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Feasibility Study on Fiber-optic Radiation Sensor for Remote Gamma-ray Spectroscopy

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1. Introduction

The expansion of nuclear industry has become unavoidable any more due to the growing demand for energy. However, nuclear wastes generated in the nuclear reactor should be managed consistently to use the nuclear energy. Therefore, the management technique of radioactive wastes by monitoring the radioactive isotopes is very important as much as the development of nuclear industry.

The basic principle of radiation detection is to detect the signals caused by interactions between radiations and materials. There are various types of radiation detectors depending on types of radiation to be detected and physical quantities to be measured. As one of the radiation detectors, a fiber-optic radiation sensor using a scintillator and an optical fiber has two advantages such as no space restraint and remote sensing. Moreover, in nuclear environments, this kind of sensor has immunities for electromagnetic field, temperature, and pressure. Thus, the fiber-optic radiation sensor can be used in various fields including nondestructive inspection, radioactive waste management, nuclear safety, radiodiagnosis and radiation therapy.

As a fundamental study of the fiber-optic radiation sensor for remote gamma-ray spectroscopy, in this study, we fabricated a fiber-optic radiation sensor using an optical fiber and various scintillators. To select an adequate inorganic scintillator for the sensing probe of fiber-optic radiation sensor, 5 types of scintillators were evaluated. The spectra of gamma-rays emitted from a Na-22 radiation source were measured by using the manufactured sensors.

2. Materials and Experimental Setup

2.1 Probe of sensor

As sensor probes of the fiber-optic radiation sensor, cylindrical inorganic scintillators (LYSO:Ce, YSO:Ce, BGO, YAP:Ce, LuAP:Ce) were used throughout this study. The scintillators used in this study have a diameter of 3 mm and a length of 15 mm. The peak emission wavelength of LYSO:Ce and YSO:Ce is 420 nm. In cases of BGO, YAP:Ce and LuAP:Ce, the peak emission wavelengths are 480 nm, 370 nm, and 355 nm respectively.

A multi-mode step-index plastic optical fiber (POF; CK120, Mitsubishi Rayon) was used to guide scintillation signal to a photo detector. Core and cladding of the fiber are composed of polymethyl methacrylate (PMMA) and fluorinated polymer respectively. The refractive indices of the Core and the cladding are 1.49 and 1.402 respectively. The numerical aperture (NA) of the POF is 0.5 and the outer diameter is 3 mm.

The inner structure of the sensing probe can be found in Fig. 1. In order to improve the collection efficiency of scintillation light, inorganic scintillators are surrounded by TiO_2 reflective tapes. Then, the inorganic scintillators are covered with aluminum foils and black PMMA holders to minimize the interference of visible light from outside.

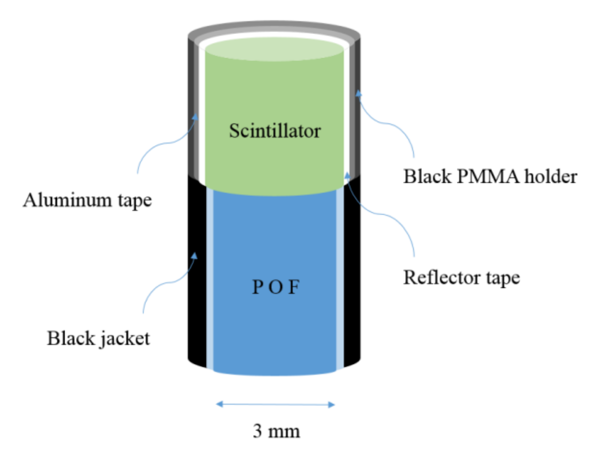

Fig. 1. The inner structure of the sensing probe of fiber-optic radiation sensor.

2.2 Experimental setup

Fig. 2 shows the fiber-optic radiation sensor system for gamma-ray spectroscopy. Throughout this study, a high-voltage power supply was used to operate a photomultiplier tube (PMT; H9305-03, Hamamatsu Photonics). Also, in order to supply powers to a shaping amplifier (ORTEC®572A, Advanced Measurement Technology) and a multichannel analyzer (ORTEC®927 ASPEC MCA, Advanced Measurement Technology), a minibin (ORTEC®4006, Advanced Measurement Technology) was exploited.

The scintillation signals emitted from the inorganic scintillators by interactions with gamma-rays are converted into electric signals by the PMT and amplified by a low-noise amplifier (C7319, Hamamatsu Photonics) and shaping amplifier. At last, the electric signals are transmitted to the MCA.

As a gamma-ray source, a Na-22 isotope was exploited. The energy of gamma-rays emitted from the Na-22 is 511 keV. The activity of the isotope is 78 μCi.

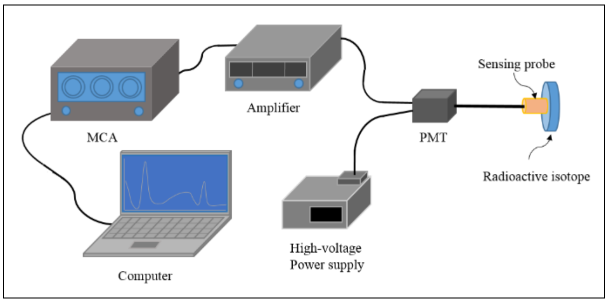

Fig. 2. Experimental setup for gamma-ray spectroscopy using a fiber-optic radiation sensor system.

3. Experimental Results

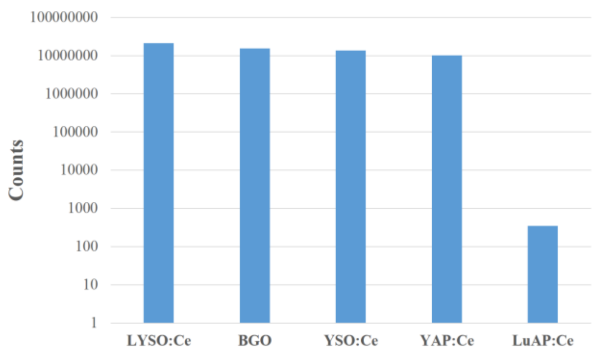

Fig. 3. Integrated scintillation counts of various inorganic scintillators induced by gamma-rays of Na-22.

Fig. 3 shows the integrated scintillation counts of various inorganic scintillators induced by gamma-rays of Na-22. As a result, LuAP:Ce has the lowest count compared with those of other scintillators. And it was verified that the scintillation count of LYSO:Ce was the highest among the scintillators used in this experiment.

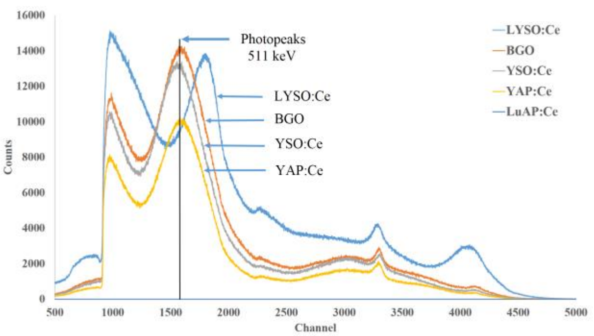

Fig. 4. Gamma-ray energy spectra of Na-22 obtained by the fiber-optic radiation sensors.

Fig. 4 shows the measured gamma-ray energy spectra of Na-22 obtained by the fiber-optic radiation sensors. In this experiment, we could not measure the spectrum of gamma-rays using the LuAP:Ce scintillator due to its small scintillation output. The gamma-ray energy spectra obtained by using the fiber-optic radiation sensors had a peak around 511 keV except for the sensor incorporating the LYSO:Ce scintillator. Although the scintillation count of LYSO:Ce was the highest among the scintillators used in this study, its photoelectric peak did not arise at 511 keV. The peak of LYSO:Ce was arisen upper channel than the channel of the peaks of other scintillators. As a result, we can conclude the adequate scintillator for sensing probe of the fiber-optic radiation sensor is the BGO due to its high scintillation output and exact photoelectric peak for the gamma-ray energy.

4. Conclusions

In this study, we fabricated a fiber-optic radiation sensor using an optical fiber and various scintillators. To select an adequate inorganic scintillator for the sensing probe of fiber-optic radiation sensor, 5 types of scintillators were evaluated. The spectra of gamma-rays emitted from a Na-22 radiation source were measured by using the manufactured sensors. As a result, the BGO was suitable for the sensing probe of fiber-optic radiation sensor due to its high scintillation output and exact photoelectric peak for the gamma-ray energy.

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