Validation of detection efficiencies of NaI(Tl) scintillation detector in the energy range of 80–1332 keV

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Abstract: Amity Institute of Nuclear Science & Technology (AINST), Amity University Uttar Pradesh (AUUP) in technical collaboration with the Center for Nuclear Security Science and Policy Initiatives (NSSPI) at Texas A & M University (TAMU), Oak Ridge National Laboratory (ORNL) and financial assistance from Defense Threat Reduction Agency (DTRA), jointly established the Nuclear Security Educational Laboratory. Detectors play a significant role in quantification of radiation irrespective of their applications in many different fields namely health physics, industry, energy, and environmental application. Consideration must also be given to efficiency of these devices as no detector can have 100% efficiency. It can vary with the volume and shape of the detector material, absorption cross-section in the material, attenuation layers between source and detector, and distance and position from the source to the detector. However, absolute efficiency of the detector depends on detector properties and also on the details of the counting geometry. In the present work, a straightforward analytical for the computation of total and full-energy peak efficiencies formulation using Osprey MCA based NaI (Tl) detector ranging energies from 80 to 1332 keV are presented. To obtain the energies various standard gamma ray sources supplied by BRIT, India were used. The variation of detection efficiency with the gamma ray energy and detection distance has also been investigated. Moreover, these experimental results are compared with the existing literature for conformity.

1. Introduction:

Scintillation detectors are commonly used in various fields such as health physics, industry, and environmental measurements as they are considered to be a fundamental instrument among radiation detectors. To operate these systems, it is essential to have accurate knowledge of the detection efficiency, which is determined by several factors such as the source-detector geometry, detector electronics, and peak-analysis procedure. The detection efficiency plays a crucial role in determining the amount of radiation emitted by a radioactive source and the amount measured in the detector [1]. The detection efficiency of a detector system is influenced by several parameters, such as the type and energy of radiation being detected, the detector material and geometry, and the presence of additional materials such as collimators or attenuators. Accurate measurement of radioactivity requires precise knowledge of the absolute efficiency of the detector system. This parameter is determined by calculating the ratio of the number of counts registered by the detector (N_C) to the total number of radiation emitted by the source (N_S) in all directions, as shown in the following equation [2]:

$$\xi_{abs} = N_C/N_S \quad \ldots\ldots(1)$$

The detector's overall efficiency is influenced not only by its inherent properties but also by the specific characteristics of the counting geometry. Several studies have been conducted to investigate the detection efficiency, as reported in the literature [3-8].

In gamma ray spectrometry, determining the absolute efficiency and energy resolution is crucial. As the number of energy peaks obtainable from radioactive sources is limited, these parameters are typically derived by fitting a function to the efficiency data over a wide range of energies. In this study, we experimentally determined the absolute efficiency and energy resolution of a NaI(Tl) detector at eight different energies (80 keV, 122 keV, 302 keV, 356 keV, 662 keV, 835 keV, 1173 keV and 1332 keV), using radioactive isotopes including ^{54}Mn, ^{57}Co, ^{60}Co, ^{133}Ba and ^{137}Cs.

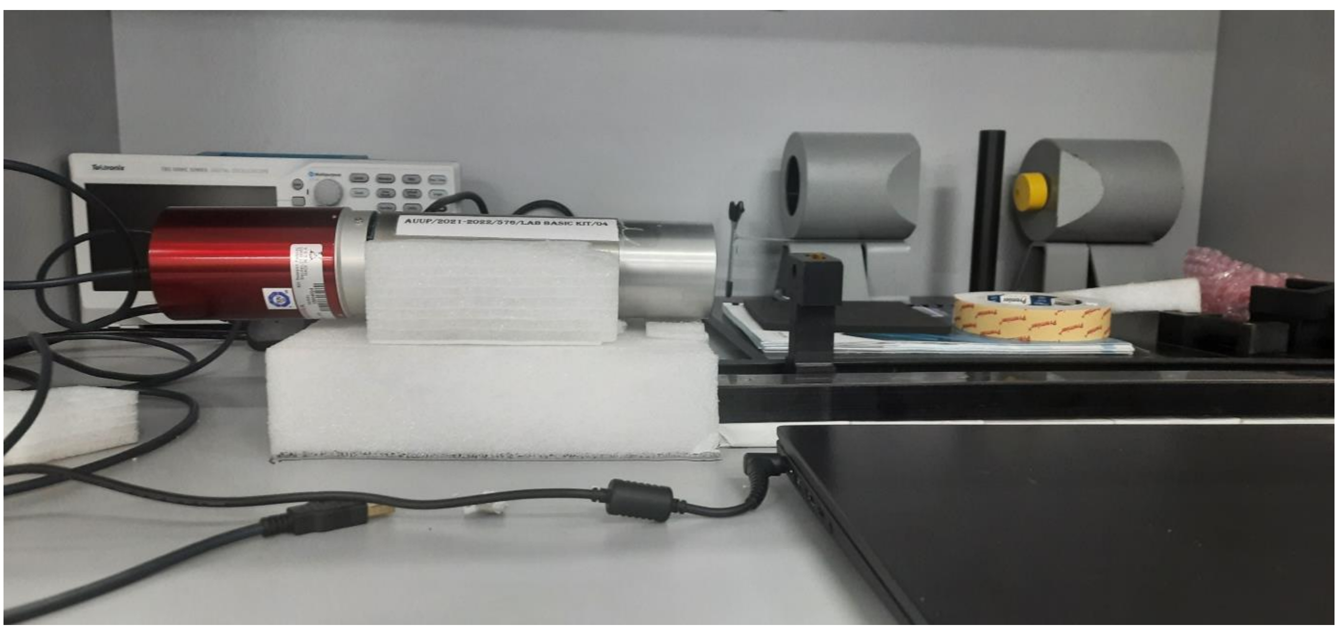

Figure 1: Experimental setup along with position of radioactive source.

2. Experimental Details:

A 2" × 2" NaI(Tl) detector was utilized in gamma ray spectrometry, connected to an osprey-based 2048-channel Multichannel Analyser (MCA). The resulting spectrum was analyzed using the Genie 2000 software from Canberra [9-11]. Data was acquired in tool kit format and subsequently converted into a two-column format before being converted into the RADWARE format [12,13]. Energy and channel numbers were identified, and the experimental data was calibrated using custom software packages developed in ROOT [14]. Figure 1 shows a schematic view of the system.

Measurements were taken using five different radiation sources obtained from BRIT, India (^{54}Mn, ^{57}Co, ^{60}Co, ^{133}Ba and ^{137}Cs) at three different distances (4, 8, and 12 cm) from the face of the detector. The sources emitted gamma rays with energies of 80 keV, 122 keV, 302 keV, 356 keV, 662 keV, 835 keV, 1173 keV, and 1332 keV. Each measurement was taken for a period of 30 minutes to ensure sufficient statistics for evaluating each gamma peak. The complete calibrated spectrum is shown in Fig. 2.

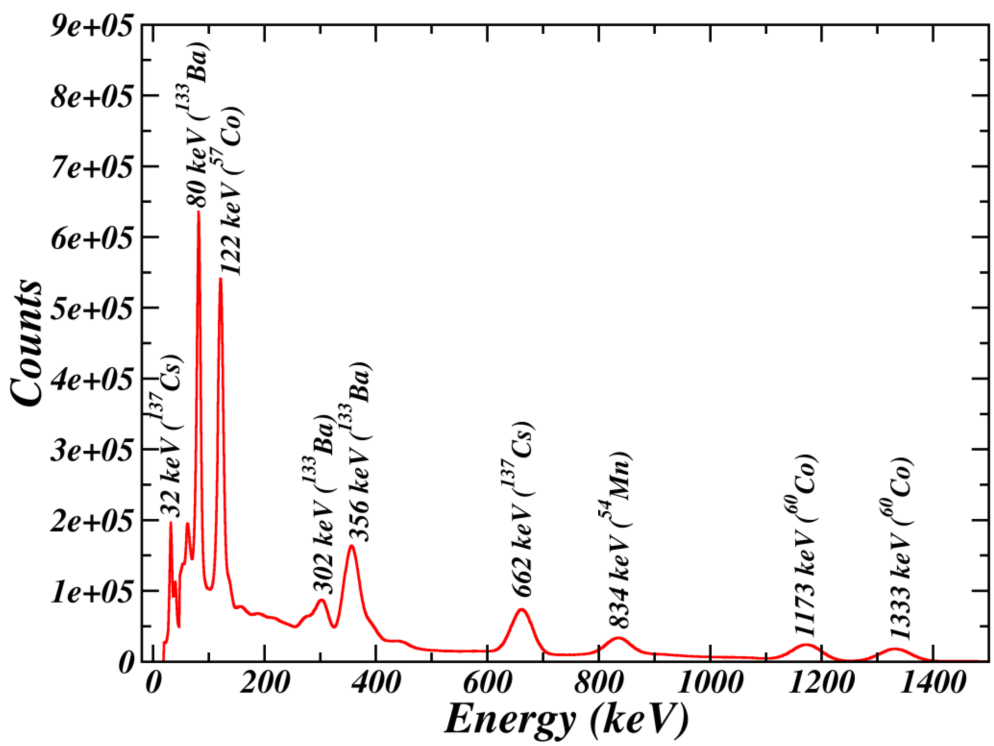

Fig 2: The calibrated gamma ray spectrum obtained from the combination of five different sources ^{54}Mn, ^{57}Co, ^{60}Co, ^{133}Ba and ^{137}Cs.

3. Results and Discussions:

Measurements were conducted to determine properties such as energy calibration, energy resolution, and detector efficiency of a ospray based NaI(Tl) detector.

(a) Energy Calibration:

Energy calibration is a critical step in gamma ray spectroscopy that establishes the relationship between the energy of detected photons and their corresponding channels in the detector. It involves identifying reference gamma-ray sources with known energies, typically emitting mono-energetic photons, and measuring their peaks in the detector spectrum. By fitting a mathematical function to these peaks, a calibration curve is generated, which can be used to convert channel numbers in the spectrum to corresponding gamma-ray energies. The energy calibration of the combined photopeaks were calibrated using the relation

$$E\gamma = a + bx + cx^2 + dx^3 + ex^{1/2} + fx^4 \text{ ---}(2)$$

where, x represents the channel number. The a, b, c, d, e, and f are the calibration coefficients. Here we have used six-point calibration including the $x^{1/2}$ factor, which is mainly useful for low energy calibration. The fitting is presented in Fig 3.

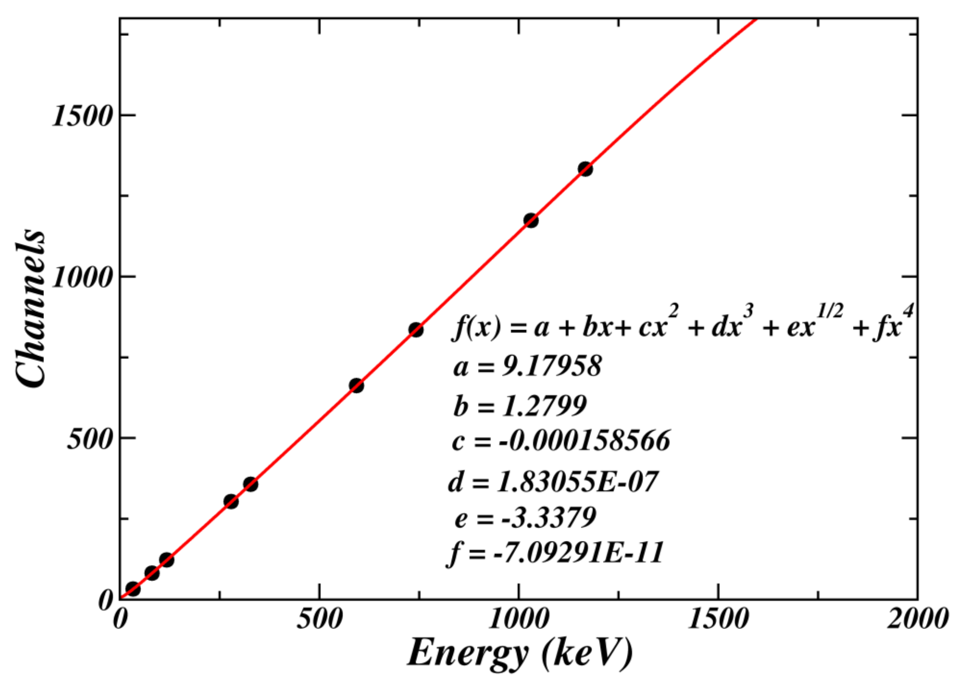

Fig 3: The measured and the fitted calibration plot for five radioactive sources ^{54}Mn, ^{57}Co, ^{60}Co, ^{133}Ba and ^{137}Cs for a 2” × 2” NaI(Tl) detector.

(b) Energy Resolution:

Energy resolution is a critical parameter for gamma ray detectors that measures the ability of the detector to distinguish between photons of different energies. It is defined as the full width at half maximum (FWHM) of the peak in the energy spectrum divided by the energy of the gamma ray. A detector with good energy resolution has narrow peaks, allowing for the detection of closely spaced energy lines and improved identification of radionuclides in complex spectra. The energy resolution of a detector depends on its intrinsic properties such as the crystal material, size, and shape, as well as external factors such as temperature and electronics. The energy resolution of a detector system can be determined by calculating the full width at half maximum (FWHM) of a single peak using the following equation:

$$R\ (\%) = (FWHM/E\gamma) \times 100 \text{ --(3)}$$

Energy resolution (R) is a key parameter in gamma ray spectroscopy that characterizes the detector's ability to distinguish between photons of different energies. A smaller value of R corresponds to better energy resolution and allows for the detection of closely spaced energy lines. The measured energy resolution of the NaI(Tl) detector as a function of gamma ray energy is shown in Figure 4. As seen from the figure, the energy resolution of the detector improves with increasing gamma ray energy, as indicated by the decreasing FWHM. Accurate determination of energy resolution is important for identifying different nuclides in a spectrum and for improving the overall accuracy of gamma ray measurements. The variation of resolution as a function of the gamma-ray energy $E\gamma$, has been fitted with a polynomial relation as

$$R(\%) = p + q(E\gamma) + r(E\gamma)^2 \text{ --(4)}$$

where p, q, and r are the fitting coefficitents.

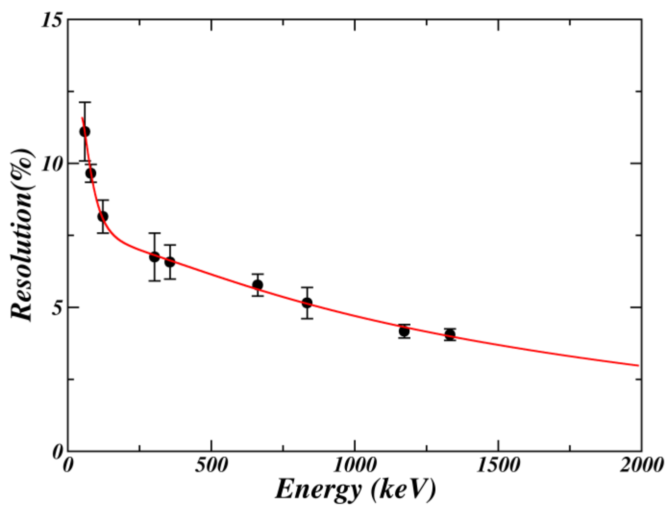

Fig4: Variation of resolution as a function of gamma energy for a 4cm distance of the source.

b) Absolute Efficiency of the detector:

Absolute efficiency is a term used to describe the effectiveness of a radiation detector in detecting and measuring the intensity of radiation from a source. It represents the fraction of incident radiation that is actually detected by the detector. The absolute efficiency depends on the detection mechanism, the energy of the radiation, the geometry of the detector, and the distance between the source and detector. A high absolute efficiency is desirable in order to detect as much radiation as possible, but it is often limited by factors such as the detector's physical size and the energy range of the radiation being detected. Measuring and understanding the absolute efficiency of a detector is important for a wide range of applications in fields such as nuclear physics, medical imaging, and environmental monitoring.

In this study, the absolute efficiency of the detector was measured at source distances of 4 cm, 8 cm, and 12 cm. Fig. 5 shows the variation of efficiency as a function of gamma energy. The experimental efficiency data was fit using the following functions:

$$\xi(\%) = l + m/(E\gamma) + n/(E\gamma)^2 \text{ --(5)}$$

Where l, m, and n are the fitting parameters that describe the efficiency coefficient. A detailed description of the complete procedure will be presented during the conference.

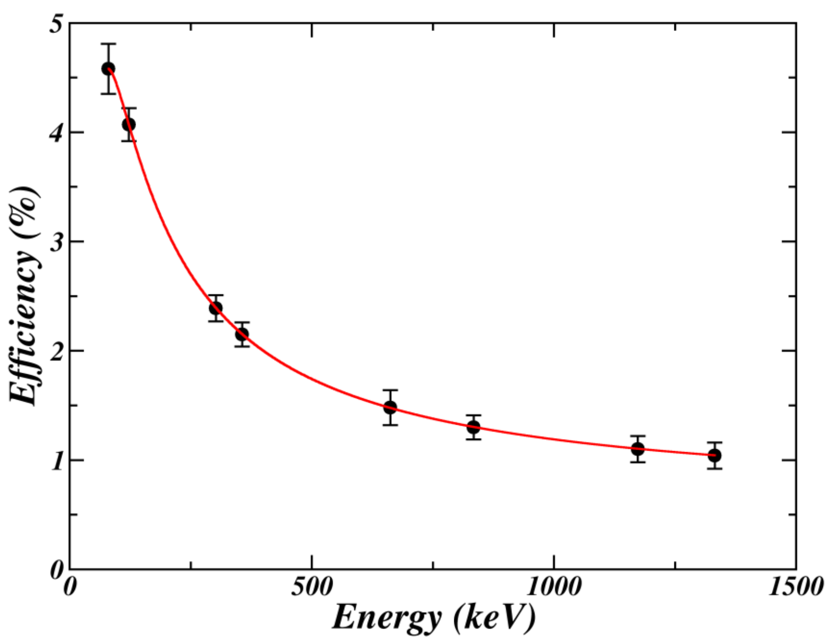

Fig5: Variation of photo-peak efficiency as a function of gamma energy for a 4 cm the distance of the source.

Summary:

In this study, we conducted measurements to determine the detection efficiency and energy resolution of NaI(Tl) scintillation detectors. Additionally, we investigated how the detection efficiency varies with gamma ray energy and detection distance. Our findings suggest that the detection efficiency is influenced by both the gamma ray energy and the distance between the source and the detector. These results can have important implications for applications in nuclear physics and radiation detection, as they can inform the design and optimization of detection systems for specific experimental conditions. The complete results will be described during the meeting.

Acknowledgement:

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