Determination of Resolution and Detection Efficiency of NaI (Tl) Scintillation Gamma-Ray Spectrometer

Su Su Win[1], Nyein Nyein[2], Nyi Nyi Tun[3]

Abstract

NaI (Tl) scintillation detector is the most commonly used scintillator in experimental physics for the measurement of the gamma-ray activity of various samples. This detector is used in the measurement of nuclear reaction cross-section induced by neutrons and protons in the activation technique. In addition, the scintillation detector has a lot of applications in the elemental analysis of various and compounds, alloys using activation analysis. In each application, the precise values of detection efficiency for different gamma energies and knowledge of detector resolution for different gamma energies are necessary. The detection efficiency and resolution depend on the detector size and different detector parameters. Therefore it is essential to know these parameters for NaI detector before applying of detector for the quantitative analysis purpose. With this intention, in the present work, detection efficiency and resolution of NaI (Tl) scintillation detector are measured and optimized for following gamma-ray energies: 121.78 keV, 244.69 keV, 344.28 keV, 662 keV, 778.9 keV, 1173.81 keV, and 1332.91 keV. Values of detection efficiencies for these gamma energies are found to be respectively 11.28 %, 20.68 %, 3.35 %, 2.37 %, and 2.17 %. The values of percent resolution for above different gamma-ray energies are found to be 11.12 %, 10.93 %, 10.45 %, 8.36%, 6.93 % , 6.19 % , and 5.81 % respectively. The standard gamma sources provided by the IAEA (International Atomic Energy Agency) are used in the present work. The result shows that the efficiency and resolution of NaI (Tl) detector decrease with increasing energy.

Key words: Efficiency, IAEA, Resolution, Radioactive Gamma source, NaI (Tl) gamma-ray spectrometer

Introduction

Sodium Iodide doped with thallium, NaI(Tl) is a relatively high density and high atomic number combined with a large volume of very high efficiency. For detectors which are designed to measure the energy of the incident radiation, the most important factor is the energy resolution [1]. The energy resolution is the extent to which a detector can distinguish two close-lying energies. The resolution (R) is usually given in terms of the full width at half maximum (FWHM) of a peak. Although semiconductor detectors have a better energy resolution, many researchers cannot replace the NaI (Tl) in experiments where large detector volumes are needed. NaI (Tl) scintillation detector has many applications in the various research fields such as cross-section estimation of nuclear reactions produced by neutrons and charged particles elemental analysis of different alloys, explosives, polymer grafting, using neutron activation analysis technique, development of nuclear reactor technology. The precise values of detection efficiency for different gamma energies are based on the measurement of gamma-ray activity of various samples. In each application, to avoid the interference of different gamma energies, it is needed to know the detector resolution depends on gamma energies. The values of detection efficiency and resolution vary with detector type and size and different detector operating parameters. Therefore, it is essential to know these values for a given detector for the quantitative analysis purpose [7]. In the present work, the detection efficiency and resolution of 3"x 3" NaI (Tl) scintillation detector are measured and optimized for the present detector assembly for following gamma-ray energies 121.78 keV, 244.69 keV, 344.28 keV, 662 keV, 778.9 keV, 1173.81 keV, and 1332.91 keV.

[1] Lecturer, Dr, Department of Physics, University of Mandalay
[2] Lecturer, Dr, Department of Physics, University of Mandalay
[3] Lecturer, Dr, Department of Physics, Shwebo University

Materials and Methods

Experimental Set-Up

The experiments were carried out in the Experimental Nuclear Physics Laboratory, Department of Physics, University of Mandalay, using NaI(Tl) detector, gamma rays spectroscopy methods, lead as a shielding material. Experimental arrangement for gamma-ray spectroscopy system with NaI(Tl) detector shown in figure (1). This system is surrounded by a lead shield to reduce background radiation. In this experiment, NaI (Tl) 3 inches × 3 inches scintillation detector is used to detect the gamma radiation after passing through the crystal and then passed the information (electron pulse) are amplified by the preamplifier and the fast spectroscopy amplifier and collected by using MCA based on a personal computer. The operating voltage for NaI (3"x 3") scintillation detector set 1000 V dc. This value is fixed for all measurements and the time taken for data acquisition was 100, 200,300,400, and 500 seconds respectively. The accumulated spectrum for each measurement is stored and analyzed by using Gamma Vision 32 software. The efficiency and energy resolution were determined by using standard sources Eu-152, Cs-137, and Co-60 produced by the IAEA as a function of gamma-ray energies. The analysis is done by selecting the Region of Interest or ROI from the recorded spectrum and the photopeak has been identified.

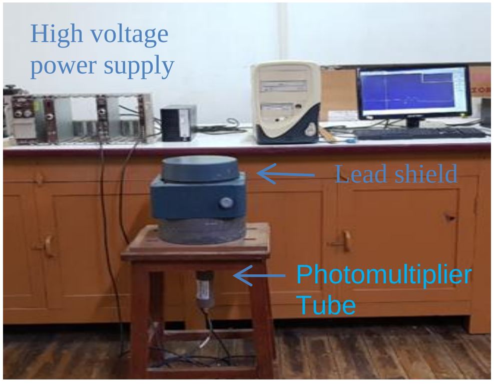

Figure (1) Gamma-Ray Spectroscopy System with NaI(Tl) Detector and Standard Sources Provided by IAEA

Energy Calibration

Before any measurement detection system has to be calibrated. Energy calibration of the spectrometer is to be able to identify the energy associated with each photopeak in the gamma-ray spectra. The standard radioactive sources of known energies were used to calibrate the spectrometer. Therefore, energy calibration was first made in 300 seconds by using ^{60}Co and ^{137}Cs sources. In this work, conversion gain is set at 1024. And then sources were placed on the detector surface and a spectrum was accumulated for a time period long enough to determine the peak position. The amplifier gain and shaping time were adjusted until peaks were obtained at the desired energy. An energy calibration curve is constructed by plotting gamma-ray energy versus channel number of the corresponding photopeak center. Establishing a direct relationship between photopeak energy and channel number can do the energy calibration process. In doing so, the energy calibration curve was obtained as shown in figure (2).

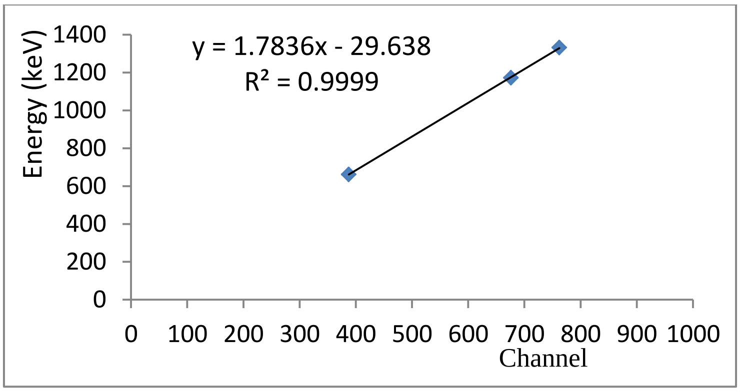

Figure (2) Energy Calibration Curve

Measurement of Efficiency

The detection efficiency of energy E was computed by the equation below.

$$\epsilon(\%) = \frac{NA}{T \times A_\gamma} \times 100$$

Where NA is the net peak area, T is the life time, A_γ is gamma activity, which is equal to (source activity × gamma branching ratio). A is source activity and it is calculated using the following equation

$$\mathrm{A} = \mathrm{A_0 e^{-\lambda t}}$$

λ is the decay constant, t is the time between the date of manufacturer of the source and date of experiment, A_0 is initial activity at t= 0 [7].

Energy Resolution

The ability of a detector to identify particles of different energies is defined as the energy resolution. It is important to resolve between two interference gamma-ray energies emitted by the sample. The experimental resolution is estimated using the equation,

$$\text{Resolution }(\%) = \frac{\mathrm{E_2 - E_1}}{\mathrm{E_0}}$$

$\mathrm{E_2 - E_1 = \Delta E}$ is Full-Width Half Maximum (FWHM), $\mathrm{E_0}$ is gamma energy. The value of FWHM from the measured spectrum can be obtained directly using software and manually. Table (2) represents the average value of full width at half maximum, FWHM, corresponds to the resolution of sodium iodide, NaI (Tl) detector. Table (3) shows the resolution of the detector for gamma rays is a function of gamma energy [7].

Results and Discussion

For the gamma-ray spectrometry, the absolute efficiency and energy resolution are important parameters to be determined. Those parameters are usually done using a function to fit the efficiency at a wide energy range, as the number of energy peaks obtained from a radioactive source. For these purposes, the absolute efficiency and the energy resolution of the NaI(Tl) detector have been determined experimentally at 121.78, 244.67, 344.3, 662, 778.9, 1173.2, and 1332.5 keV energies obtained from Eu-152, Cs-137, and Co-60. And the energy resolution of NaI (Tl) detector was determined by measuring and analyzing the gamma-ray activities of the above radioactive standard sources. The data obtained were tabulated and graphically presented. The measured values of the efficiencies of NaI (Tl) detector for different gamma energies are given in table (1). The variation of measured values of efficiency of NaI

(Tl) gamma-ray detector for different gamma energies is plotted in figure (3). The sensitivity depends on the detector's diameter and thickness. At higher energies, the efficiency starts to decrease sharply and it is shown that efficiency decreases exponentially with increases in gamma-ray energy. The average value of the full-width at half maximum, FWHM, corresponds to the resolution of sodium iodide (NaI (Tl)) detector shown in figure (4) describes the detector cannot resolve two adjacent higher energy peaks for unambiguous nuclide identification. Nevertheless, although counting times are different, the detector displays a similar behavior with FWHM increases. According to figure (5), it can also be concluded that the resolution of the detector for gamma rays decreases with an increase in gamma energy. Gamma-ray spectra for different gamma energies are given in figures (6), (7) and (8) for different radioactive sources.

Table (1) Experimentally measured Efficiency of NaI (Tl) Detector

Energy	**ε (100s)**	**ε (200s)**	**ε (300s)**	**ε (400s)**	**ε (500s)**	**ε** (%)
244.67	0.1107	0.1168	0.1104	0.1115	0.1146	11.28
344.3	0.2055	0.2094	0.2060	0.2055	0.2076	20.68
662	0.0335	0.0334	0.0335	0.0335	0.0335	3.35
1173.2	0.0236	0.0236	0.0236	0.0235	0.0237	2.37
1332.5	0.0216	0.0217	0.0216	0.0216	0.0217	2.17

Table (2) Experimental data obtained from NaI (Tl) detector for FWHM (keV)

Energy (keV)	FWHM (100s)	FWHM (200s)	FWHM (300s)	FWHM (400s)	FWHM (500s)
121.78	18.068 ± 0.21	18.126 ± 0.46	17.96 ± 0.12	17.578 ± 0.34	17.702 ± 0.49
244.67	25.026 ± 0.55	24.748 ± 0.14	25.238 ± 0.72	24.968 ± 0.45	25.002 ± 0.19
344.3	33.502 ± 0.35	33.234 ± 0.34	33.356 ± 0.37	33.304 ± 0.14	33.276 ± 0.17
662	50.306 ± 0.29	49.882 ± 0.06	49.806 ± 0.19	49.88 ± 0.11	49.684 ± 0.11
778.9	47.688 ± 0.98	48.468 ± 1.17	48.516 ± 0.75	47.992 ± 1.25	49.494 ± 0.35
1173.2	64.670 ± 1.51	63.858 ± 0.84	63.642 ± 0.50	63.956 ± 0.88	64.094 ± 0.55
1332.5	68.518 ± 1.64	67.834 ± 0.92	67.562 ± 0.65	68.62 ± 1.45	67.856 ± 0.81

Table (3) Measured percentage resolution of NaI (Tl) detector

Energy (keV)	R % (100s)	R %(200s)	R % (300s)	R % (400s)	R% (500s)	Average R %
121.78	11.22	11.26	11.16	10.92	11.06	11.12
244.67	10.88	10.85	11.02	10.96	10.96	10.93
344.3	10.5	10.45	10.45	10.47	10.46	10.45
662	8.39	8.36	8.34	8.37	8.35	8.36
778.9	6.8	6.94	6.94	6.88	7.1	6.93
1173.2	6.27	6.18	6.15	6.18	6.18	6.19
1332.5	5.85	5.79	5.76	5.85	5.79	5.81

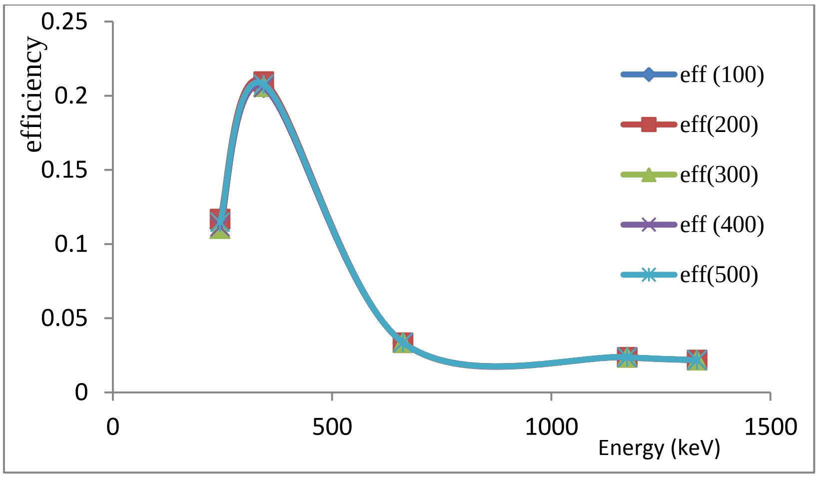

Figure (3) Efficiency of NaI (Tl) detector as a function of energy

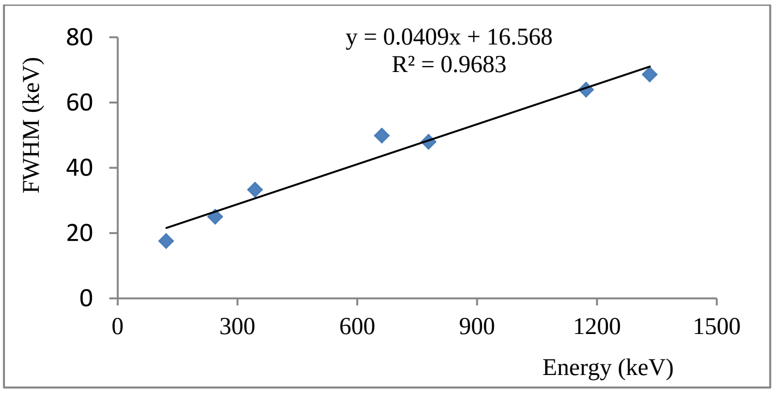

Figure (4) FWHM as a function of gamma-ray energies for NaI (Tl)

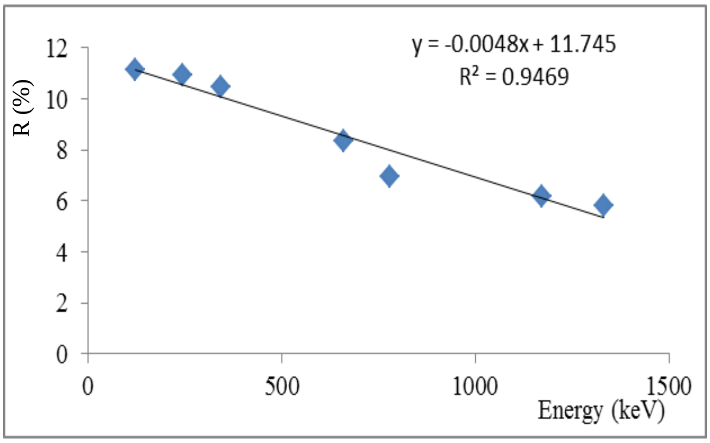

Figure (5) Resolution of NaI (Tl) detector as a function of energy

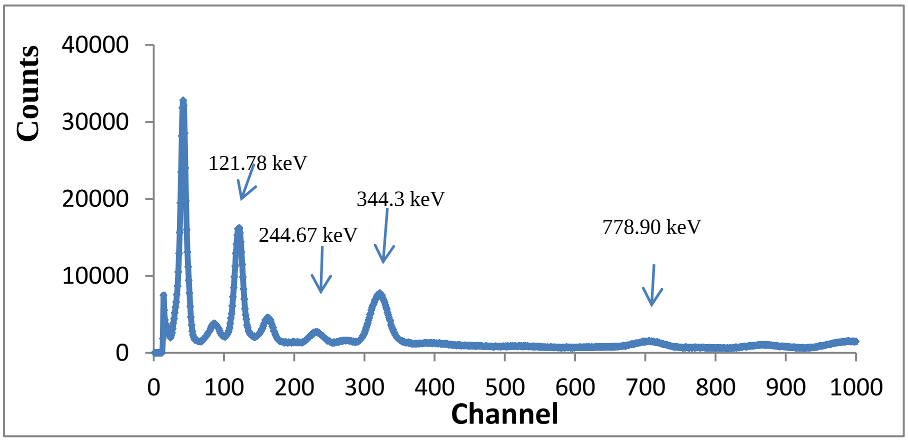

Figure (6) Gamma-Ray Spectrum of Eu-152

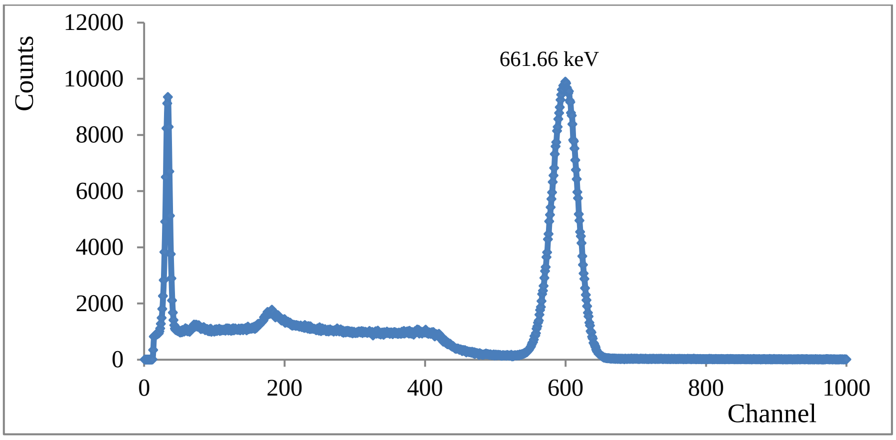

Figure (7) Gamma-Ray Spectrum of Cs-137

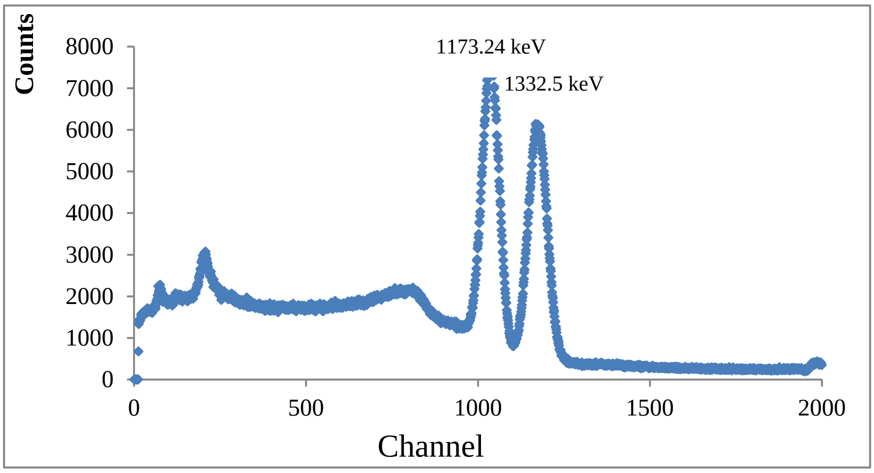

Figure (8) Gamma-Ray Spectrum of Co-60

Conclusion

The efficiency and resolution of NaI(Tl) detector were investigated in this paper. The energy resolution of NaI (Tl) is 8% and the FWHM is 49.8 keV for 0.662 MeV gamma of Cs^{137}. As the FWHM is roughly proportional to the square root of the energy, the resolution in percent deteriorates as the energy decreases. Its efficiency starts decreasing with energy 344 keV and exponentially decreases with energy and only can detect nuclides with lower energy rather than nuclides at higher energy. The value of detection efficiency depends on detector type and size and different detector operating parameters. Therefore, it is essential to know these values for a given detector for the quantitative analysis purpose.

Acknowledgement

The authors would like to thank Dr Lei Lei Win, Professor, Head of Physics Department, the University of Mandalay for her encouragement.

References

[1] Tsoulfanidis, N., 1995, "Measurements and Detection Radiation, Taylor& Francis", USA.

[2] Turner, J. E., 2007, ''Atoms, Radiation and Radiation Protection'', Wiley-VCH Verlag GmbH & Co. KGaA: Germany.

[3] Leo, R.W., 1994 "Techniques for Nuclear and Particle Physics Experiments", Springer Verlag, Germany.

[4] Pansare G.R., P.M. Dighe and V.N. Bhoraskar,1992, "Estimation of Zirconium in Fe and Ti Based Alloys Through formation of Zr-90m At 14.7 MeV Neutrons", Rad. Phys. Chem.,vol. 40, pp.213-216.

[5] Pansare G.R., N. Nagesh and V.N. Bhoraskar, 1994. "A study on grafting of acrylonitrile onto high density polyethylene by the neutron activation" J. Phys. D: appl. Phys., vol. 27, pp. 871-874.

[6] Muraleedhara Varier K., A. Joseph and P.P. Pradyumnan, 2015," Advanced Experimental Techniques in Modern Physics", Calicut, India.

[7] Pansare G.R., Ansari S.J. and Kamthe U.R., 2016, "Measurement of Energy Resolution and DetectionEfficiency of NaI (Tl) Scintillation Gamma Ray Spectrometer for Different Gamma Ray Energies", Res. J. Material Sci., vol.4(4), pp.7-12.