Dose Response of the Position-Sensitive Plastic Scintillation Optical Fiber Bundle Detector

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1. Introduction

In a large-scale nuclear accident, surveying and characterizing radionuclides of interest, including their activity and geographic/topological distributions, are essential for understanding the stabilization and decontamination of radionuclides [1]. Monitoring of the dispersed radionuclides during decontamination and after decontamination decisions is also required to assess the decontamination processes.

A detector for ground surveys should be able to cover large areas and have small volumes for high spatial resolution. Additionally, it can detect radiation such as dose rate accurately. In this respect, plastic scintillation optical fiber (PSOF) has many advantages, such as its good flexibility, long length usability, high water resistance, cost-effectiveness in manufacturing, and lack of interference from electromagnetic fields. Moreover, it is possible to improve the detection sensitivity by fabricating a bundle-type PSOF detector [2]. A PSOF bundle detector can provide one-dimensional data on the contaminated area, enabling faster measurements than conventional point-measuring detectors.

In this study, we fabricated position-sensitive PSOF bundle detector to ground survey in real-time with measuring dose distribution. The dose response of the position-sensitive PSOF bundle detector are evaluated using a Co-60 uncollimated solid-disc-type radioactive isotope.

2. Methods and Results

The position-sensitive PSOF bundle detector consisted of a sensing probe, two PMTs (H6533, Hamamatsu Photonics), two fast amplifiers, a controller (A4818, CAEN), and a digitizer (DT5742, CAEN). To increase the quantity of scintillation light, the sensing probe was made up of seven PSOFs (SCSF-78, Kuraray) of 2.0 mm diameter and 5 m length. These PSOFs can emit blue light with a peak wavelength of 450 nm and have a multi-cladded structure. The trapping efficiency of a multi-cladded PSOF is about 5.4%, which is higher than that of a single-cladded PSOF [3]. Both the inner and outer cladding thicknesses are 0.04 mm, that is, 2% of the PSOF diameter. The materials of the core and the inner and outer cladding are polystyrene (PS), polymethyl methacrylate (PMMA), and fluorinated polymer (FP), respectively. The physical properties of the PSOF and the technical specifications for the PMT are listed in Tables I and II.

Seven multi-cladded PSOFs were bundled together and packed within a light-tight, flexible black shrink tube of 1.68 mm thickness. Both ends of the PSOFs were polished with various sizes and types of polishing pads.

Table I: physical properties of plastic scintillation optical fiber

	SCSF-78
Wavelength of emission max	450 nm
Attenuation length	>4.0 m
Decay time	2.8 ns

Table II: Technical specification of the photomultiplier tube

	H6533
Rise time	0.7 ns
Transit time spread	160 ps
Wavelength of maximum	420 nm
Gain	5.7×10^6

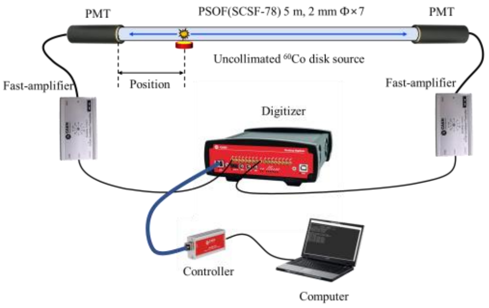

Fig. 1. Schematic diagram of the position-sensitive PSOF bundle detector.

Figure 1 shows the overall experimental setup. To evaluate the dose response, a Co-60 uncollimated solid-disc-type radioactive isotope wave placed at the center of the position-sensitive bundle detector. The dose rate of Co-60 gamma-ray sources was measured using an ion chamber (451B, Fluke).

The scintillation light generated from the PSOF was transmitted to two PMTs, which were placed at both ends of the PSOF bundle as light-measuring devices. The output current signals of the PMTs were amplified using a fast amplifier and sampled using a digitizer. A digitizer with a sampling rate of 5 GS/s was used to obtain signal data close to the original data generated from the PMTs. Moreover, cubic spline interpolation was applied to improve the accuracy of the signal data acquired by the digitizer. The values at query points were based on cubic interpolation of the values of neighboring data points. The signal data obtained using cubic spline interpolation provided the position of the gamma-ray source after applying a digital signal processing approach designed using MATLAB.

The gamma-ray source position was estimated through constant fraction triggering (CFT). Figure 2 shows the position spectra and fitted Gaussian curves for the positions of the Co-60 sources, which were placed at 2.5 m along the PSOF bundle.

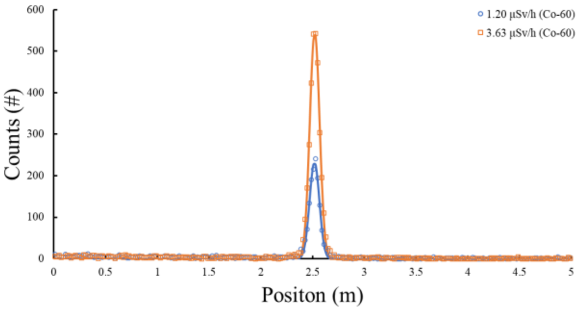

Fig. 2. Measured position spectra and fitted Gaussian curves for non-collimated Co-60 gamma- ray sources located at 2.5 m.

Table III: Experimental results

Dose rate (μSv/h)	1.20	3.63
Actual position (m)	2.5	2.5
Estimated Position (m)	2.52	2.52
Position Error for Total PSOF Length (%)	0.4	0.4
FWHM (cm)	11.15	11.14

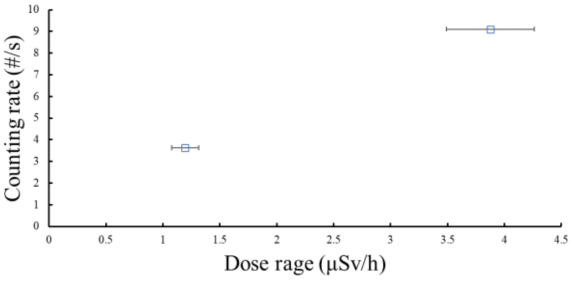

Fig. 3. Dose response of the position-sensitive PSOF bundle detector.

The experimental results are listed in Table III, and they show the differences between actual and measured positions are 2 cm at the source positions of 2.5 m. The full width at half maximums (FWHM) of the curves are 11.15 and 11.14 cm when the source dose rates of 1.20 and 3.63 μSv/h, respectively. Figure 3 shows the dose response of the position-sensitive PSOF bundle detector. The sensitivity of the position-sensitive PSOF bundle detector are evaluated using a dose response. The counts per 1 μSv/h are 3.24 and 2.51 when the source dose rates of 1.20 and 3.63 μSv/h, respectively.

3. Conclusions

In this study, a position-sensitive PSOF bundle detector was fabricated, and its dose response was evaluated. The proposed PSOF bundle detector was composed of a multi-cladded PSOF bundle, two PMTs, two fast amplifiers, a controller and a digitizer. To improve the sensitivity of the proposed PSOF bundle detector, seven multi-cladded PSOFs were bundled together and packed. The FWHM measured using our proposed PSOF bundle was approximately 10 cm using a 5 m long PSOF bundle. It was confirmed that the counts per 1 μSv/h are 3.24 and 2.51 when the source dose rates of 1.20 and 3.63 μSv/h, respectively.

The PSOF bundle detector proposed in this study can be used for fast and accurate detection of radionuclides over wide contaminated areas, not only due to nuclear power plant accidents, but also large-scale nuclear events or accidents, including the detonation of radiological dispersal devices (RDDs) and improvised nuclear devices (INDs). The proposed 5 m length of the PSOF bundle detector can be used with a vehicle to cover larger contaminated areas.

In future studies, a PSOF bundle detector of 10 m or more will be fabricated, and the sensitivity of PSOF bundle the detector will be optimized according to the dose rate by adjusting the number of PSOFs.

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