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Alpha energy resolution improvement of a general purpose plastic scintillation detector

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Abstract Alpha energy spectra of ^{210}Po and ^{226}Ra radioactive sources were achieved by using a BC400 type plastic scintillation detector. In order to enhance the energy resolution of the detector, constant fraction timing method was used. Obtained results showed that the used timing method was successful on improving the energy resolution of the detector with the amendment of about 1 % even at the low count rates.

Keywords Constant fraction timing method · Plastic scintillation detector · ^{210}Po · ^{226}Ra

Introduction

The plastics such as polyvinyltoluene and polystyrene are commonly used in nuclear and particle physics measurements. These plastics have decay time constant of 2–3 ns [1]. One of the polyvinyltoluene based plastic scintillator is Bicron BC400 type. The advantages of the BC400 type plastic scintillation detectors are their low costs and high light outputs [2].

Dividing the full width at half maximum (FWHM) of a peak to the peak centroid (E_0) identifies the energy resolution (R) of a detector as shown in Fig. 1 [3].

$$R(\text{energy resolution}) = \text{FWHM}/E_0$$

The time intervals between different events are measured in time spectroscopy experiments. The timing signals that are related to these events are exactly derived. The interactions of a nuclear radiation with a detector material are commonly interested in nuclear timing spectroscopy [4].

The figure of merit of a timing circuit is usually measured in terms of time resolution [5]. Time resolution is a measure of how small a difference in times of arrival that the circuit can recognize [6].

A discriminator which employs leading edge and constant fraction timing methods was developed by Sanders et al. [7] for NaI(Tl) and plastic scintillation detectors. Ohtsuki et al. [8] measured bremsstrahlung photons of ^{210}Po by using α–γ coincidence measurements. Separation of α–γ particles was performed by Ichihara et al. [9] via pulse shape discrimination method.

In the spectroscopy measurements, one of the important parameter is energy resolution value of the used detector. So, we constituted a spectrometer containing a BC400 type general purpose plastic scintillation detector to improve its energy resolution through constant fraction timing method. An energy resolution enhancement of about 1 % was achieved in the alpha spectra of the used radioisotopes obtained from the scintillation detector.

Experimental

Energy spectra of ^{210}Po and ^{226}Ra radioisotopes were initially obtained by using BC400 type plastic scintillation detector, and the energy resolution values of the detector for the isotopes were calculated. Then, the time spectra of the used isotopes were achieved by means of constant fraction timing method. After that, time resolution values of the detector were determined for both isotopes. By means of the suggested spectrometer, finally, the energy

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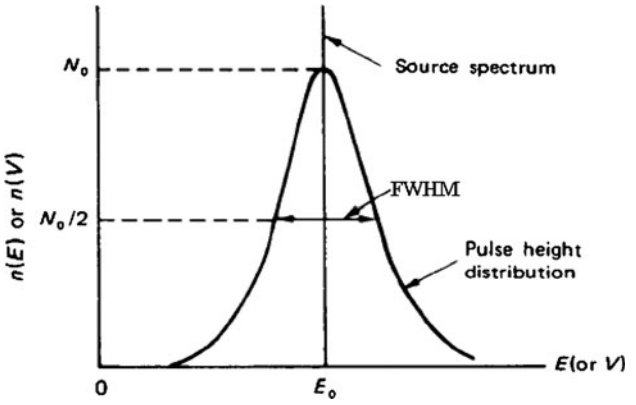


Fig. 1 Essential quantities for energy resolution

spectra of each radioactive source were coincidently gated by timing spectra in a multichannel analyzer (MCA).

In the present study, ^{210}Po and ^{226}Ra radioactive point sources with the activities of 0.1 and 9.10^{-2} μCi respectively were used. The half-lives of the sources are 138.376 days for ^{210}Po and 1,600 years for ^{226}Ra. They emit 5.407 and 4.871 MeV-energy alpha particles, respectively [10]. The source-detector apart was set to 50 mm during the measurements. A BC400 plastic scintillation detector which has 3 inch diameter and 0.04 inch thickness was used to obtain energy spectra. A ZnS(Ag) layer of 10 mg/cm^2 was fixed in front of the detector for the alpha detection. Data acquisition time was chosen as 900 s for all measurements, and the measurements were carried out in a dark medium and at a constant room temperature (20 °C) to prevent artificial counts and detector noise [1].

The experimental setup is shown in Fig. 2.

In this setup, energy (slow positive) signal derived from the dynode output of the photomultiplier tube (PMT, Ortec 266) mounted on the detector was forwarded to a delay line amplifier (DLA, Ortec 460) through a preamplifier (PA, Ortec 113). The unipolar output of the DLA was first connected to a delay amplifier (DA, Ortec 427A) and then an MCA (MCA, Ortec Trump 8 K) respectively so as to obtain energy spectrum. This part of the circuit formed the energy branch of the spectrometer. The anode output of the PMT, from which timing (fast negative) signal is obtained, was split into two lines. These lines were connected the two timing filter amplifiers (TFA, Ortec 454). Time constants of the TFAs were chosen as 10 ns since it should be set 5–10 times greater than the scintillator decay time (2.4 ns) [3]. One of the TFAs output was directly connected to start input of a time to amplitude converter (TAC, Ortec 566). TAC is based on the start-stop principle and provided with a unit for preliminary selection of the start and stop input pulses [11], and it gives a logic output proportional to the time difference between its start and

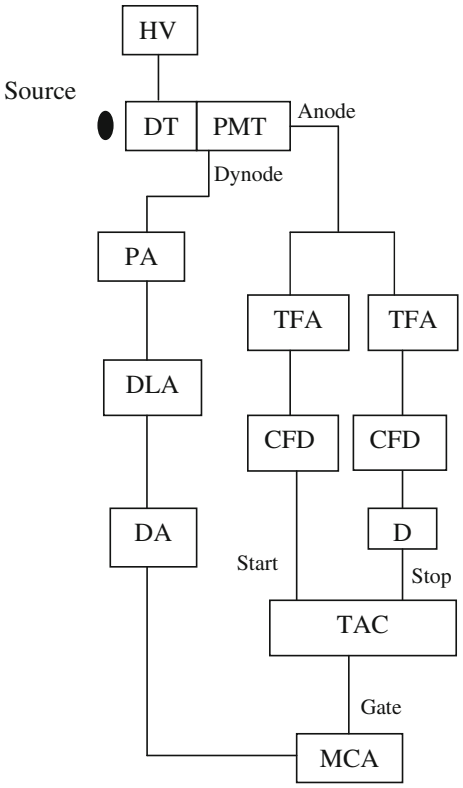


Fig. 2 Block diagram of the used spectrometer

stop input signals. Output of the other TFA was first sent to the other CFD then to a delay unit (D, Ortec 425A) in order to generate certain time difference start and stop signals. Delay output was connected to the stop input of the TAC. When a TAC output is sent to a MCA, a time spectrum is achieved. We finally connected the energy signals to the line input and timing signals to the gate input of the MCA. Thus, coincident energy spectra with the timing signals were obtained to enhance the energy resolution of the detector.

Output signal shapes of the DLA, the TFA, the CFD and the TAC are shown in Figs. 3 and 4.

Before acquisition of the time spectra of the used isotopes, time calibration of the MCA was carried out. For this process, delay time values of the stop signal was chosen so as to be equal to the rise time of the PMT output pulses from 20 % to maximum [12]. Since the rise time (time intervals between 10 and 90 % of signal amplitude) of the PMT output signal was 54.53 ns (Fig. 5), delay times were chosen between 10 and 55 ns in the calibration. Thus, time calibration graph was achieved as shown in Fig. 6. Inverse of the slope of this graph gives time value per channel of the MCA. This value was calculated as 20.81 ± 4.17 ps.

The constant fraction discriminator (CFD) maintains a constant timing edge since it is not affected by the

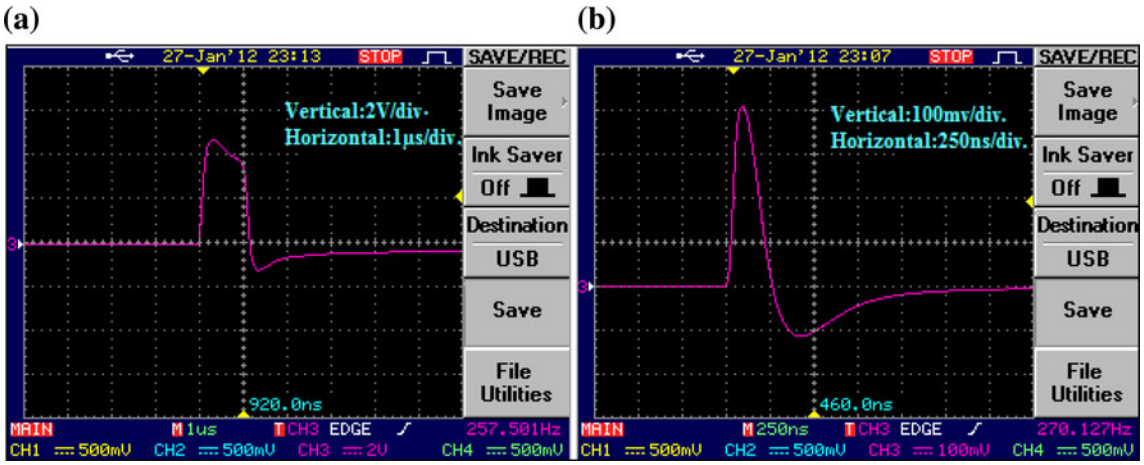


Fig. 3 Output signal shapes of **a** DLA, **b** TFA

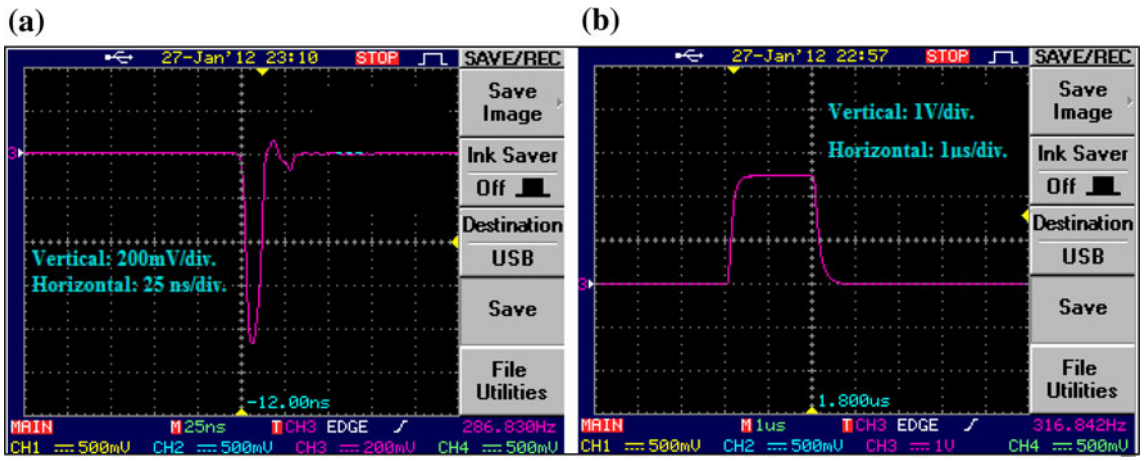


Fig. 4 Output signal shapes of **a** CFD, **b** TAC

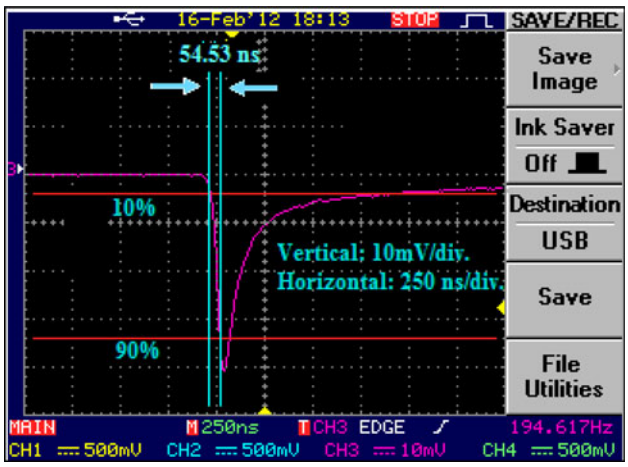


Fig. 5 Output signal shape of the PMT

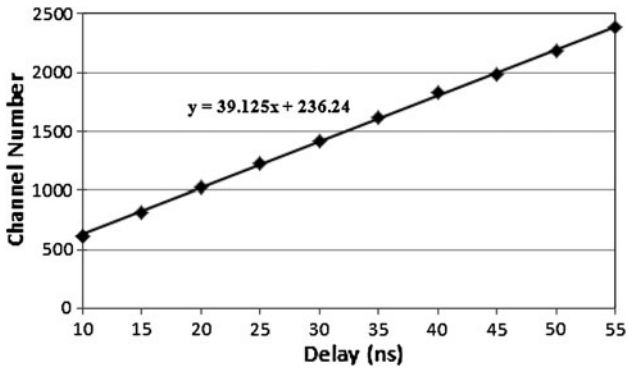


Fig. 6 Time calibration graph

amplitude of the input pulse. In order to achieve a constant timing edge, it is customary to use an attenuator and a delay. The input signal is split. One part is delayed, and the other is attenuated. After these two signals are re-mixed, a comparator detects the zero cross points. The timing of the zero cross point is not influenced by the amplitude of the input signal [13]. These processes are called as constant fraction timing method and shown in Fig. 7.

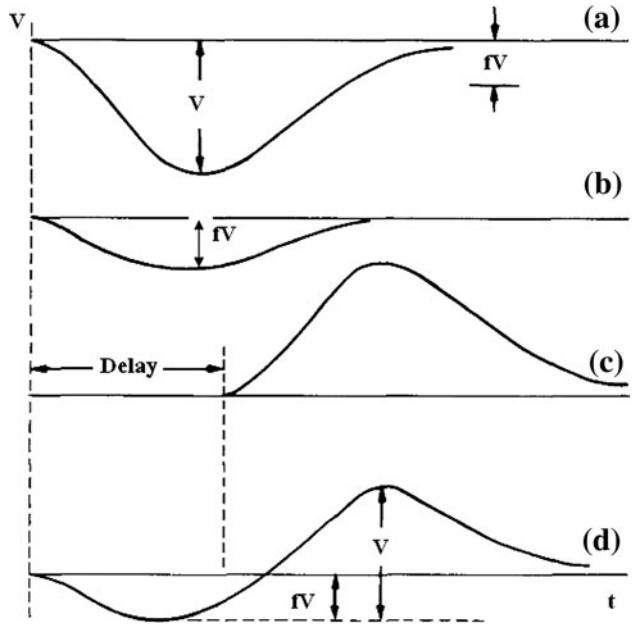


Fig. 7 Constant fraction timing method

Results

The energy spectrum of ^{210}Po before timing application is shown in Fig. 8. Horizontal and vertical axes in all figures below correspond to the number of channels and counts, respectively.

Obtained time spectrum of this isotope by means of constant fraction timing method is shown in Fig. 9.

The time per channel of the MCA was determined as 24.4 ps from this time spectrum. This value was compatible with the time obtained from the calibration graph.

Time resolution value was calculated as 2.63 ns from Fig. 9. We also calculated this value by using time calibration graph and found as 2.24 ± 0.45 ns. This resolution value was compatible with the resolution obtained from the calibration graph, also.

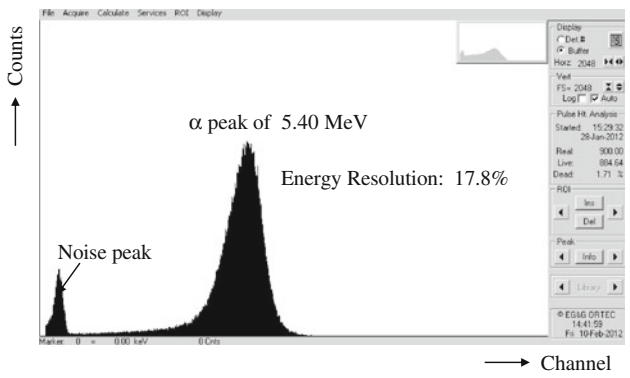


Fig. 8 Energy spectrum of ^{210}Po before timing process

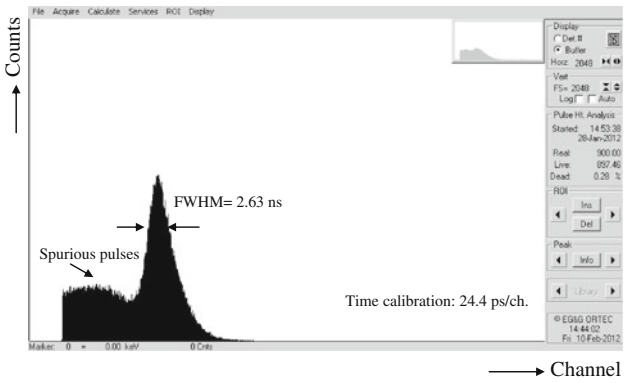


Fig. 9 Time spectrum of ^{210}Po

Coincident energy spectrum with timing process of the isotope is shown in Fig. 10.

The energy resolution of the detector before timing application was found as 17.8 % from Fig. 8 and the energy resolution after the timing process was obtained as 16.8 % from Fig. 10. The obtained energy spectra of ^{210}Po without and with timing process are compared with each other in Fig. 11.

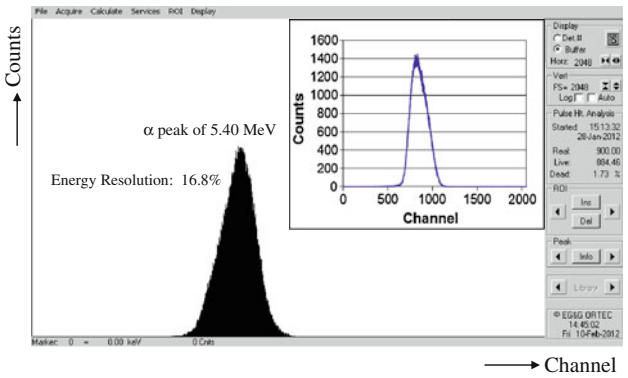


Fig. 10 Coincident energy spectrum with the time spectrum of ^{210}Po

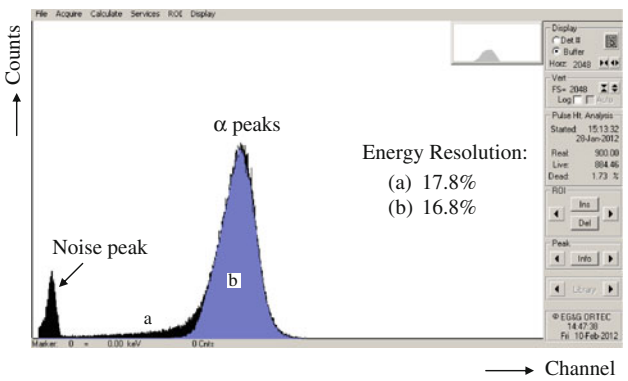


Fig. 11 Comparison of the energy spectra of ^{210}Po before (*a*) and after (*b*) timing process

Gross count rates under the alpha peaks from Figs. 8 and 10 were determined as 233.27 s^{-1} and 217.532 s^{-1}, respectively.

In Fig. 12, energy spectrum of ^{226}Ra without timing process is shown.

Obtained time spectrum of the isotope via the timing method is given in Fig. 13.

In Fig. 13, time resolution value of 3.10 ns was found for ^{226}Ra from the MCA. Similar calculation was carried out through the time calibration graph and time resolution value of 2.64 ± 0.52 ns was obtained in the compatibility with the result from Fig. 13.

Coincident energy spectrum with timing method of the second isotope is shown in Fig. 14.

The energy resolutions of 28.2 and 27.1 % were obtained before (from Fig. 12) and after (from Fig. 14) timing process, respectively.

Comparison of the acquired energy spectra of ^{226}Ra without and with timing process is given in Fig. 15.

Gross count rates of 382.761 and 350.776 s^{-1} were calculated from alpha peaks in Figs. 12 and 14, respectively.

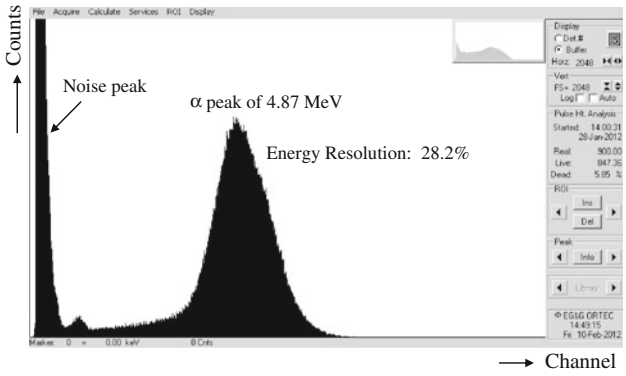


Fig. 12 Energy spectrum of ^{226}Ra before timing process

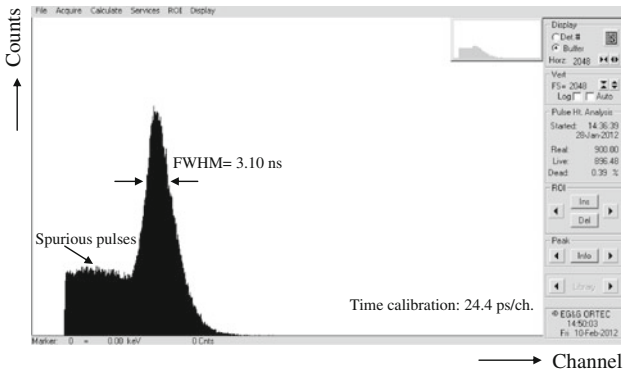


Fig. 13 Time spectrum of ^{226}Ra

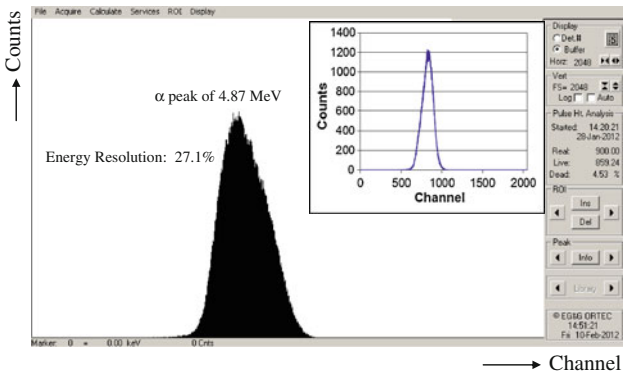


Fig. 14 Coincident energy spectrum with the time spectrum of ^{226}Ra

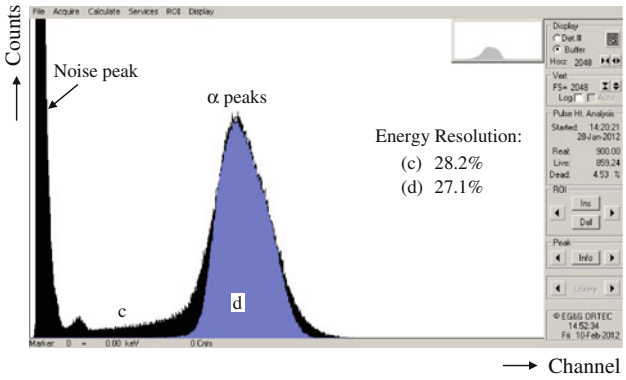


Fig. 15 Comparison of the energy spectra of ^{226}Ra before (*c*) and after (*d*) timing process

Discussion and conclusion

The energy resolution values of a general purpose plastic scintillation detector for the obtained alpha energy spectra of ^{210}Po and ^{226}Ra were enhanced about 1 % in this work. This enhancement was achieved by means of constant fraction timing method.

Since the sensitivity of the used detector to alpha particles is low, the energy resolution values for the isotopes were found high which means poor resolution. In addition, the energy resolution value of the detector for ^{226}Ra was normally showed poorer resolution in comparison with ^{210}Po since the activity of ^{226}Ra was lower than ^{210}Po.

As can be stated at the previous section, low count rates for both isotopes were found since they were under the count rate of 5.000 s^{-1} [14]. In addition, dead time lower than 30–40 % was obtained from the MCA as shown in Figs. 8, 9, 10, 11, 12, 13, 14, and 15. It can be deduced from these results that acquired data did not contain pulse distortion, pulse pile-up and thus spectrum distortion effects in the measurements, leading to increase their reliabilities [1, 3].

Owing to the low activity of ^{226}Ra, higher amplification was carried out for the detector signals of this isotope with

respect to ^{210}Po signals. Therefore, noise peaks in ^{226}Ra energy spectra were bigger than those of ^{210}Po as shown in Figs. 8 and 12. This case is noticeable from the count rates and the dead time values of the MCA screen images in Figs. 8, 9, 10, 11, 12, 13, 14, and 15.

Counts except for the alpha peaks in the energy spectra (Figs. 8, 12) were shown in the lower channel numbers than timing peaks as spurious pulse in the time spectra (Figs. 9, 13). As a result of this, noise peaks and these spurious counts were discriminated through the timing method as shown in Figs. 10 and 14. It can be concluded from these results that the used timing application became quite successful in the spectrum improvement.

Finally, it was concluded that the alpha energy resolution improvement more than 1 % can be obtained in the count rates higher than the depicted values here because the energy resolution enhancement of 1 % was acquired even at the low count rates as in the presented study.

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