Feasibility study on the development of remote gamma spectroscopy system based on fiber-optic radiation sensor for burnup estimation of spent fuel

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In this study, we fabricated the remote gamma spectroscopy system based on the fiber-optic radiation sensor (FORS) to estimate burnup of spent fuel and measured the energy spectra of Cs-137 according to the length of the plastic optical fiber (POF) to evaluate the performance of the gamma spectroscopy system. As the experimental results, we detected the energy peak of Cs-137 using the FORS. It is expected that the FORS can be used for measuring energy spectrum of Cs-137 to estimate burnup of the spent fuel remotely.

I. INTRODUCTION

Burnup estimation of a spent fuel is widely used for the management of the nuclear fuel and safeguards purposes. Normally, burnup estimation of a spent fuel can be theoretically calculated by tracking a history of neutron irradiation. Also, it can be experimentally estimated by measuring and analyzing gamma-ray spectra of relatively long-lived fission products [1-2]. Cs-137 is the one of isotopes which can be used for an estimation of a fuel burnup due to its characteristics such as a reasonably well-known decay scheme, a low capture cross section, a long half-life, a very low yield from Cs-136 by a neutron capture, and a high-fission yield [3]. Another method to estimate burnup is known that Cs-134/Cs-137 activity ratio is measured and corrected by Monte Carlo simulation [4].

The fiber-optic radiation sensor (FORS) has been applied to measure the radiation in the various fields because of many its advantages such as a small size, a high spatial resolution, and a possibility to remote sensing [5-7]. Therefore, the FORS can be used for measuring gamma-ray in real time at the place where access is difficult such as the spent fuel storage pool.

In this research, we fabricated the remote gamma spectroscopy system which is composed of the FORS and multi-pixel photon counters (MPPC) array module of multi-channel analyzer (MCA) type and measured the energy spectrum of Cs-137 to estimate the burnup of a spent fuel.

II. MATERAILS AND METHOD

As a sensing element of the FORS probe, an inorganic scintillator (LYSO:Ce, EPIC Crystal) is used for gamma spectroscopy. The size of LYSO:Ce is 3 x 3 x 15 mm^3 and the physical properties of LYSO:Ce used in this study are listed in Table 1. To transmit scintillating light generated in the LYSO:Ce, a plastic optical fiber (POF,CK-120, Mitsubishi Rayon) was used. The POF is a step-index multimode fiber and the diameter of POF is 3.00 ± 0.18 mm.

A MPPC array module of MCA type (C13368-3050EM, Hamamatsu Photonics) is used as a light-measuring device to measure the energy spectrum. The MPPC array module has a peak sensitivity wavelength of 500 nm and spectral response ranges from 320 nm to 900 nm. The scintillating light generated in the FORS probe is guided to the MPPC array module through POF and the energy spectrum is measured, displayed and stored via the software.

TABLE I. Physical properties of LYSO:Ce scintillator

Density (g/cm^3)	7.20
Max. wavelength of emission (nm)	420
Light output (photon/MeV)	29,000
Primary decay time (ns)	40
Refractive index	1.82

III. RESULTS

Fig.1 shows the variation of the gamma energy spectra for Cs-137 measured with the FORS having different length of the POF. As the experimental results, the energy resolution is decreased because the full width at half maximum (FWHM) of the energy peak is increased in accordance with increasing the length of the POF from 0 m to 10 m. However, even if the length of the POF changes, the overall shapes of the pulse height spectra is similar, so that the gamma energy spectrum can be measured. Therefore, the measurements show that the 10 m-long FORS can be used as a remote gamma spectroscopy system in hazardous nuclear environments.

IV. CONCLUSION

In this study, we developed a remote gamma spectroscopy system, which is composed of an FORS and a MPPC array module of MCA type, to measure the gamma energy spectrum of Cs-137. The experimental results show that the proposed 10 m-long FORS can measure and discriminate Cs-137 energy spectrum remotely. Further studies are planned to fabricate a FORS with the longer length POF and other inorganic scintillator for measuring gamma energy spectra and to optimize a remote gamma spectroscopy system. It is expected that the FORS can be used as a useful remote gamma spectroscopy system to estimate a fuel burnup by measuring Cs-137 energy spectrum.

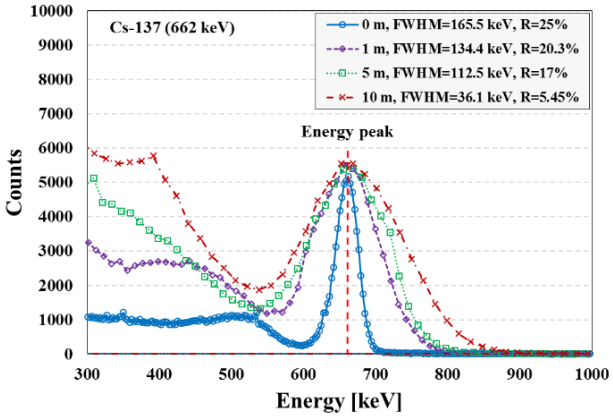

Fig.1. Variation of measured energy spectrum for Cs-137 according to the length of the POF

ACKNOWLEDGMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and future Planning(No. 2014R1A2A2A04002620) and this research was supported by National Nuclear R&D Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and future Planning(No. 2016M2B2B1945255).

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