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Technical note

Effects of detector–source distance and detector bias voltage variations on time resolution of general purpose plastic scintillation detectors

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HIGHLIGHTS

- Effect of the source-detector distance on time spectra was investigated.
- Effect of the detector bias voltage variations on time spectra was examined.
- Optimum detector–source distance was determined for the best time resolution.
- Optimum detector bias voltage was determined for the best time resolution.
- ^{133}Ba and ^{207}Bi radioisotopes were used.

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ABSTRACT

Effects of source-detector distance and the detector bias voltage variations on time resolution of a general purpose plastic scintillation detector such as BC400 were investigated. ^{133}Ba and ^{207}Bi calibration sources with and without collimator were used in the present work. Optimum source-detector distance and bias voltage values were determined for the best time resolution by using leading edge timing method. Effect of the collimator usage on time resolution was also investigated.

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1. Introduction

Timing experiments in nuclear physics, that is, the measurement of very small time intervals of arriving pulses, are used in measurement of the time evolution of an event (e.g., measurement of radioactive decay), measurement of true coincident events out of a large group of events, and discrimination of different types of particles based on the different time characteristics of their pulses (pulse-shape discrimination) (Tsoulfanidis, 1995). Accurate measurements of these time intervals require special techniques (Leo, 1987).

Plastic scintillators are often used in these types of experiments and the most commonly used materials are polyvinyltoluene, polyphenylbenzene and polystyrene. These detectors offer an extremely fast signal with a decay constant of about 2–3 ns (Leo, 1987). BC400 type plastic scintillators are the most economical in comparison with other types as well as those with the highest light output, and detailed information about this material can be obtained from the manufacturer (Saint-Gobain, 2012).

A circuit for producing a timing signal from the leading edge of slow rising Ge–Li detector output signals was described by Waugh (1968). Singkarat et al. (1981) have constructed a simple leading edge discriminator for use a time pick off device with a NaI(Tl) and NE102 type plastic scintillation detectors.

We have discovered from our literature inspection that no paper has been published on the effects of source to detector distance and bias voltage changes on time resolution. Therefore, the effects of the detector–source distance and the detector bias voltage variations on the time resolution of a BC400 type general purpose plastic scintillation detector for ^{133}Ba and ^{207}Bi calibration sources were investigated in the present work by the leading edge timing method.

2. Experimental

The leading edge timing method was used in this study. This technique determines the time of arrival of a pulse with the help

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of a discriminator. A discriminator threshold is set and the time of arrival of the pulse is determined from the point where the pulse crosses the discriminator threshold (Tsoulfanidis, 1995). Further information about the method can be found in (Gedcke and McDonald, 1968; Moszynski and Bengtson, 1979; Paulus, 1985).

^{133}Ba and ^{207}Bi calibration sources of 3.503×10^5 Bq (9.468 μCi) were used in the present work, and their half-lives are 10.51 and 31.55 y, respectively (Matpack, 2012). The thicknesses and the diameters of both sources were 0.3 and 2.5 cm, respectively (Fig. 1).

A Bicron BC400 type (equivalent to NE102A) plastic scintillation detector is preferred for general purpose radiation measurement application (Saint-Gobain, 2012). Since it is a general purpose radiation detector, we used this type plastic scintillation detector in this study with a thickness of 3 mm and a diameter of 3 in.

A block diagram of the spectrometer used is illustrated in Fig. 1.

As can be seen in Fig. 1, the detector output was input to a delay line amplifier (DLA, Ortec 460) through a preamplifier (PA, Ortec 113). To have a bipolar output and avoid the baseline shift, the integration time of the DLA was set to 0.04 μs according to the manufacturer's instructions. The bipolar output of the DLA was split into two branches and these outputs were connected to two timing single channel analyzers (TSCA, Ortec 420A). The bipolar output should be used for time spectroscopy if the time signal is derived from a baseline crossover (Ortec, 1973). The threshold levels of the TSCAs were adjusted above the noise level in order to minimize the amount of noise in the observed signal. Output signals are produced when the input signals cross this threshold level. The outputs of the TSCAs were connected to a time to amplitude converter (TAC, Ortec 566), the output of which was sent to a multichannel analyzer (MCA, Ortec Trump 8k). The TAC range was adjusted to 200 ns for the proper time resolution. (Knoll, 2000). The output signal shapes of the PA (fast negative output) and the TAC (logic output) can be seen in Fig. 2.

The TAC converts the time period between two input pulses (a "start" pulse and a "stop" pulse) into a logic output pulse whose height is proportional to this duration. The time period measured by the TAC is thus proportional to the decay time of the detector pulse.

A time calibration of the MCA was done to determine the time value per channel of the MCA. For this process, delay times of the stop signals were changed and the timing peak positions were determined for each delay time value. Since delay switches are available on the front panels of the TSCA, no additional delay module between the start and stop inputs of the TAC was needed. The channel numbers of the peak positions vs. delay time data were plotted and this time calibration graph is given in Fig. 3.

In this figure, channel numbers of the timing peaks increased linearly with the increasing delay times, as expected. The time

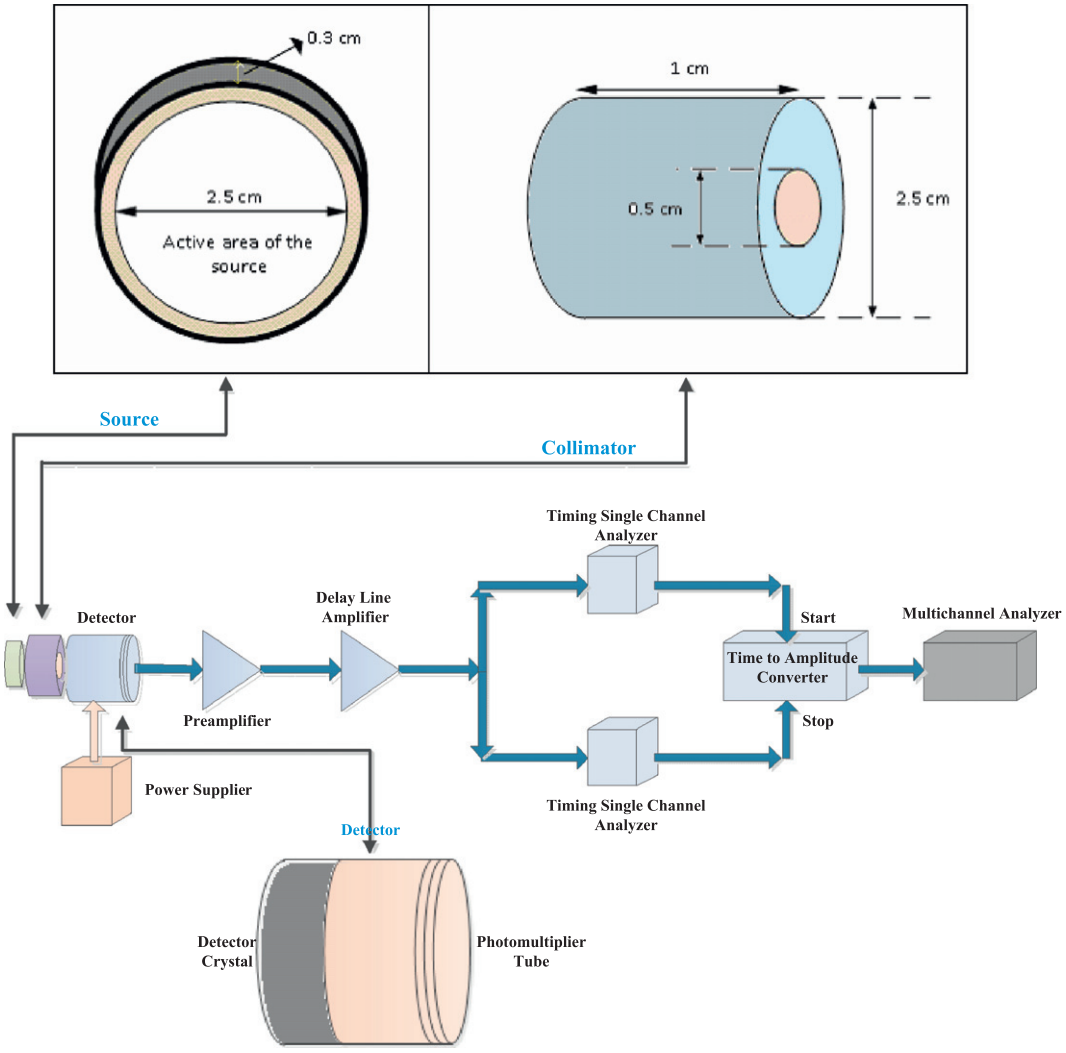


Fig. 1. Block diagram of the used spectrometer.

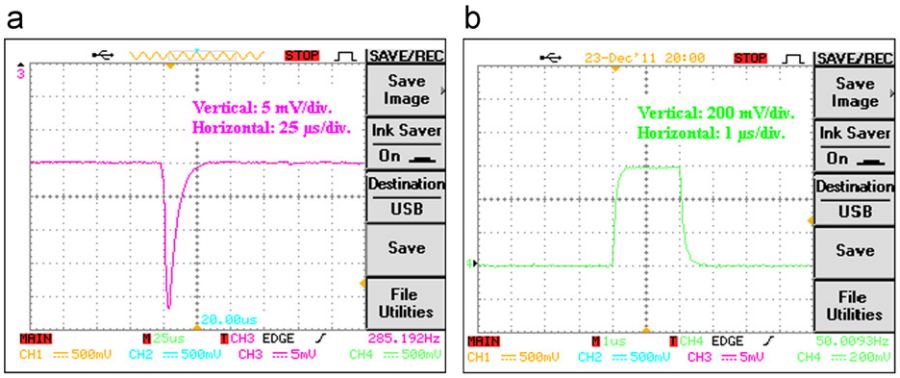


Fig. 2. Signal shapes of (a) preamplifier and (b) TAC outputs.

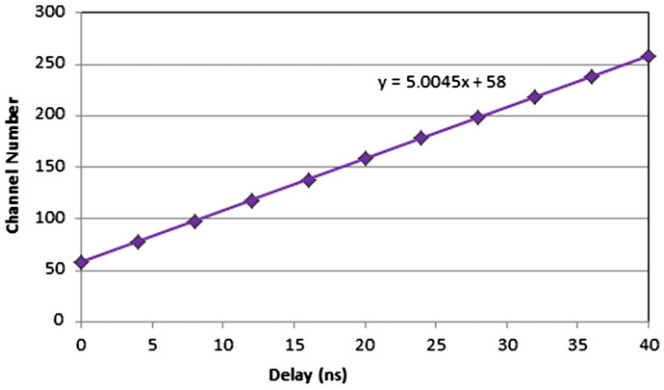


Fig. 3. Time calibration graph.

value per each channel of the MCA was calculated from the inverse of the slope of the time calibration graph, and this value was found so as to be 195.3125 ± 0.0051 ps/ch. This value also equals the result of the ratio of the TAC range to the conversion gain (1024 ch.) of the MCA. The uncertainty was calculated from the fit equation shown in Fig. 3. The fact that the time value per channel of the MCA from this graph equals to the result from this ratio indicates a good time calibration was acquired.

The distance between the detector surface and the source was increased from 2 cm to 9.5 cm and the time spectra of the radioisotopes were accumulated. Supplementary time spectra vs. the detector bias voltage variations at the source to detector apart of 4 cm were also recorded. After that, the measurements were repeated using an Al collimator. The collimator was mounted on the active surfaces of the sources. The thickness, the hole and the outer diameter of the collimator were 1 cm, 0.5 cm and 2.5 cm, respectively (Fig. 1).

All measurements were acquired with a data acquisition time of 300 s in a dark room at a constant room temperature (22 °C) to minimize dark noise.

3. Results

Best time resolution values were obtained at the source–detector distance (d) of 4 cm as can be seen in Table 1.

Since the optimum detector–source distance was taken to be 4 cm, the sources with and without collimator was separately placed at this distance to obtain optimum detector bias voltage for the best time resolution. The applied detector bias voltage was changed from 900 V to 1,300 V for this purpose. Since the detector did not give any output signal at a bias voltage of 900 V and below, the time spectra for ^{133}Ba with and without collimator could not be acquired at this voltage. The detector bias voltage was kept below 1,300 V to prevent detector damage. The dependence of the time resolutions to the applied voltage is shown in Table 2.

These results have shown us that optimum detector bias voltage for the detector was 1,250 V. The dead time of the MCA was less than 1% during the whole data acquisitions. From this, no pulse pile-up effect and signal distortion on the obtained results can be inferred (Knoll, 2000; Leo, 1987).

Table 1
Time resolution results with respect to the source-detector distance of ^{133}Ba and ^{207}Bi (with and without collimator).

Source-detector distance (d) (cm)	Time resolution (with collimator) (ns)		Time resolution (without collimator) (ns)	
	^{133}Ba	^{207}Bi	^{133}Ba	^{207}Bi
2.0	3.075 ± 0.075	3.059 ± 0.065	3.198 ± 0.073	3.190 ± 0.065
4.0	2.408 ± 0.065	2.408 ± 0.131	2.473 ± 0.066	2.799 ± 0.065
6.0	3.124 ± 0.196	3.059 ± 0.196	3.189 ± 0.131	3.255 ± 0.130
8.0	3.255 ± 0.130	3.255 ± 0.065	3.320 ± 0.195	3.450 ± 0.260
9.5	3.450 ± 0.065	3.385 ± 0.130	3.515 ± 0.390	3.515 ± 0.195

Table 2
Time resolution results with respect to the detector bias voltage of ^{133}Ba and ^{207}Bi (with and without collimator).

Applied voltage (V) (d=4 cm)	Time resolution (with collimator) (ns)		Time resolution (without collimator) (ns)	
	^{133}Ba	^{207}Bi	^{133}Ba	^{207}Bi
900	N/A	2.604 ± 0.065	N/A	2.864 ± 0.130
1,000	2.864 ± 0.065	2.799 ± 0.130	3.190 ± 0.065	2.994 ± 0.065
1,100	3.059 ± 0.130	3.124 ± 0.195	3.254 ± 0.325	3.190 ± 0.130
1,200	2.799 ± 0.064	2.604 ± 0.065	2.994 ± 0.130	2.669 ± 0.260
1,250	2.603 ± 0.130	2.017 ± 0.260	2.929 ± 0.196	2.278 ± 0.130
1,300	2.603 ± 0.065	2.017 ± 0.131	2.929 ± 0.195	2.278 ± 0.065

4. Discussions and conclusions

In this work, optimum detector–source distance and the detector bias voltage for the best time resolution for a spectrometer consisted of a BC400 plastic scintillation detector were

obtained by using leading edge timing method for ^{133}Ba and ^{207}Bi calibration sources with and without collimator. Circuit scheme of the used spectrometer and the time calibration graph were given in Figs. 1 and 3. Obtained time resolution results for the used radioisotopes with and without collimator according to source detector apart and bias voltage variation were presented in Tables 1 and 2.

It was shown that the optimum detector–source distance for the best time resolution was determined as 4 cm for both radioisotopes with and without collimator. We concluded that the detector–source distance was quite effective parameter on the time resolution. In addition, time resolution improvement was obtained by using collimator.

We also investigated the effect of the detector bias voltage variation on the time resolution for both radioisotopes with and without collimator. In order to discover this effect, detector–source distance was set to 4 cm since the optimum time resolution values were obtained at this distance. As can be seen from Table 2, number of obtained counts at lower bias voltage (900 V) is lower than that of the higher ones since this voltage value corresponds nearly to the beginning of the detector operation voltage plateau. For this reason, small time resolution values were obtained at this voltage level. As the bias voltage was increased, the time resolution values were saturated at 1,250–1,300 V for both radioisotopes. We deduced from these results that the optimum resolution was achievable at the detector bias voltage of 1,250 V.

It was emphasized from the present work that the optimum source to detector distance, the optimum detector bias voltage and the collimator effects to the results for the best time resolution should be inspected before the data acquisition. This conclusion can be applied to any time resolution measurement. Future experiments will be focused on the obtaining the best time resolutions for the time coincidence spectrometers by means of this conclusion.

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