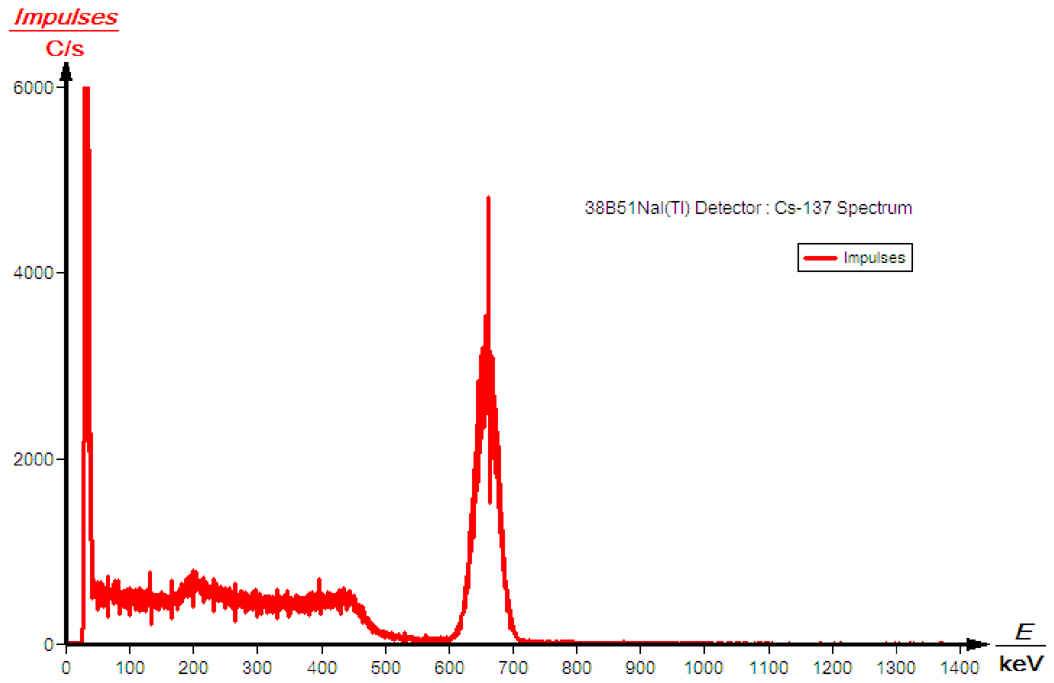

Figure (4) Gamma Ray Spectrum Obtained from ^{137}Cs Source for 2 cm Distance

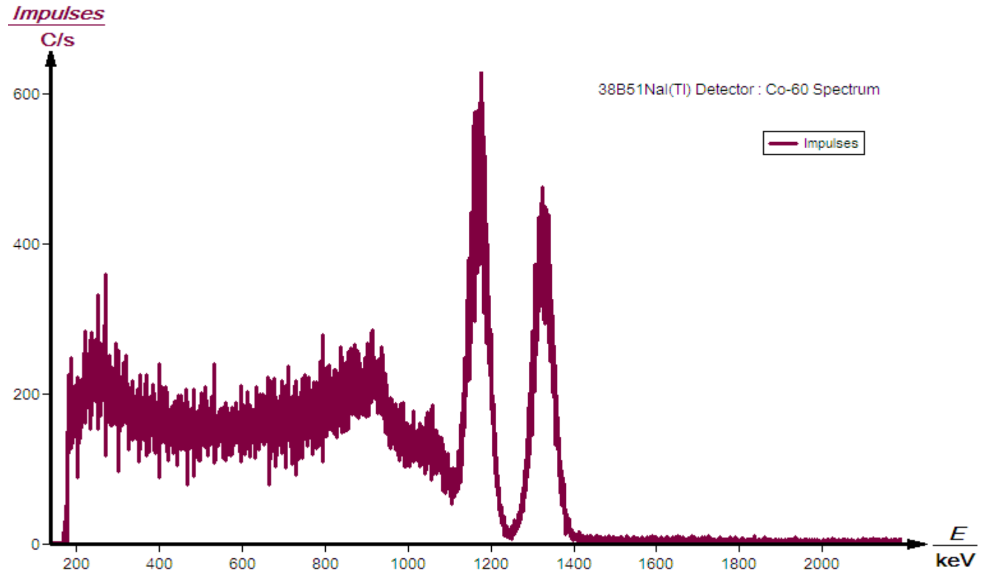

Figure (5) Gamma Ray Spectrum Obtained from ^{60}Co Source for 2 cm Distance

Energy Resolution

Energy resolution (R) is the ability of the detector to accurately determine the energy of the incoming radiation. The typical energy resolution that can be obtained with NaI (Tl) is ~7 % for the 662 keV ^{137}Cs gamma-ray line. Calculation of the FWHM energy resolution of a NaI (Tl) detector for ^{137}Cs is displayed in Figure (6). For NaI (Tl) detectors, the resolution is a strong function of energy. The resolution is primarily controlled by the statistical fluctuation of the number of photoelectrons produced at the photocathode surface in the photomultiplier tube.

The energy resolution should be checked at least quarterly. An increasing value indicates a problem with electronic noise, decoupling of the crystal and the PMT, yellowing of the crystal or a cracked crystal. With an MCA, the FWHM is easily checked in conjunction with daily calibration. The measured FWHM should be less than 10 %, using ^{137}Cs as the source. The energy resolution (in percent) is defined as

$$R = \frac{FWHM}{E_0} \times 100\ \% \qquad (1)$$

where E_0 is the related energy. R is better (i.e., its % value is lower) for higher energies.

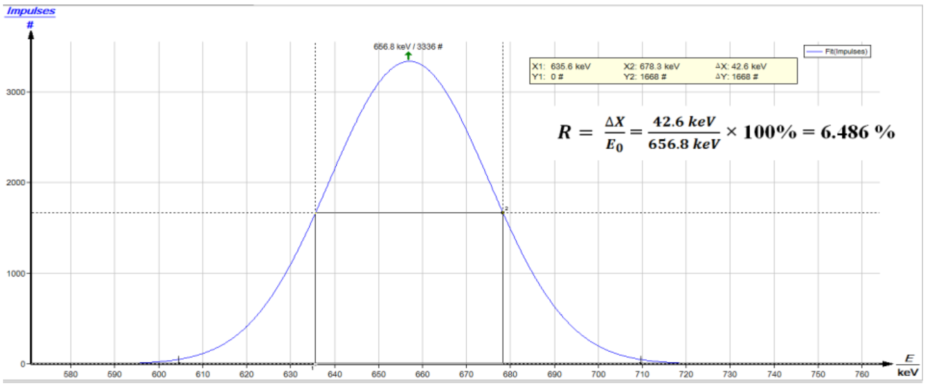

Figure (6) Calculation of the FWHM Energy Resolution of a NaI (Tl) Detector for ^{137}Cs (662 keV Gamma Ray)

RESULTS AND DISCUSSIONS

The properties such as energy calibration and energy resolution of a NaI (Tl) detector have been measured for 4 different gamma ray energies. The detector system should be calibrated before using in radiation detection in order to covert channel number to energy scale. This is carried out under laboratory conditions that mimic as closely as possible the experimental conditions. Several radioactive sources (at least three different energy peaks) are used to get certain peak to see channel number. This is usually done using ^{137}Cs and ^{60}Co radioactive sources as they produce γ-ray energy of 662 keV, 1173 keV, and 1332 keV respectively. The energy calibrations fit data for ^{137}Cs and ^{60}Co sources are tabulated in Table (3). In Figure (7), energy calibrations fit for ^{137}Cs and ^{60}Co sources have been displayed.

The energy resolution of the NaI (Tl) detector is obtained using equation (1) for each gamma ray energy emitted by the ^{241}Am, ^{60}Co, and ^{137}Cs radioactive isotopes. The obtained results for energy resolution (%) of $1.5'' \times 2''$ NaI (Tl) detector are tabulated in Table (4). The measured energy resolution of the NaI (Tl) detector is displayed in Figure (8) as a function of gamma ray energy. It can be seen from this figure that the energy resolution of the NaI (Tl) detector decreases with the FWHM with the increasing gamma ray energy.

As the energy resolution of the NaI (Tl) detector can vary with the distance to the detector face, the energy resolutions have been obtained from 5 different distances of the detector. The results are displayed in Figure (9), (10), (11) and (12) for five different distances and four different energies. It can be seen from these figures that the energy resolution decreases with the increasing distance from the detector's face. As seen in these figures, there is a great variety of analytical functions that is used to describe the energy resolution dependence on the source-detector distance. The solid line represents a second degree polynomial fit that gives a good description with the correlation coefficient between the energy resolution values and the source-detector distances, which is about $R^2 = 0.99$.

Table (3) Energy Calibrations Fit Data for ^{137}Cs and ^{60}Co Sources

Nuclide	Channel number	Energy (keV)
^{137}Cs	1278	662 keV
^{60}Co	2017	1173 keV
^{60}Co	2327	1332 keV

Table (4) Experimental Results for Energy Resolution (%) of 1.5″ × 2″ NaI (Tl) Detector

Energy (keV)	1.5″ × 2″ NaI (Tl) detector	Source-detector distance (cm)				
		0.5 cm	2 cm	4 cm	6 cm	8 cm
60	Energy Resolution (%)	11.298	11.055	10.942	10.850	10.740
662	Energy Resolution (%)	6.486	6.267	6.171	6.125	6.101
1173	Energy Resolution (%)	5.330	5.219	5.137	5.080	5.061
1332	Energy Resolution (%)	4.571	4.418	4.370	4.322	4.310

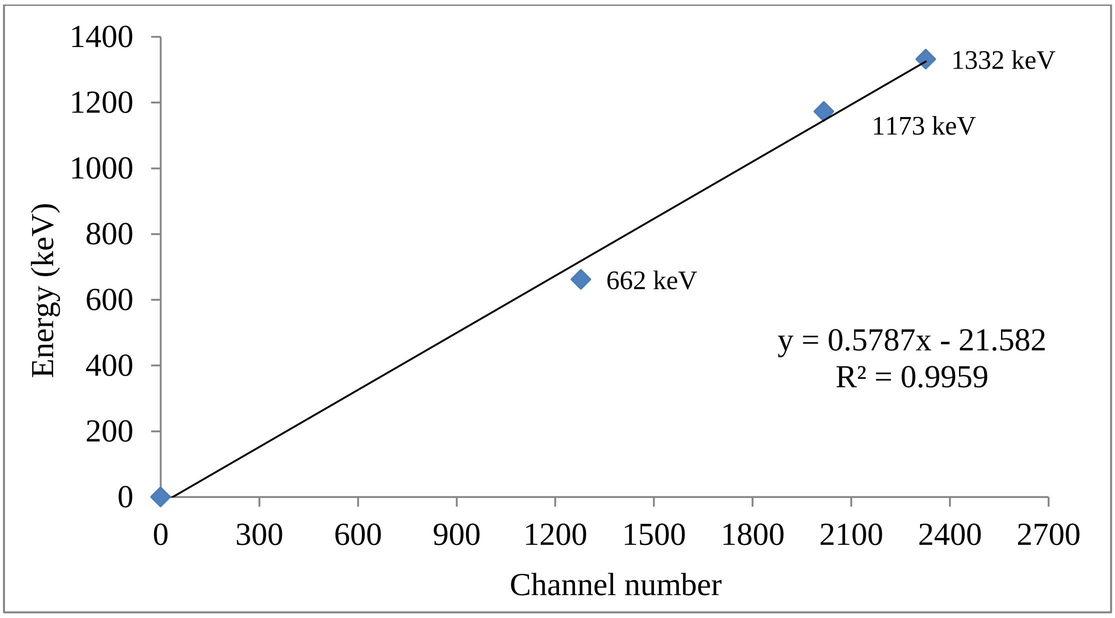

Figure (7) Energy Calibrations Fit for ^{137}Cs and ^{60}Co Sources

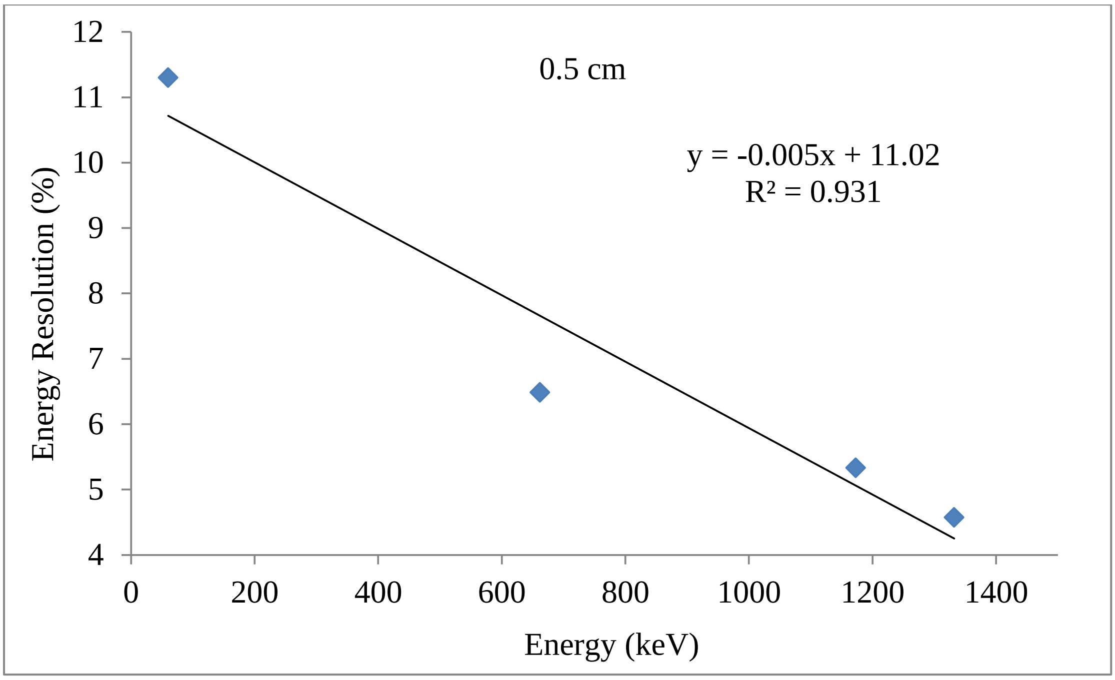

Figure (8) Energy Resolution of the NaI (Tl) Detector as a Function of Gamma Ray Energies Obtained for 0.5 cm Distance

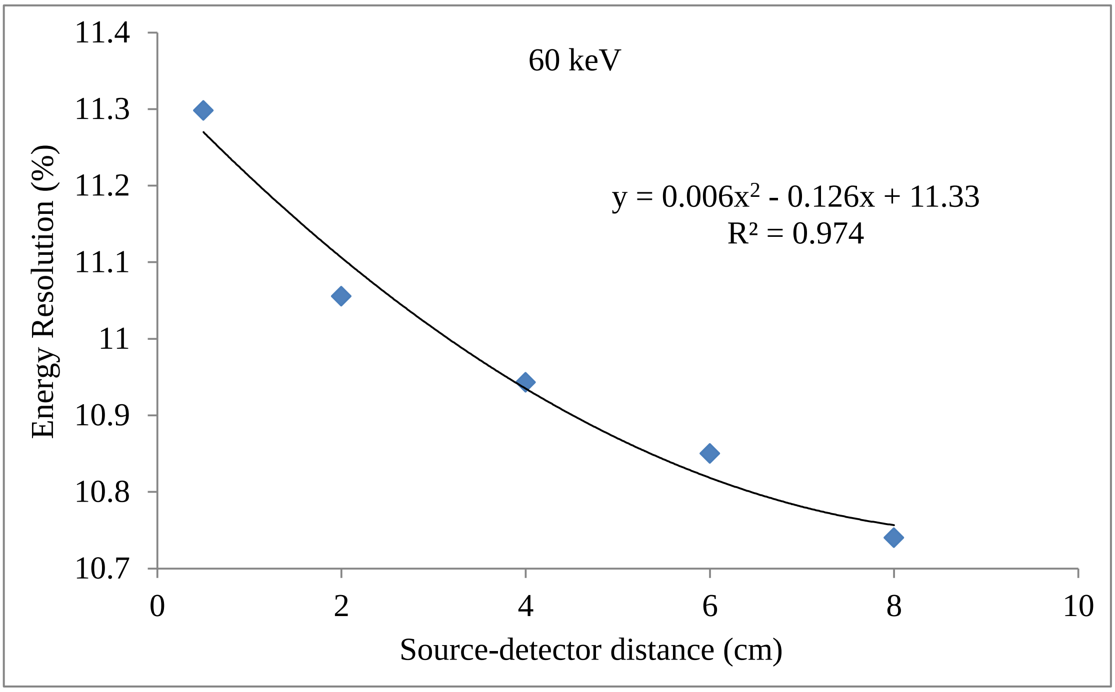

Figure (9) Variation of Energy Resolution as a Function of Distance for Gamma Ray Energy of 60 keV

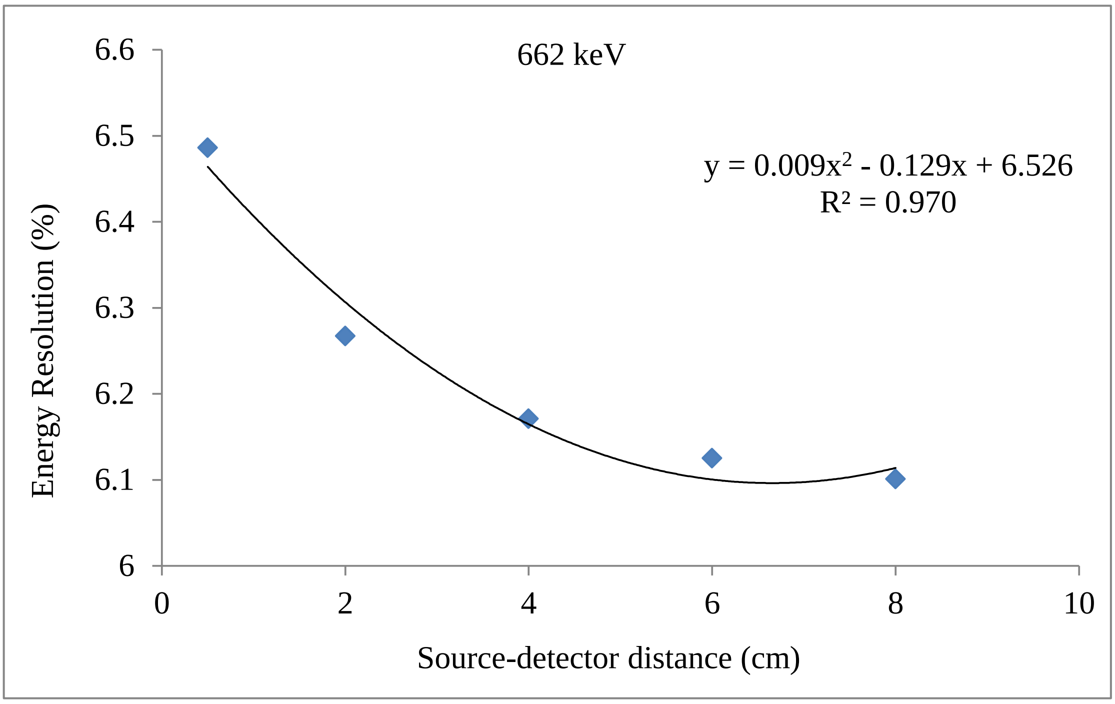

Figure (10) Variation of Energy Resolution as a Function of Distance for Gamma Ray Energy of 662 keV

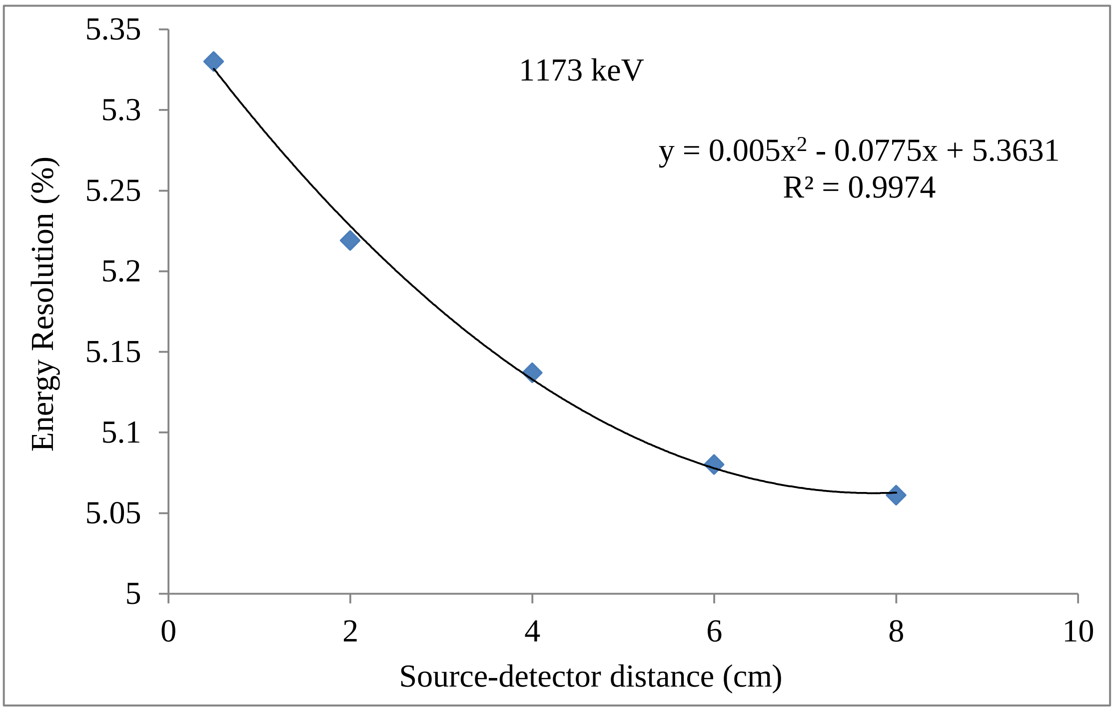

Figure (11) Variation of Energy Resolution as a Function of Distance for Gamma Ray Energy of 1173 keV

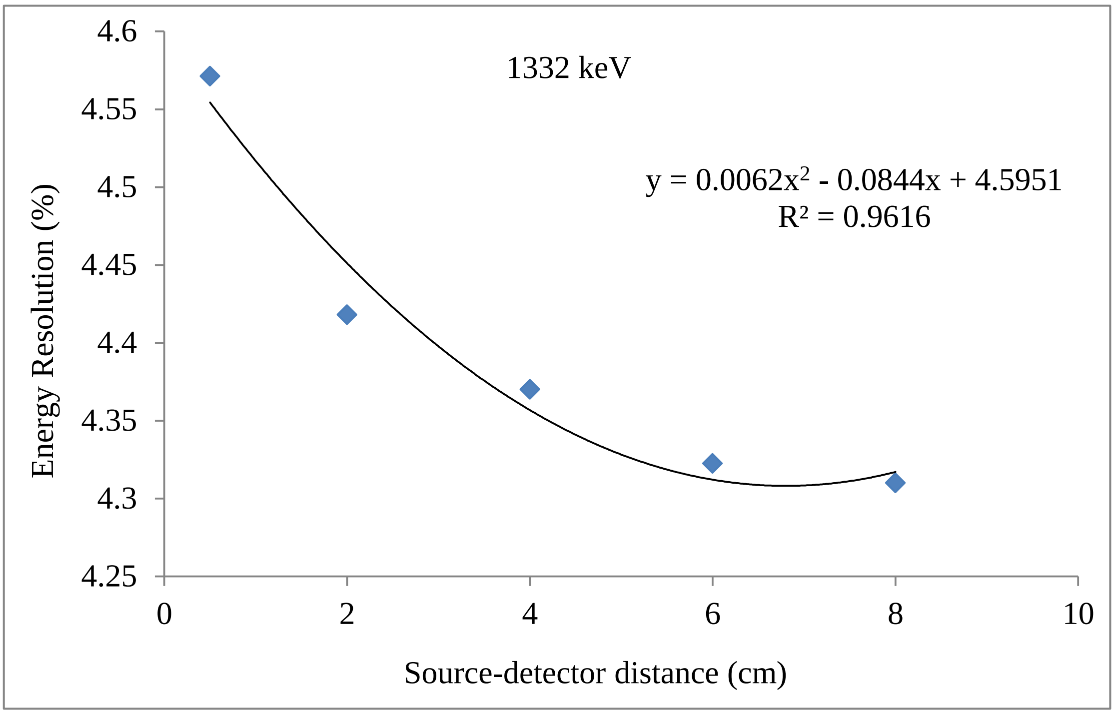

Figure (12) Variation of Energy Resolution as a Function of Distance for Gamma Ray Energy of 1332 keV

CONCLUSION

The energy resolution of 1.5″×2″ NaI (Tl) detector has been measured at five different distances from the radiation source at gamma ray energies of 60 keV, 662 keV, 1173 keV and 1332 keV obtained from ^{241}Am, ^{137}Cs and ^{60}Co radioactive sources. The results for energy resolution are described in Table (4). The variations of energy resolution values with the gamma ray energy and source-detector distance were also investigated. It was found that the energy resolution depends on gamma ray energy and is also a source distance to the detector.

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