Energy and Time Resolution of $CeBr_3$ Scintillators Using Digital Detection Methods

Young-Su Jeong [a], Bo-Young Han [a*], Jinyu Kim [a], Jaegi Lee [a], Gwang-Min Sum [a], Yongmin Kim [b]
[a]*HANARO Utilization Division, Korea Atomic Energy Research Institute, Daejeon 305-353, Republic of Korea*
[b]*Department of Radiological Science, Daegu Catholic Univ., Gyeongsan 13-13m Republic of Korea*
[*]*Corresponding author: byhan@kaeri.re.kr*

Keywords : Energy resolution, Time resolution, $CeBr_3$ scintillator, Digital method

1. Introduction

Scintillation spectrometry is widely utilized for nuclear research, particle physics, and medical imaging [1]. The $CeBr_3$ scintillator shows good energy and time resolutions due to its high light output (~68,000 photons/MeV) and fast decay constant (17 ns to 25 ns). The advancement of fast digitizer technology enables new methodologies in positron annihilation spectroscopy (PAS). The primary advantage of digital PAS is that the output signals from the detectors are directly sampled in real-time using a fast digitizer and immediately stored on a computer. The analysis of the sampled waveforms can be efficiently conducted offline through appropriate software procedures.

Digital methods hold several key advantages: (1) The random noise generated by analog nuclear instrument modules (NIM) is eliminated, resulting in enhanced accuracy of the sampled output signals. (2) Direct access is possible to all output signals, allowing significantly more information to be recorded compared to analog methods. (3) Data analysis can be repeatedly performed, enabling the optimal approach to be found for extracting necessary physical information and eliminating unwanted distortions or damaged signals.

This study measured the energy resolution of $CeBr_3$ detectors using digital methods. It also analyzed the time resolution of the gamma peaks of the ^{60}Co source.

2. Methods and Results

In this experiment, the energy and time resolutions of $CeBr_3$ scintillation detectors were measured using digital methods. A cylindrical $CeBr_3$ crystal measuring 25 mm × 25 mm was supplied by Epic-Crystal. It was mounted on a photomultiplier tube (PMT) (R329-02, HAMAMATSU) and sealed in an aluminum case. The ORTEC 265A was used as the PMT base. Voltages of 1.15 keV and 1.20 keV were applied to detectors $CeBr_3$ #1 and #2, respectively. The high voltage power supply (HVPS) module was the NDT1470 model supplied by CAEN. Figure 1 illustrates that the two $CeBr_3$ detectors were positioned at 90 degrees to each other. An isotopic source was placed at their orthogonal position to measure the energy and time resolutions.

The output signals from the anode of detectors were directly inputted into a 12-bit digitizer (NKFADC500-4, NOTICE) for sampling. The digitizer was set to a bin width of 0.61 keV/channels, a recording length of 4 μs, and a sampling frequency of 500 MHz. The energy and time information obtained from the amplitudes was analyzed offline.

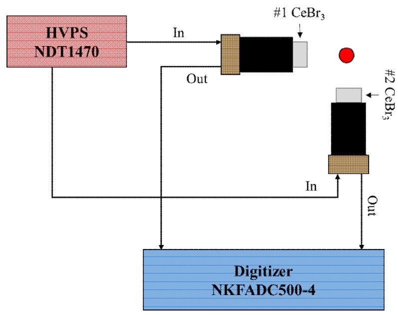

Fig. 1. Schematics of the digital setup used to measure energy and time resolution of the $CeBr_3$ detectors. HVPS: high voltage power supply.

The ^{137}Cs and ^{22}Na sources were used to measure the energy resolution, which was determined by measuring the full width at half maximum (FWHM) of the full energy (FE) peaks. The accumulated histogram of the primary pulse amplitude was calibrated using the known energies of the radioactive isotopes ^{137}Cs (662 keV) and ^{22}Na (511 keV and 1,274 keV). The time resolution was determined by coincidence recording the FE peaks and Compton edges of 1173.2 keV and 1332.3 keV emitted from a ^{60}Co source and analyzing the zero-crossing point using the digital constant-fraction discriminator (dCFD) method [2].

3. Results and Discussion

The calibrated energy spectra obtained through the digital setup are depicted in Fig. 2. Figure 3 shows the FWHM (in keV) of the FE peak at various energies (511 keV, 662 keV, and 1,274 keV), as revealed by the digital setup. It is well known that the width of the full energy peak measured by the detector is found to be proportional to the square root of the energy absorbed by the detector from the detected photons [3]. The points illustrated in Fig. 3 are placed on a red straight line drawn against the square root of the energy. The FWHM for the energies of the radioactive isotopes ^{137}Cs and ^{22}Na are determined through linear interpolation. For $CeBr_3$ detector #1, the FWHM values are measured to be (49.7± 0.2) keV, (53.7 ± 0.3) keV, and (70.7 ± 0.8) keV, while for $CeBr_3$ detector #2, they are (55.0± 0.3) keV, (59.9 ± 0.3) keV, and (79.5 ± 0.9) keV.

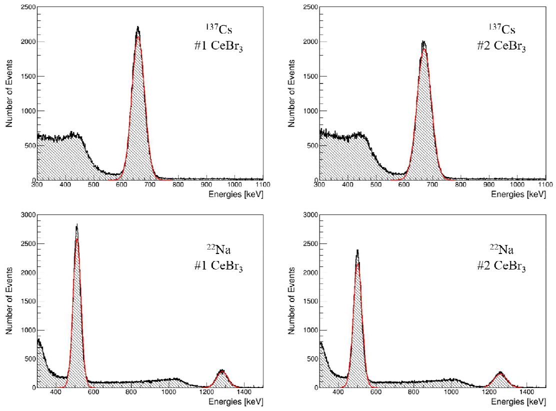

Fig. 2. Energy spectra of ^{137}Cs and ^{22}Na measured through $CeBr_3$ detectors #1 and #2.

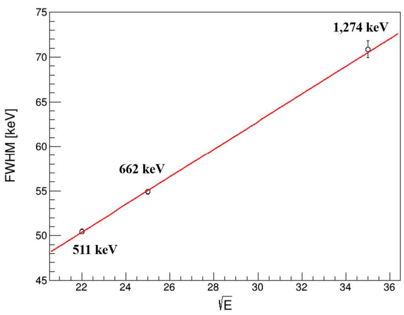

Fig. 3. Energy resolution using digital method: FWHM of full energy peaks from ^{137}Cs and ^{22}Na radioisotopes plotted against square root of detected photon energy. Red line: linear interpolation line.

Figure 4 presents the energy window set to determine the time resolution. The energy window for $CeBr_3$ detectors #1 and #2 is approximately 808 keV to 1,471 keV. The simultaneous measurement results for the ^{60}Co source are shown in Fig. 5. The measured time resolution ($FWHM_T$) is (0.355 ± 0.052) ns.

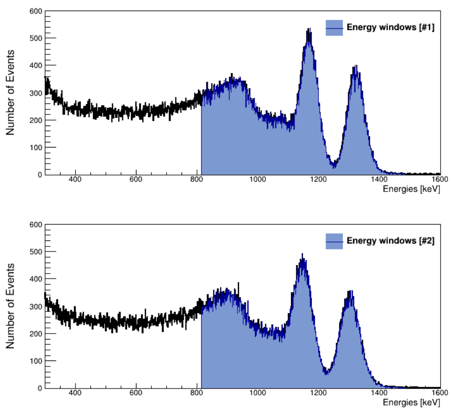

Fig. 4. Energy window for determining time resolution.

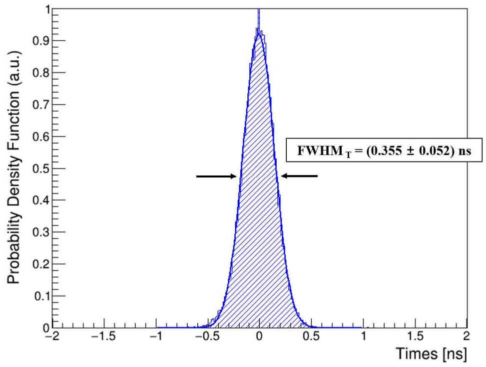

Fig. 5. Time resolutions for $CeBr_3$ detectors (#1 and #2) in coincidence using digital method.

The energy and time resolution of $CeBr_3$ detectors based on the digital method are measured. This study suggests that the digital method using $CeBr_3$ detectors can be applied to PAS technology. It is confirmed that there might be potential to assist the age-momentum correlation (AMOC) technique, which requires both energy and time resolution, within PAS technology. In the future, it is planned that signals from three detectors, including a high-purity germanium (HPGe) detector with good energy resolution, will be simultaneously measured to utilize in the AMOC technique.

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