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Comparison of Theoretical and Experimental Alpha Energy Spectra

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Abstract:

Energy spectra of ^{210}Po were achieved by means of theoretical and experimental methods. The spectrometer which was consisted of a BC400 type plastic scintillation detector was used to obtain experimental energy spectrum of the alpha source. The theoretical alpha energy spectrum was also achieved by using FLUKA Monte Carlo (MC) program. The energy resolution values of both spectra were calculated. The performances of the methods were compared with each other.

Keywords:

Alpha Spectrum; Plastic Scintillation Detector; Energy Resolution; FLUKA; ^{210}Po

1. INTRODUCTION

The energy distribution of particles emitted by a radioactive source or produced by a nuclear reaction is investigated by spectroscopy. A particle energy spectrum is given in terms of particle's energy. In order to obtain energy spectrum of a radioactive source, a multichannel analyzer (MCA) is used [1]. The width corresponding to half the maximum ordinate of a peak in an energy spectrum is called as full width at half maximum (FWHM) value of the energy distribution (**Figure 1**). The energy resolution of the detector is conventionally obtained by the FWHM divided by location of the peak centroid (H_0) (Eq. (1)). Thus, energy resolution value (R) is dimensionless and also expressed as percentage [2].

$$R = \frac{FWHM}{H_0} \quad (1)$$

A scintillation detector is the most popular device in nuclear and particle physics [3]. It can be produced by organic or inorganic type scintillators. Organic scintillators are hydrocarbon compounds. They have very rapid decay times which are on the order of a few nanoseconds, low costs and high light outputs [3, 4].

The interactions of radiations with matter may be simulated by Monte Carlo (MC) methods. MC simulation can be demonstrated as a black box to which we have to provide some input data, such as details of geometry of radiation source, target and medium, type of radiation, energy, and direction of radiation flight. The black box diagram of a MC code is shown in **Figure 2**. Firstly,the geometry of the problem with a source and a detector is designed. Then, the simulation can be started [5].

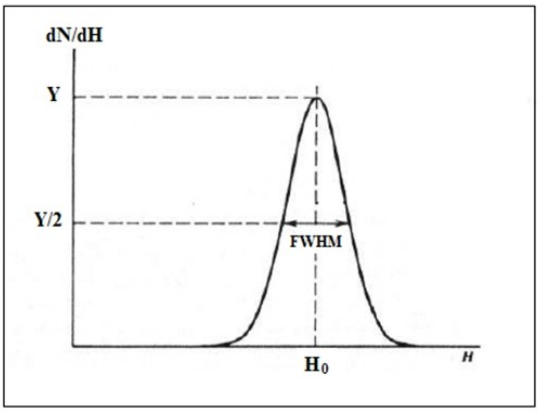


Figure 1. Definition of detector resolution [2].

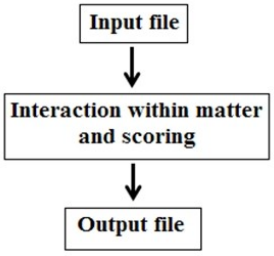


Figure 2. Black box of a MC Code [5].

FLUKA is one of the MC programs. Major reason of design and development of FLUKA MC is that implementation and improvement of modern physical models are very important. Interaction and propagation in matter of any particles can be simulated by means of FLUKA [6, 7].

^{210}Po energy spectrum was obtained by means of microcalorimeter and the energy resolution value was calculated as 4.4 keV by Ullom et al. [8]. Misiaszek et al. investigated ^{210}Po distribution in the lead disk by using semiconductor detector. They also simulated geometry and spectrometer via GEANT4 MC Method [9]. Calin et al. evaluated FWHM values corresponding to different source-detector distances in alpha spectrometers consisted of solid state detectors [10]. ^{210}Po and ^{226}Ra energy spectra were acquired using a plastic scintillation detector, and energy resolutions of the spectrometers were enhanced via timing method by Celiktas and Ermis [11]. Ermis and Celiktas also investigated energy resolution of a Si surface barrier detector by using standard alpha sources (^{210}Po and ^{226}Ra) [12].

In this work, ^{210}Po energy spectra were obtained by experimental and theoretic always. Experimental energy spectrum was achieved by using a scintillation detector consisted of a BC400 type organic (plastic) scintillation crystal. FLUKA MC Program was used to obtain theoretical energy spectrum of the source. Experimental and theoretical energy spectra were compared to each other. When the literature was browsed, it was determined that no study was found containing a comparison between experimental results through plastic scintillation detectors and FLUKA MC Simulation. This was the reason of the introduced work.

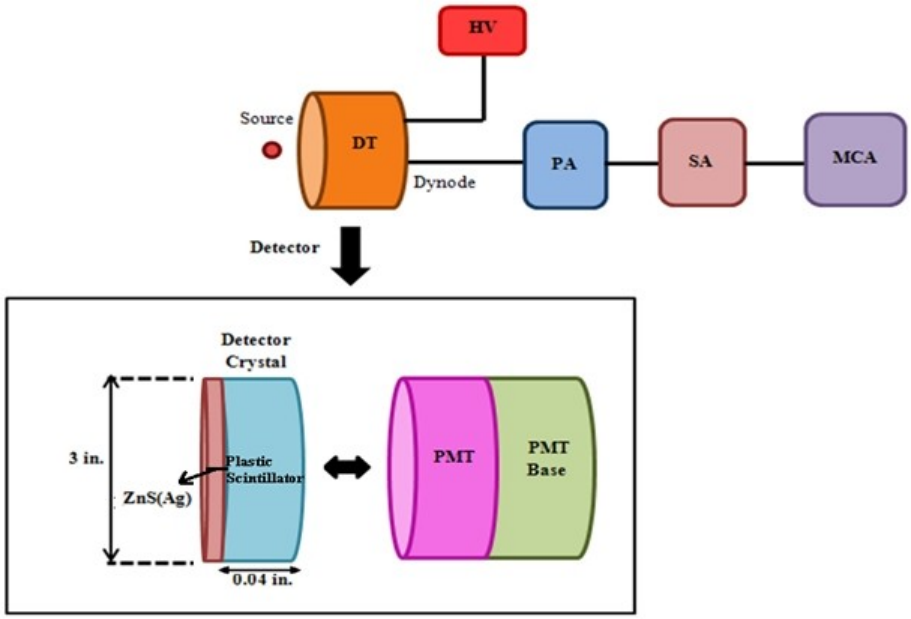


Figure 3. Block diagram of the used spectrometer.

(HV: High voltage supplier, DT: Detector, PMT: Photomultiplier tube, PMT Base: Photomultiplier tube base, PA: Preamplifier, SA: Spectroscopy amplifier, MCA: Multichannel analyzer)

2. MATERIAL AND METHODS

The experimental energy spectrum of ^{210}Po was achieved using a BC400 type plastic scintillation detector in cylindrical shape. The diameter and the thickness of the scintillation crystal were 3 and 0.04 inches, respectively. In order to detect alpha particles emitted from the source, the detector has a ZnS(Ag) layer with a thickness of 10 mg/cm^2 in front of the crystal. A solid point source with the half-life of 138.376 days emits 5.304 MeV-energy alpha particles [13]. The activity of the used source was 0.1 μCi. Since its first half-life was completed during the data acquisition,the source-detector distance was adjusted to 2 mm and the data acquisition time was chosen as 900 s in the experiment.

A scheme of the used experimental setup is shown **Figure 3**.

A RCA 8575 type photomultiplier tube (PMT) was contacted to the crystal. An Ortec model 266 type PMT Base was mounted to the PMT. Its dynode output which gives energy (slow positive) signals was connected to a preamplifier (PA, Ortec 113). Its output was then forwarded to a spectroscopy amplifier (SA, Ortec 671). Bipolar signals were preferred in the experiment so that baseline shift can be eliminated [2]. Bipolar output of the SA was finally connected to a multichannel analyzer (MCA, Ortec Trump 8K). Thus, the energy spectrum of the source was acquired.

The output signal shape of the SA is shown in **Figure 4**.

Theoretical energy spectrum of the radioisotope was compared to the experimental spectrum. For this purpose, FLUKA MC Simulation program was used. The FLUKA (ver. 2011.2b) was installed on an Ubuntu (ver. 11.04) operating system. Source and detector construction in the program in enlarged size can be seen in **Figure 5**. All parameters such as diameter and thickness of the crystal in the simulation were provided so as to be the same as the experiment to check and increase the accuracy of the theoretical results. The source was also sampled and the alpha energy spectrum was obtainedby the program calculating energy deposition in the crystal.

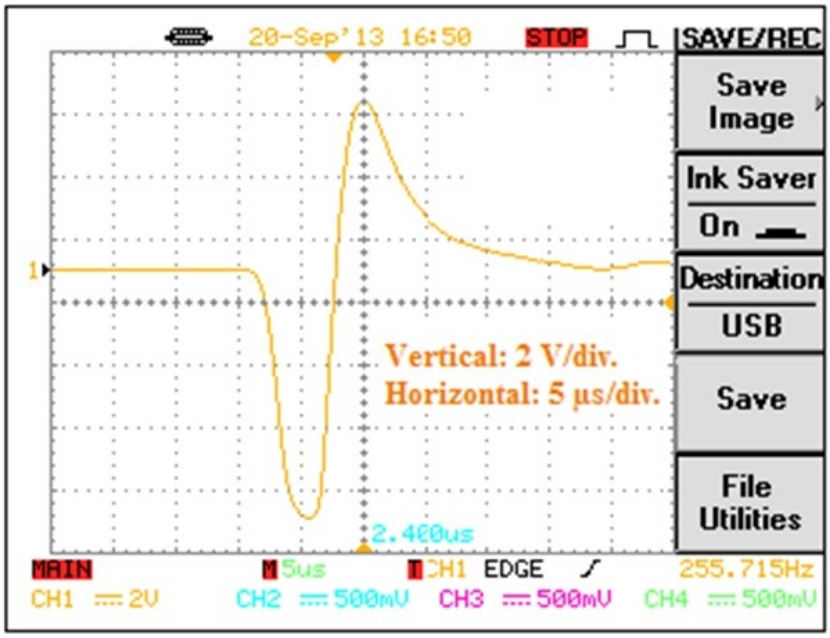


Figure 4. Output signal shape of SA.

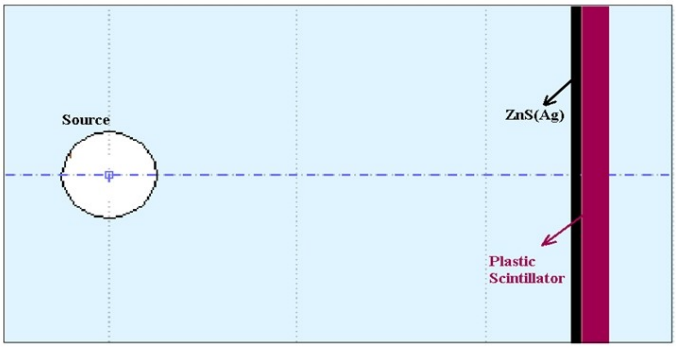


Figure 5. Position of the detector and the source in FLUKA.

3. RESULTS

Obtained experimental energy spectrum is given in **Figure 6**. Horizontal and vertical axes in the figure represent the number of channels and the counts per channel, respectively. The energy resolution of the detector was determined as 8.25%from the spectrum.

The count rate under the alpha peak and the detection efficiency of the detector (the ratio of the number of pulses recorded to the number of radiation quanta emitted by the source) were also found as $552s^{-1}$ and 18.39%, respectively (**Figure 6**).

The theoretical energy spectrum of ^{210}Po was achieved through FLUKA MC Program. Obtained theoretical alpha energy spectrum is shown in **Figure 7**. The energy resolution was calculated as 6.84% from this spectrum.

To compare and plot the obtained theoretical alpha energy spectrum with the experimental one, the ROOT [14] (ver. 5.34/18) program was used. The comparison is shown in **Figure 8**.

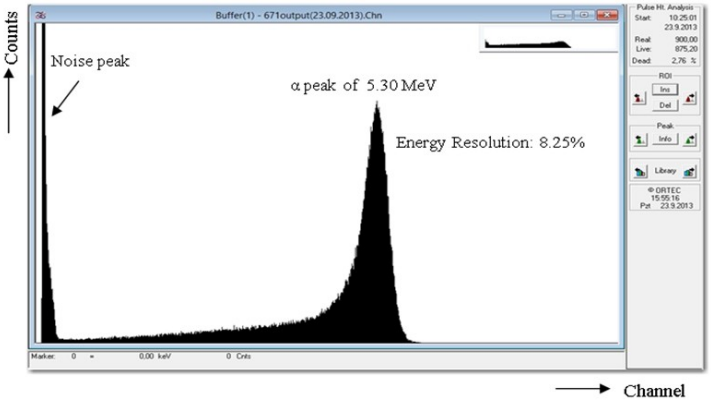


Figure 6. Obtained experimental energy spectrum of ^{210}Po.

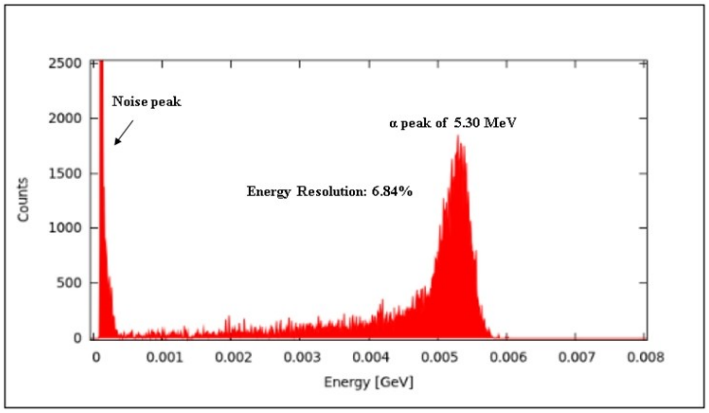


Figure 7. Theoretical alpha energy spectrum from FLUKA program (GeV is the standard energy unit).

4. DISCUSSION AND CONCLUSION

The energy resolution value of the BC400 type plastic scintillation detector for alpha spectroscopy was determined as 8.25% in the present study. This resolution was lower than that of the value given in the Celiktas and Ermis's previous work [11]. This means that better energy resolution was achieved in the introduced study.

The count rate (counts per second) was calculated as 552 s^{-1}.This corresponds to low count rate since it is lower than the threshold value of 5,000 $s^{-1}$for count rate [15]. It is also remarkable that the obtained count rate was higher than that of the value given in the Celiktas and Ermis's previous work [11]. As can be seen in (**Figure 6**),in addition, dead time of 2.76% was obtained from the spectrometer. This value was lower than the limit of 30-40% for dead time, as well. This shows that the pulse distortion and the pile-up effects did not appear in this spectrum [2, 3].

The alpha detection efficiencyof the detector was found as 18.39%. Obtained energy resolution and the count rate under the alpha peak were better than the previous work [11].

The energy spectrum was also acquired through the FLUKA MC program and the theoretical energy resolution was found to be 6.84%(**Figure 7**).Since spurious pulses which are produced by electronic modules (i.e. electronic noise) did not consider in the MC program, the counts per channel in the theoretical spectrum were normallyless than the experimental one. For this reason, the energy resolution

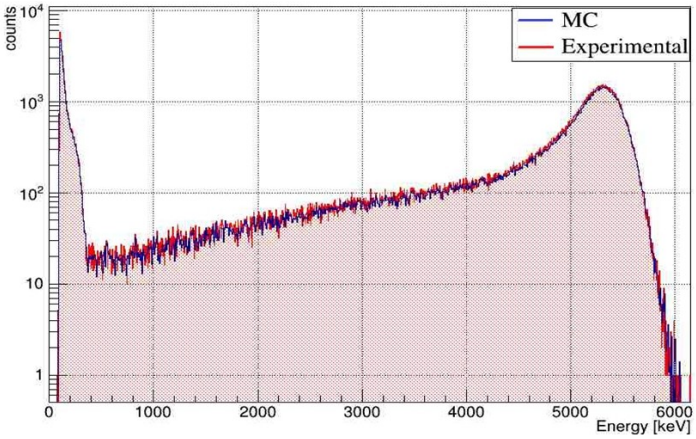


Figure 8. Comparison of the obtained experimental energy spectrum with that of FLUKA via ROOT program.

obtained from theoretical spectrum was lower than that of the experimental result.

Experimental and theoretical energy spectra were compared to each other. It was noticed that there was a harmony between experimental and theoretical spectra. It can be concluded from the results that FLUKA MC program can be used to get an alpha spectrum of any alpha source, leading to comparisons with the experimental results.

5. ACKNOWLEDGEMENTS

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