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The Pulse-height Spectra of a Plastic Scintillation Optical Fiber Detector according to the Position of Gamma-ray Emitting Radioactive Nuclides

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1. Introduction

The occurrence of a large-scale nuclear accident, such as the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident in 2011, resulted in the release of significant amounts of volatile radionuclides into the environment [1]. After the FDNPP accident, there was a new demand for measurements, including rapid measurement of radiation distribution over a wide area, such as surveying the distribution of contamination and confirming the effectiveness of decontamination. To comprehend the stabilization and decontamination of radionuclides in large-scale nuclear accidents, it is essential to identify areas that are contaminated with radioactive substances. Additionally, radiation monitoring during and after decontamination is necessary to access the effectiveness of the decontamination process [2].

A Plastic scintillation optical fiber (PSOF) detector is suitable for localizing and quantifying radiation sources in a wide range of contaminated areas due to the sensing part is in the form of a string. After the FDNPP accident, research on environmental radiation measurement was conducted, and the Japan Atomic Energy Agency (JAEA) utilized the PSOF detector in Fukushima to measure radioactive cesium concentrations at the bottom of irrigation ponds and survey on-site surface contamination in forested area [3,4,5].

In this study, a position-sensitive PSOF detector was developed using a single-stranded PSOF with a length of 10 m and a diameter of 2 mm. The amount of attenuation of the scintillation light generated by the PSOF varies according to the position of the gamma-ray source. The pulse-height spectrum for each position of the gamma-ray source can be obtained to evaluate the energy dependence of the position-sensitive PSOF detector. The pulse-height spectra of the POSF detector were measured according to the position of gamma-ray emitting nuclides such as ^{137}Cs and ^{133}Ba.

2. Methods and Results

The position-sensitive PSOF detector was composed of a sensing part, two PMTs (H6533, Hamamatsu Photonics), four fast amplifiers (ABL0300-00-4030, WENTEQ & A1424, CAEN), a controller (A4818, CAEN), and a digitizer (DT5742, CAEN). The sensing part was a single 5 m-long PSOF (SCSF-78, Kuraray) with a diameter of 2.0 mm. These PSOFs have a multi-cladded structure and are capable of emitting scintillation light at a peak wavelength of 450 nm.

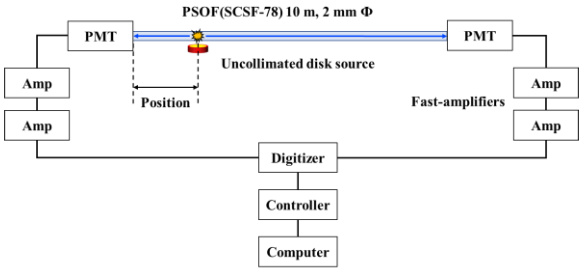

Fig. 1. Schematic diagram of the position-sensitive PSOF detector.

The PSOF was wrapped with a flexible, light-tight heat-shrink tube (FP-301, 3M) and both ends were polished and coupled to the PMT window. To reduce light loss due to light trapping, silicone rubbers (EJ-560, Eljen Technology) were placed between the PMT windows and the ends of the PSOF. Figure 1 shows the overall experimental setup which was evaluated using the gamma-ray sources such as ^{137}Cs and ^{133}Ba.

When gamma-rays interact with the PSOF, it emits scintillation light at a solid angle of 4π, and the light transmitted to both ends of the PSOF through total reflection if it is less than the critical angle. The fast amplifiers amplify the output current pulses of the PMT as voltage pulses, which are then input to the digitizer. The pulse data generated from the PMTs were obtained using a digitizer with a sampling rate of 5 GS/s. The pulse-height spectra for each position of gamma-ray emitting radionuclides were obtained by analyzing the time difference and height of the pulse data using MATLAB.

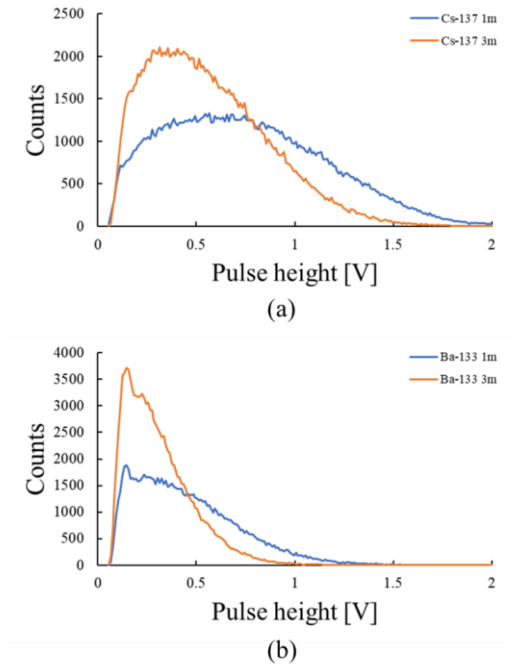

Fig. 2. Pulse-height spectra according to the positions of gamma-ray emitting radionuclides ((a) ^{137}Cs and (b)^{133}Ba).

The pulse-height spectra were obtained by analyzing the height of the voltage pulse of the PMT close to the gamma-ray source. As the position of the gamma-ray emitting radionuclide moves further away from the PMT, the pulse height of the Compton edge (CE) for the same radionuclide decreases, as shown in Figure 2. The scintillation light generated by the reaction between the gamma-ray and the PSOF undergoes attenuation primarily due to absorption and scattering losses as it is transmitted to the PMT via total internal reflection.

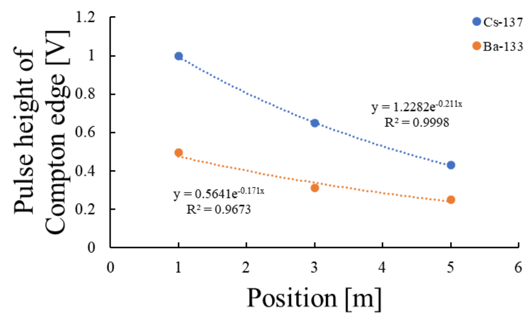

Fig. 3. Compton edge for each gamma-ray emitting radionuclides according to the position of the gamma-ray sources.

Figure 3 shows the pulse height of CEs according to the position of the gamma-ray source. The pulse height of CEs decreases exponentially according to the position of gamma-ray source.

3. Conclusion

In this study, we fabricated a PSOF detector that is position-sensitive and used it to evaluate the pulse-height spectrum based on the position of gamma-ray emitting radionuclide. While the PSOF detector has various applications, the alteration in CE of the pulse-height spectrum based on the gamma-ray emitting radionuclide has not been previously reported. The PSOF detector, we proposed can detect radionuclides over large contaminated areas and can be used for radionuclide identification. In future studies, we plan to measure energy spectra for more diverse radionuclides, including alpha and beta emitting radionuclides, using the proposed PSOF detector.

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