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# A Study on Calculation of Full Energy Peak Efficiency of NaI (Tl) Detectors using Point Source

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**Abstract:** In this study, the energy dependence of efficiency and resolution of NaI(Tl) detector were investigated using gamma ray spectrometry system. The full energy peak efficiency and energy resolution of NaI(Tl) detector were experimentally measured using $^{152}$Eu, $^{137}$Cs, and $^{60}$Co radioactive sources at the energy range of 204 keV to 1408 keV. It was found that that the efficiency and resolution of NaI(Tl) detector decreases with the increasing gamma ray energy.

**Keywords:** NaI (Tl) gamma ray spectrometer, Full energy peak efficiency, Point source

## 1. INTRODUCTION

Gamma-ray spectrometry with NaI(TI) scintillation detector is broadly used instruments in various research areas such as high energy physics, nuclear physics, environmental studies, nuclear medicine, industry and radiation protection (Moszyński et al., 2016). Especially it is used to make qualitative and quantitative analysis of natural and artificial radionuclides in various samples. Because of its high detection efficiency, NaI(TI) scintillator detector is the most commonly used materials for detection of gamma rays. The advantage of this spectrometer is that it is cheap and is operated without using liquid nitrogen in room temperature conditions (Gilmore and Hemingway, 1995; Tsoulfanidis 1995).

The full energy peak efficiency (FEPE) of a detector system is related to the measurement conditions such as the source and detector geometry, and the various detector parameters including detector type (scintillation, solid state), the density and size of the detector material (Diango et al.,2017; Perez-Andujar et al., 2004). A full-energy peak contains all the information about a radionuclide therefore, accurate knowledge of FEPE is one of the most important parameters in gamma ray spectrometry practice to identify and quantify gamma activity of any radionuclides (Diango et al., 2017).

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Recently various study has been carried out using either by measurement or by calculation methods to determine FEPE and energy resolution of NaI(TI) detector and improve the new efficiency calibration techniques.

Akkurt et al. (2014) experimentally determined absolute efficiency and energy resolution of a 3×3 NaI(Tl) detector for 511, 662, 835, 1173, 1275 and 1332 keV photon energies and also investigated variation of detection efficiency with the gamma ray energy and detection distance. Demir et al. (2008) experimentally determined the photopeak efficiency and energy solubility of 3 x 3 NaI (Tl) detector for photon energies between 23 and 1,333 keV using polyester coated radioisotopes such as $^{22}$Na, $^{54}$Mn, $^{57}$Co, $^{60}$Co, $^{109}$Cd, $^{137}$Cs and $^{133}$Ba. They also measured energy resolution of the NaI (Tl) detector. El-Khatib et al. (2016) calculated full energy peak efficiency of a Well-type NaI(Tl) detector using analytical method and ANGLE 4 software based on radioactive point sources located out the well cavity. Kadum and Dahmani, (2014) determined detection efficiency of a well type 2×2 NaI(Tl) detector using several calculations including linear attenuation coefficient, geometric and intrinsic efficiencies. In this study, the FEPE and the energy resolution of NaI (TI) detector were measured experimentally using the polyester coated point radioactive sources $^{152}$Eu, $^{137}$Cs and $^{60}$Co) at 244.69, 344.27, 661.66, 778.89, 963.38, 1173.24, 1332.50 and 1407.95 keV. The full energy peak efficiency and total efficiency of a 3×3 NaI(Tl) detector were measured by Akar Tarim and Gurler 2018 at different axial distances. They investigated the effects of the gamma ray energies and the effects of distance the source to detector on detector efficiency using four different point sources such as $^{241}$Am, $^{137}$Cs, $^{60}$Co and $^{22}$Na that have peak at 59.5,511,661.6,1173.2,1274.5 and 1332.5 keV.

## 2. MATERIALS AND METHODS

The experiments were carried out in the radiation measurement laboratory, Department of Physics, Kafkas University, Turkey using gamma ray spectrometry system. The spectrometer consists of a 3×3 NaI(Tl) detector that connected to 1024-channel Multichannel Analyzer (MCA). Experimental set up of NaI (Tl) gamma ray spectrometer is shown in Figure 1.

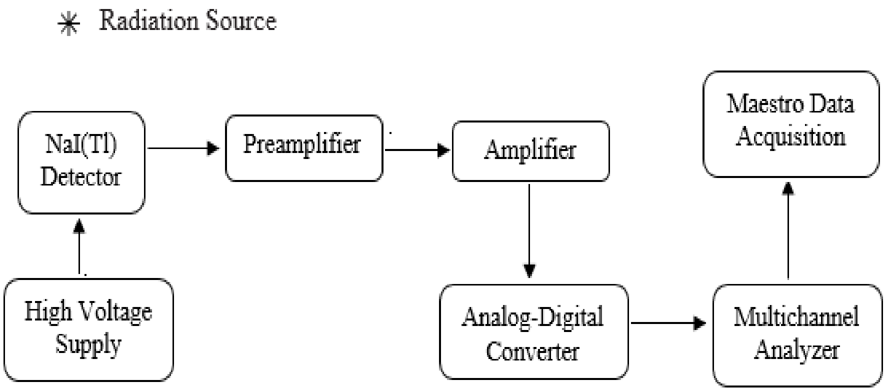


**Figure 1.** Schematic diagram of the experimental setup.

Thallium doped sodium iodide scintillation detector NaI(Tl), 7.6 cm diameter x 7.6 cm thickness crystal and biased at 700 V, was used for measurements. The gamma-ray spectra were analyzed using the Maestro-32 software package for nuclide identification, peak searching, peak evaluation, data acquisition, energy and efficiency calculation. For reducing the background radiation due to cosmic rays and radiation near the system, the detector is protected by using 6 cm lead from each side. To determine full-energy peak efficiency three different polyester coated point sources of $^{152}$Eu, $^{137}$Cs, and $^{60}$Co were used in the experiments. The activity, half-life and other different nuclear parameters of the radionuclides from taken the available literature are listed in Table 1 (IAEA, 1989).

**Table 1.** Different nuclear parameters of the radionuclides used in the experiments (IAEA, 1989).

| Nuclide | Energy (keV) | Half-life (year) | Emission Probability (%) | Present Activity (kBq) |
|---|---|---|---|---|
| $^{152}$Eu | 244.69 | 12.7 | 7.51 | 171.25 |
| | 344.27 | | 26.58 | |
| | 778.89 | | 12.96 | |
| | 963.38 | | 14.0 | |
| | 1407.95 | | 20.85 | |
| $^{137}$Cs | 661.66 | 30.1 | 85.00 | 129.48 |
| $^{60}$Co | 1173.24 | | 99.85 | 4.82 |
| | 1332.50 | 5.27 | 99.9824 | |

Point sources were placed at 6.5 cm from the top of Al windows of the NaI (Tl) detector and the measurement were performed for each point source. The counting time was selected 3600 second for each point source to obtain good statistics in the evaluation of each gamma peak. The measured gamma ray spectrum of the $^{137}$Cs and $^{60}$Co radionuclides are given in Figures 2 and 3, respectively. The obtained gamma ray spectra were analyzed using the Maestro-32 software package.

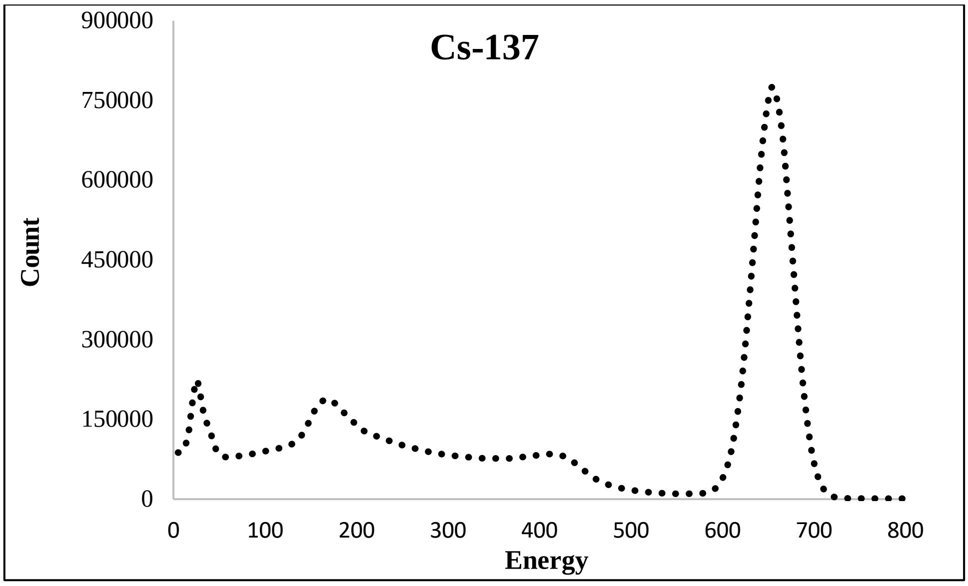


**Figure 2.** The energy spectrum determined in the 3x3 NaI(Tl) scintillation detector for 661.66 keV line from a $^{137}Cs$ source.

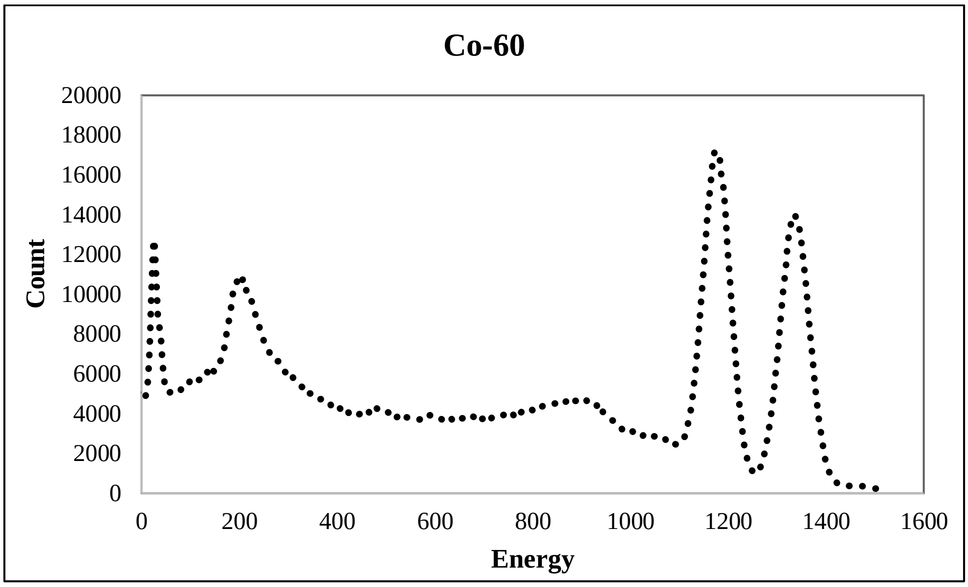


**Figure 3.** Gamma ray spectrum of $^{60}Co$ measured with NaI (Tl) scintillation detector.

## 3. RESULTS AND DISCUSSION

### 3.1. Full-Energy Peak Efficiency

The full-energy peak efficiency is the one of most significant parameter in practical gamma ray spectrometry and conventionally expressed as the ratio of the number of gamma-ray photons detected in the photo peak to the number of gamma rays of the photo peak energy emitted by the source (Tsoulfanidis 1995). The experimental full energy peak efficiency value of NaI(Tl) detector at gamma ray energy (E) can be determined using following expression 1 for a given set of measuring conditions (Demir et al., 2008).

$$\varepsilon(E) = \frac{N(E)}{T_m A_S P(E)} C \qquad (1)$$

where, N(E), is the gamma count rate under the full-energy peak after background subtracted, Tm is the measuring time in seconds and P(E) is the gamma ray emission probability for each of interested radionuclides. $A_S$, is the activity of each radionuclide at the time of the measurement in Bq and it is estimated using following well known decay equation (2) (Faanu et al., 2011).

$$A_S = A_0 e^{-\lambda \Delta T} \qquad (2)$$

where λ is decay constant and equals $ln2/T_{1/2}$, $T_{1/2}$ is the half-life of the radio nuclides. ΔT is the time elapsed between the run and the reference time, $A_0$ is initial activity of radionuclide C is the correction coefficient and consist of three factor G, I and M which indicate the efficient absorption of the photons emitted by the source and it is calculated through the formula (3): (Demir et al., 2008; Kadum and Dahmani, 2015).

$$C = G \times I \times M \qquad (3)$$

where, *G* is the geometric solid angle factor, *I* is the fraction of the photons transmitted by the intervening materials that reach the detector surface and is calculated by using equation (4):

$$I = \exp(\mu_{Al}(E) L_{Al}) \qquad (4)$$

where $\mu_{Al}$ is the linear attenuation coefficient of aluminum, $L_{Al}$ is the thickness of the aluminum container. M is the fraction of photons absorbed by the detector and given by equation (5):

$$M = 1 - \exp\left(-\mu_{NaI(Tl)}(E) L_{NaI(Tl)}\right) \quad (5)$$

where μ(E) is linear attenuation coefficient in NaI(Tl) crystal for gamma ray with energy E, and $L_{NaI(Tl)}$ is the length of crystal (Demir et al., 2008; Kadum and Dahmani, 2015).

The mass attenuation coefficients of the aluminum and NaI(Tl) crystal were determined at the energies of interest by using XCOM software which can be used for calculating mass attenuation coefficients any element, compound or mixture at photon energy from1 keV to 100 GeV. The experimental photopeak efficiency values of NaI(Tl) detector obtain from equation 1 is given in Figure 4 as a function of photon energy.

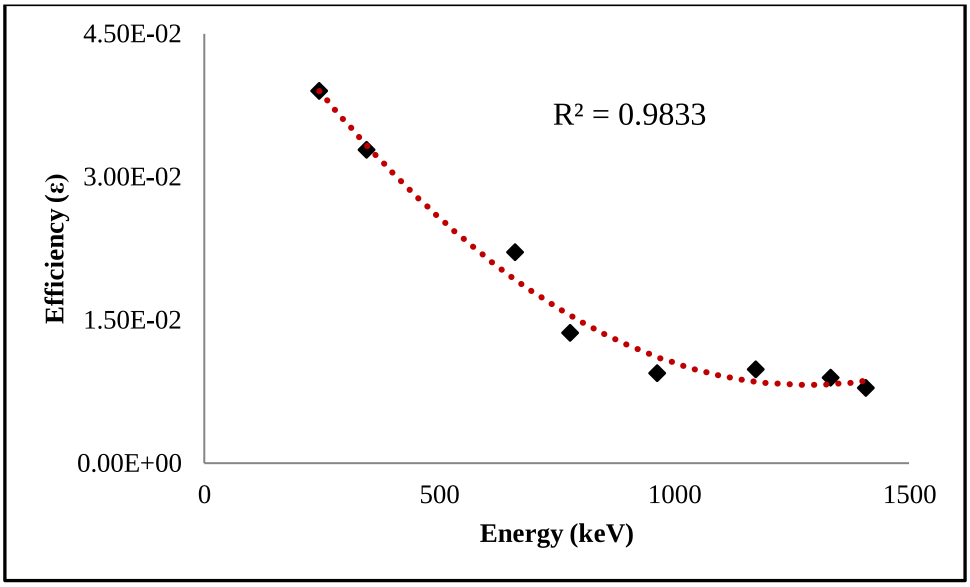


**Figure 4.** The FEP efficiency of NaI(Tl) detector as a function of energy.

The solid data points given in Figure 4 represent the experimental gamma ray photopeak efficiency values for the gamma-ray energy lines. The experimental data points were fitted a second degree polynomial equation using the M.S. EXCEL program and given as a function of gamma ray energy. Correlation study was performed and analysis showed a strong correlation between the efficiency values and the gamma ray energies with the significant value of $R^2$=0.9833.

As can be seen from Figure 4, the maximum efficiency value of the detector was measured at 244.69 keV energy. As was expected, the detector efficiency is high in the low energy region and slowly decreases with increasing energy. This may be due to decreased in the number of photoelectric events and increased Compton scattering as energy increases. The overall experimental error was found to be less than 6%. The obtained full peak efficiency FEPE values were found to be compatible with the previously reported result for the same size NaI(Tl) detector (Akkurt et al 2014, Akar Tarim and Gurler 2018).

### 3.2. Energy Resolution

Energy resolution of a detection system is described the ability of a detector to identify particles of different energies. It is given either as the full width half maximum (FWHM) of a spectrum peak in energy or as a percentage of the peak energy, E (Gilmore and Hemingway, 1995). The experimental resolution is estimated using equation (6),

$$R(E_0) = \frac{FWHM}{E_0} \tag{6}$$

where R is the energy resolution and $E_0$ is the energy of related point. As can be seen the equation Energy resolution is defined as the ratio of FWHM to the energy of that peak (E0) and depends on the detector type and the energy of gamma photons (Hoang et al., 2017).

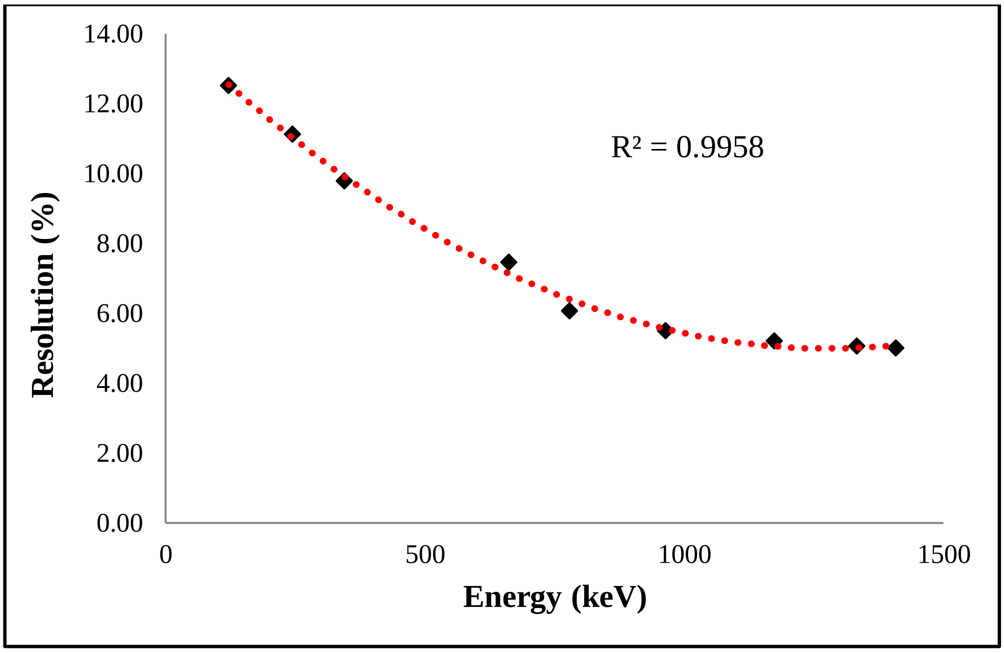


**Figure 5**. Energy resolution of the NaI(Tl) detector

Figure 2 presents the measured energy resolution of the NaI(Tl) detector as a function of gamma ray energy. The energy resolution for the 661.6 keV gamma rays of the $^{137}Cs$ source were measured 7.48% which is compatible with recommended value of 7.5% by manufacturer. As can be seen from the Figure 2, the resolution of the NaI(Tl) detector is decreased with the increasing gamma ray energy. This results are in good agreement with the results of similar studies available in literature (Demir et all., 2008, Akar Tarim and Gurler 2018, Akkurt et al. 2014).

## 4. CONCLUSION

In this study, the full energy peak efficiencies of NaI (Tl) detector was determined experimentally using a gamma ray spectrometer system in the energy range of 244 keV to 1408 keV. It is clear from the results that a NaI (Tl) detector has high efficiency, so it is the appropriate detector for use in various research areas, even if it has low energy resolution. The results of this study can provide a fundamental database for further studies with this system.

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