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Energy resolution improvement of NaI(Tl) scintillation detectors by means of a timing discrimination method

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Abstract Gamma-ray energy spectrum of a ^{137}Cs radioisotope was obtained by using a NaI(Tl) scintillation detector. Improvement of the energy resolution of the detector was aimed. To achieve this, constant fraction timing method was used. Energy resolution of the photopeak of the isotope was improved from 7.1 to 6.7% through the timing application.

Keywords Constant fraction timing method · NaI(Tl) inorganic scintillation detector · ^{137}Cs

Introduction

One of the most commonly used inorganic scintillation detectors for gamma ray detection is NaI(Tl) (sodium iodide activated with thallium). The most notable property of NaI(Tl) is its excellent light output [1].

The inorganic scintillators are mainly crystals of alkali halides containing a small activator impurity. The most commonly used materials is NaI(Tl), where thallium (Tl) is the impurity activator. In general, inorganic scintillators are 2–3 orders of magnitude slower ($\approx$500 ns) in response than organic scintillators due to phosphorescence. However, the time evolution of emission is, in most cases, well described by the simple one or two exponential decay forms. The advantage of inorganic crystals lies in their greater stopping power due to their higher density and higher atomic number. Among all scintillators, they also have some of the highest light outputs, which results in better energy resolution. This makes them extremely suitable for the detection of gamma-rays and high-energy electrons and positrons [2].

In many applications of radiation detectors, the object is to measure the energy distribution of the incident radiation. These efforts are classified under the general term radiation spectroscopy [1].

Spectroscopy is the aspect of radiation measurements that deals with measuring the energy distribution of particles emitted by a radioactive source or produced by a nuclear reaction. A particle energy spectrum is a function giving the distribution of particles in terms of their energies. To determine the energy spectrum of particles emitted by a source, one measures, with the help of a detector and appropriate electronics, the pulse-height distribution produced by these particles [3].

The quality of the performance of a detection system used for energy measurements is characterized by the width of the pulse-height distribution obtained with particles of the same energy [3]. For detectors which are designed to measure the energy of the incident radiation, the most important factor is the energy resolution. This is the extent to which the detector can distinguish two close lying energies [2].

The energy resolution of a detector is characterized by full width at half maximum (FWHM) quantity. The width, measured at half of the maximum of the bell-shaped curve, is indicated by Γ (FWHM). The ability of a detector to identify particles of different energies is given either in terms of Γ or in terms of the ratio $R(E_0)$, where

$$R(E_0) = \Gamma/E_0 \quad (1)$$

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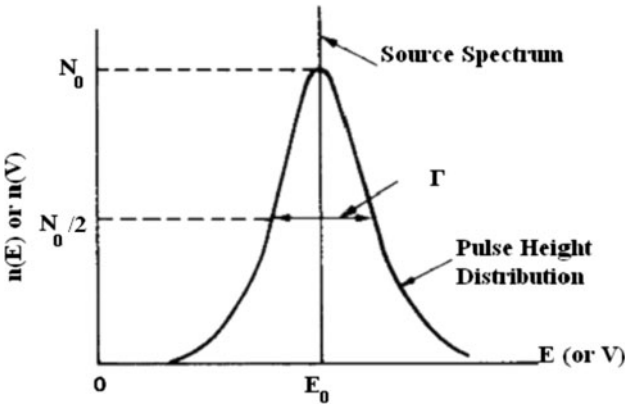


Fig. 1 The energy resolution of the detector [3]

The width Γ is given in energy units, while the ratio $R(E_0)$ is given as a percentage [3]. The definition of the energy resolution of a detector is shown in Fig. 1.

A comparison between scintillation and semiconductor detectors with respect to their timing properties for triple coincidence measurements and imaging was carried out by Abuelhia et al. [4]. Troyer et al. [5] investigated the energy resolution enhancement of a high pressure xenon gamma detector through pulse rise-time characterization. The cross section of a radiative neutron capture reaction of a nucleus was investigated by means of NaI(Tl) detector by Ohsaki et al. [6]. Lynch introduced the timing results for a coincidence spectrometer composed of a plastic and a NaI(Tl) scintillation detectors [7]. Energy spectrum of ^{241}Am was acquired by using NaI(Tl) scintillation detector by Al-Azmi [8].

In the present work, gamma-ray energy spectrum of a ^{137}Cs radioactive source was obtained by using a spectrometer which was consisted of NaI(Tl) scintillation detector and the energy resolution at photopeak energy (662 keV) was determined. To improve this energy resolution, constant fraction timing discrimination method was used. A comparison between the obtained energy resolutions without and with timing method was performed. The energy resolution with timing method was better than that of the energy resolution without timing method.

Experimental

In this work, the procedure can be summarized in one paragraph: First, energy spectrum of ^{137}Cs was obtained and the energy resolution at the photopeak energy was determined. Then, time spectrum of the radioisotope was obtained by using constant fraction timing method and time resolution was calculated. After this process, the energy spectrum was coincidentally gated by the timing application.

A ^{137}Cs radioactive source (5 μCi) and a REXON Inc. NaI(Tl) (3 × 3 inch^2) scintillation detector were used. The half-life of the source is 30.07 y [9]. It was placed in 4 cm far away from the detector surface. All measurements were obtained in a data acquisition time of 900 s.

Constant fraction timing method, which is one of the timing methods, was used in this work. Probably the most efficient and versatile method available today is the constant fraction triggering technique. In this method, the logic signal is generated at a constant fraction of the peak height to produce an essentially walk-free timing signal. The basis for this idea arose from empirical tests which showed the existence of an optimum triggering level for the best timing resolution. Depending on the type of signal, this level occurs at a certain fraction of the pulse height independent of the amplitude [2].

First, in this method, the original pulse (a) is attenuated by a factor f equal to the fraction of the pulse height on which the timing will be based (b). The original pulse is inverted and delayed (c) for a time longer than its risetime (this is the time it takes for the pulse to rise from 10 to 90% of its full amplitude). Finally, the signals in b and c are added to give the signal in (d). The time pick-off, taken as the zero-crossing point, is thus defined by the preselected fraction of the pulse height and is independent of the pulse amplitude. It can be shown that pulses with the same risetime always give the same zero-crossing time [3].

Timing diagram of the constant-fraction technique is shown in Fig. 2.

The spectrometer, which its circuit scheme was given in Fig. 3, was used in this work.

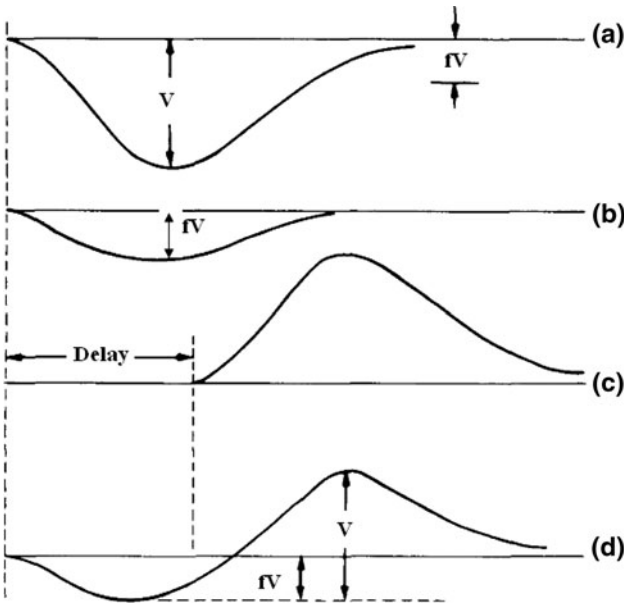


Fig. 2 Constant-fraction timing technique [3]

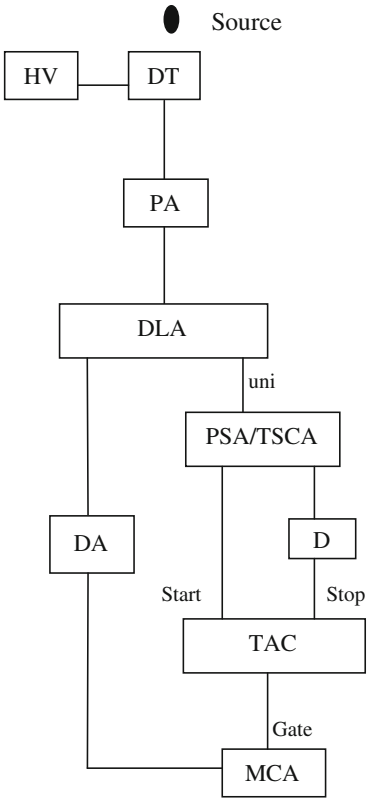


Fig. 3 Block diagram of the used spectrometer. *HV* high voltage supplier, *DT* detector, *PA* preamplifier, *DLA* delay line amplifier, *DA* delay amplifier, *PSA/TSCA* pulse shape analyzer/timing single channel analyzer, *D* delay, *TAC* time to amplitude converter, *MCA* multichannel analyzer

In the setup, the detector output was connected to a preamplifier (PA, ORTEC 113) and a delay line amplifier (DLA, ORTEC 460), respectively. Bipolar output of the DLA was forwarded to a multichannel analyzer (MCA, ORTEC Trump 8K) input through a delay amplifier (DA, ORTEC 427A). Thus, energy spectrum branch of the spectrometer was formed. Bipolar output from the amplifier was used in order to avoid baseline shift. The unipolar output of the DLA was sent to a pulse shape analyzer/timing single channel analyzer (PSA/TSCA, ORTEC 552). The PSA/TSCA is a module which its output signals are generated through its own channels A and B. These output signals are generated by the constant-fraction timing method on the trailing edge of the input signal, after the logic for acceptance has been completed [10]. One of the output signals of the PSA/TSCA (output A) was directly sent to a time to amplitude converter (TAC, ORTEC 566). The TAC is a device that produces an output pulse with amplitude proportional to the time interval between its input 'start' and 'stop' pulses [1]. To generate a significant time difference between start and stop signal, B output of PSA/TSCA was first connected to a delay unit (D, ORTEC 425A) then to the TAC. These connections formed the timing branch of the spectrometer. Connection of the TAC output to the MCA gave the time spectrum. Coincidence connection of the energy signals with the timing signals created the energy spectrum having better energy resolution. The output signal shapes from the preamplifier and the TAC can be seen in Fig. 4.

To investigate the effect of the amplifier coarse gain value to its noise voltage, we changed the amplifier coarse gain from 10 to 1,000 at constant fine gain. We obtained minimum noise voltage at the coarse gain value of 50 as shown in Fig. 5. For this reason, the coarse gain knob of the amplifier was set to this value and was not changed during all measurements.

Results and discussion

The energy spectrum of ^{137}Cs without timing discrimination method is shown in Fig. 6.

In Fig. 7, obtained time spectrum of the isotope by using timing discrimination method can be seen.

Time resolution of the detector for the used isotope was calculated from Fig. 7 as 4.309 ns. If the time resolution value is low, better time resolution is obtained. This time resolution value indicates that the detector is capable of distinguishing the signals in different shapes in the time period of 4.3 ns. This feature of the detector helps us to improve the energy resolution by discriminating the spurious signals in the energy spectrum such as noise, background, scattering and backscattering etc. from the original gamma spectrum of the isotope. This process can be explained in detail like that: as can be seen in the circuit scheme, timing branch uses the amplifier output, too. Main device in the timing branch is PSA/TSCA. This unit produces two fast negative analog pulses through its A and B outputs when the trailing edge of the input signal reaches its 10 and 90% levels as explained above. Since, naturally, the times correspond to these levels are different for different types of signals, the TAC produces time signals depending on these signal shapes. If these timing signals are connected to the gate input of an MCA coincidently with its energy input, discrimination of the spurious pulses not coming from the used radioisotope is acquired. Thus, effective energy resolution improvement can be obtained for these type measurements.

Coincident energy spectrum of the isotope with timing signals is given in Fig. 8.

The energy resolution without the timing method was calculated as 7.1% from Fig. 6 and the energy resolution with the timing method was found as 6.7% from Fig. 8.

Comparison of the energy spectra without and with timing discrimination method is shown in Fig. 9.

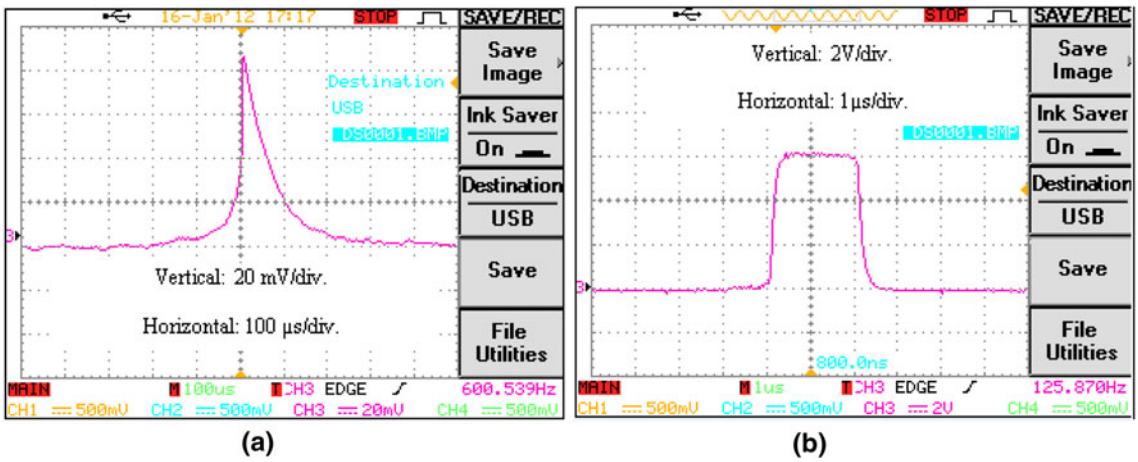


Fig. 4 Signal shapes of (**a**) the preamplifier (**b**) the TAC output

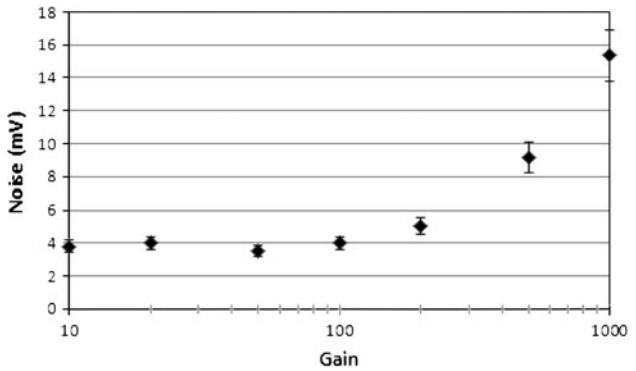
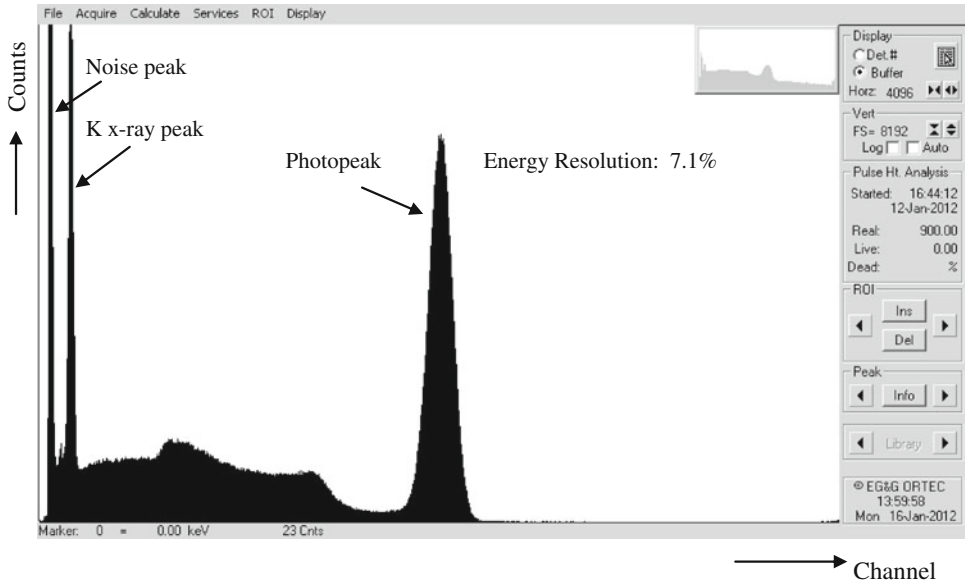


Fig. 5 Electronic noise vs. amplifier gain (detector bias = 1,000 V)

In the figures above, horizontal and vertical axes correspond to number of channels and counts, respectively.

In the work by Troyer et al. [5], the energy resolution at 662 keV of a NaI(Tl) detector was informed as ~8%. We obtained the resolution value of 7.1% without timing application. The authors applied pulse rise time characterization to the gamma-ray energy spectrum of ^{137}Cs obtained from a high pressure xenon gamma detector which was presented as an alternative for NaI(Tl) and HPGe (hyperpure Ge) detectors. The experimental setup and the procedure in this work and this reference resemble each other except for a few details. For this reason, the results in both works can be compared for discussion. The photopeak resolution for the detector was given as 7.6% after full pulse rise time application in Ref. [5]. However, in the introduced work, the photopeak resolution was obtained as 6.7% with a resolution enhancement of 0.4% for overall (full) timing application which has the same way as in that paper. Although the authors expressed in Table 1 of their paper that the xenon detector has better resolution (2% @ 662 keV) than NaI(Tl) detector, they have found a resolution value of 7.6% through full pulse

Fig. 6 Energy spectrum of ^{137}Cs



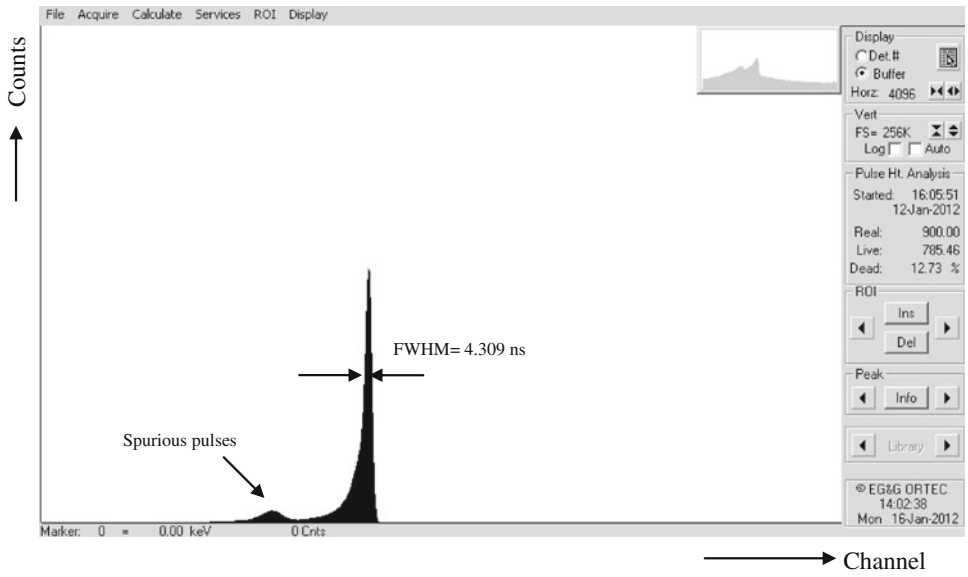


Fig. 7 Time spectrum of ^{137}Cs

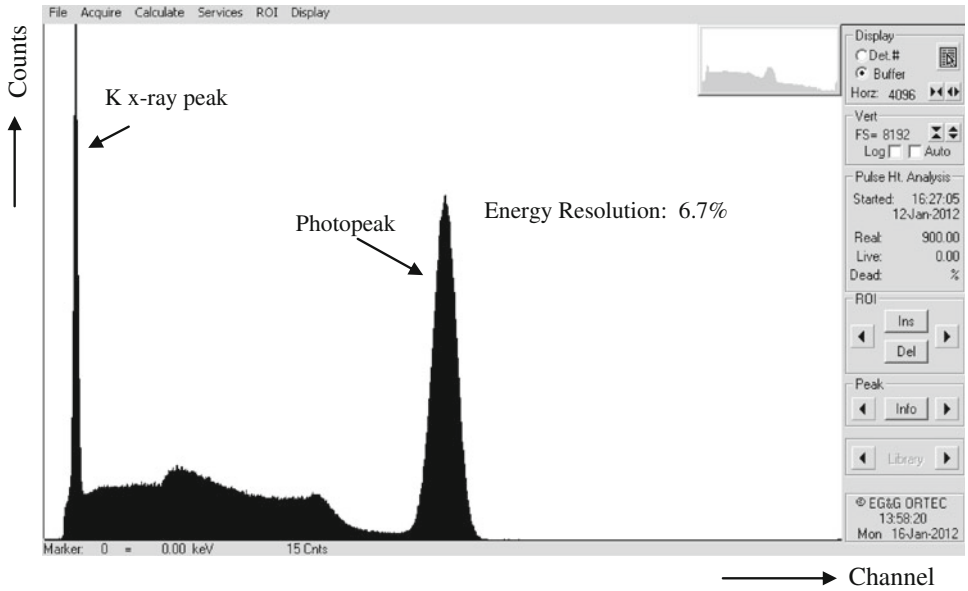


Fig. 8 Energy spectrum of ^{137}Cs after timing application

rise time characterization (Table 2). In contrast to this conclusion, the obtained results in this paper showed that the energy resolution of a NaI(Tl) detector exhibited better energy resolution of 6.7% via used timing technique at the same energy than that of the used xenon detector in that work. In Fig. 5 of the reference paper with 'Full' legend, the low-energy region (approx. 100 keV) of the gamma spectrum was discarded and the K X-ray peak (32 keV) was not available. But, in the present work, this energy region together with the X-ray peak was revealed in the final spectrum (Figs. 8, 9). It can be deduced from this comparison that the obtained results here are highly satisfactory for the energy spectrum enhancement.

Conclusions

Energy and time spectra of ^{137}Cs were obtained by using a spectrometer which was consisted of a NaI(Tl) scintillation detector. To improve the energy resolution, the energy spectrum was gated by the constant fraction timing method. After applying the timing method, energy resolution value

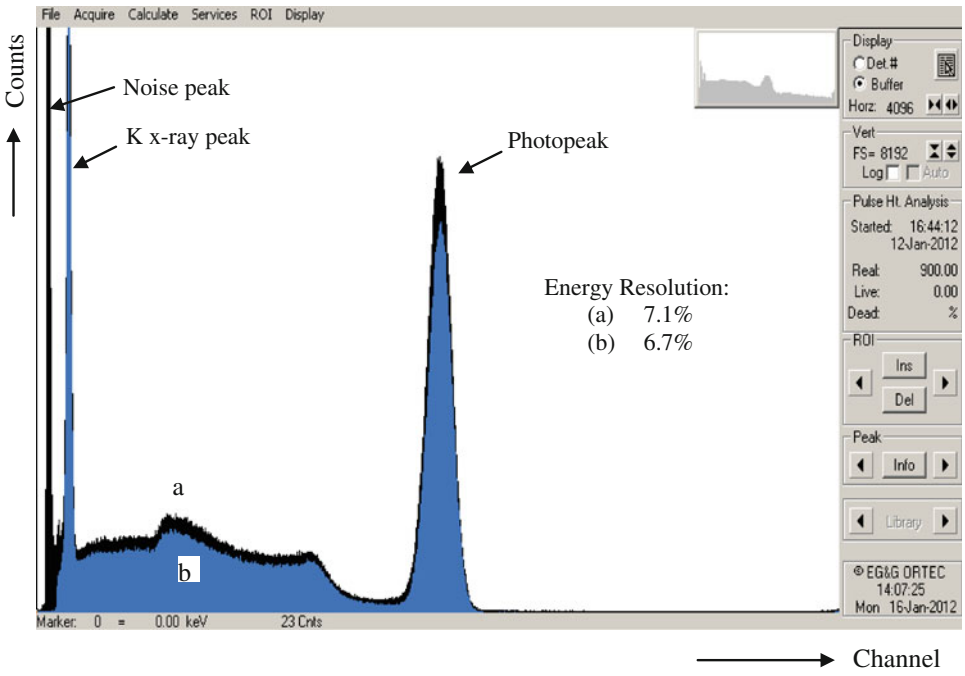


Fig. 9 Comparison of energy spectra before (**a**) and after (**b**) timing application

was decreased from 7.1 to 6.7% which means that the resolution was improved a percentage of 0.4% at the constant medium temperature. This result shows us that the applied method was successful on the improvement of the energy resolution of the radioisotope. In Fig. 9, the energy spectra of the used isotope without and with timing method were shown together for comparison.

Time resolution values for slow scintillators such as NaI(Tl), BGO were informed as 1–2 ns [1]. Time resolution value of 4.3 ns for the used NaI(Tl) detector was found in this work. The obtained time resolution is compatible with the ideally informed value in this respect.

Minimum noise level of the amplifier was obtained by changing coarse gain of the amplifier at constant fine gain. We concluded from this experience that the coarse gain value of the amplifier affects the noise level extremely. Since the minimum noise was obtained at the gain value of 50, the coarse gain of the amplifier was set to 50 during whole measurements.

The energy resolution of a spectrometer depends on the electronic noise [11]. In addition to the energy resolution improvement of the spectrometer, the electronic noise peak in low energy region in the energy spectrum (Fig. 6) was successfully discriminated by means of the used timing discrimination method as can be seen in Figs. 8, 9.

The fact that the dead time of the MCA was 0% in the spectra in Figs. 6, 8, 9 and 10% in the spectrum in Fig. 7 denotes that pulse pile-up and spectrum distortion were not included in these spectra [1, 2]. In this connection, it can be explained that this case increases the reliability of the obtained results.

As a conclusion, it can be stated that the constant fraction timing method is quite successful in the energy resolution improvement of the NaI(Tl) scintillation detectors.

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