Determination of an Optimal Radiation Scintillator for Verification Equipment of Spent Nuclear Fuel of Heavy Water Reactor

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1. Introduction

The OFPS (Optical Fiber radiation Probe System) has been used for physical inventory verification (PIV) of spent nuclear fuel in Wolsung heavy water reactor since 2007 [1]. The KINAC (Korea Institute of Nuclear Non-proliferation and Control) has been studying to improve performance of the OFPS for a few years. This paper deals with how to determine an optimal scintillation material of a radiation detector as part of upgrading the inspection equipment. After a comparative study of three scintillators – Li glass scintillator, PVT-based plastic and p-Terphenyl organic scintillator -, a p-Terphenyl scintillator was found out to be the best of the three candidates. A field test was also conducted in Wolsung Nuclear Power Plant for the purpose of proving experimentally performance of the three scintillation material. The experimental results showed the p-Terphenyl crystal was the most excellent in terms of sensitivity and resolution.

2. Methods and Results

2.1 Material and Optical Properties

In this section, material and optical properties of the three candidate scintillators were compared to find out the best scintillator for the OFPS.

Table I: Material and Optical Properties of the Selected Three Scintillators [2-4]

	Li glass Scintillator (GS30)	PVT-based Plastic Scintillator (BC-400)	p-Terphenyl Scintillator
Scintillator type	Inorganic	Organic	Organic
Density (g/cm^3)	2.50	1.02	1.23
Light output (photons/MeV)	4,000	13,000	27,000
Decay time (ns)	16	2.4	3.7
Max. emission wavelength (nm)	395	423	420
Refractive index	1.55	1.58	1.65
Hygroscopic	No	No	No

A Ce-activated lithium silicate glass scintillator (GS30) has been employed by the present OFPS to convert a radiation from spent nuclear fuel to visible lights. Those light are transferred to PMT through an optical fiber. As shown in table I, although the other two scintillators (PVT-based plastic and p-terphenyl scintillators) have lower density than the Li glass scintillator, those generates much larger number of light by interaction of a gamma-ray. The three scintillators in table I are non-hygroscopic and fast. From table I, a p-Terphenyl crystal of the three could be expected to give the best performance as a radiation detector for the OFPS.

2.2 Trade-off of Density and Light Output

Using MCNP simulation, we have considered trade-off between density and light output of the scintillators. Fig. 1 is a geometry for MCNP calculation. Because a dominant radiation from spent nuclear fuels with cooling time of a few years is a Cs-137 nuclide, we assume that an 0.662 MeV gamma-ray is incident on a scintillator with a size of 0.4 cm (Dia.) x 1.0 cm (Leng.).

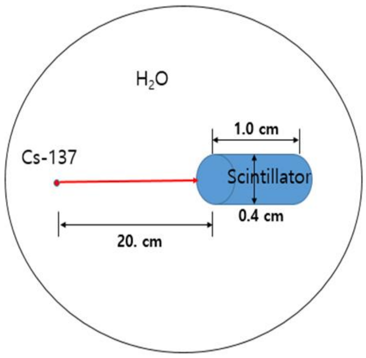

Fig. 1. Geometry for MCNP Simulation to calculate light output of a scintillator.

The goal of the MCNP simulation is to compare relatively light output of the three scintillation crystals. Thus, a Cs-137 gamma-ray was assumed to be irradiated to the scintillator in only one direction. An effect of a scintillator container was neglected. The number of light produced in a Li glass, a PVT-based plastic, and a p-Terphenyl crystals was calculated to be 33, 51, and 122 respectively. A p-Terphenyl crystal generates about four times larger light than an existing Li glass scintillator. Finally, we could ascertain that the p-Terphenyl crystal would improve remarkably performance of a radiation sensitivity for the OFPS.

3. Experiments

An optical fiber-based scintillation radiation detector for the OFPS was made by bonding a scintillation crystal to an end part of a 15 m optical fiber ; The other end of the optical fiber was connected to a PMT (Photomultiplier tube) installed in data acquisition system of the OFPS. The size of the PVT-based plastic (BC-400) and p-Terphenyl scintillator is the same 0.4 cm x 0.4 cm x 1.0 cm. A bundle type fiber with a cross section of a 1.8 mm diameter was constructed by assembling 64 small-size fibers of a 200 μm in diameter. The length of the existing optical fiber is about 15 m and the size of its scintillator is about 0.1 cm in diameter and 0.5 cm in length. Fig. 2 shows an exiting and newly developed optical fiber-based scintillation detector. As shown in Fig. 3, we conducted a field test in Wolsung unit 1 to compare performance of the newly selected two scintillators (BC-400, p-Terphenyl) with that of the existing one (GS30). Here, the BC-400 and GS30 are product names of PVT-based plastic and Li glass scintillator makers.

Fig. 2. An existing (Left) and newly developed (Right) optical fiber-based scintillation detector

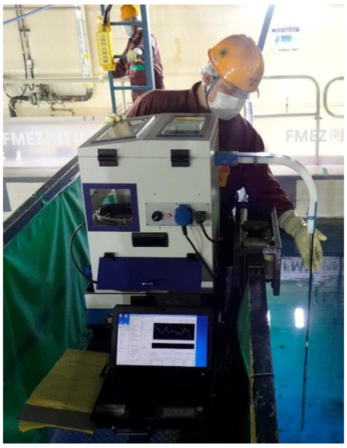

Fig. 3. A field test in Wolsung Nuclear Power Plant to evaluate performance of the selected three scintillators

Fig. 4 is experimental results (electric current) measured by the three scintillation detectors. From Fig. 4, sensitivity of the BC-400 and p-Terphenyl crystals appeared to be dozens of times larger than the present Li glass scintillator(GS30). In particular, signal amplitude of the p-Terphenyl crystal increased dramatically by almost one hundred times in comparison of the GS30 crystal. Two peaks in the region marked ‘A’ in Fig. 4 is more obvious in case of the BC-400 and p-Terphenyl than that of the existing GS30 crystal. Particularly, in the ‘B’ region, the peak which the the GS30 crystal could not detect was observed by the the BC-400 and p-Terphenyl crystals. Therefore, the field test exhibited that compared with the existing Li glass scintillator, the p-Terphenyl gives excellent performance in terms of detector resolution and sensitivity.

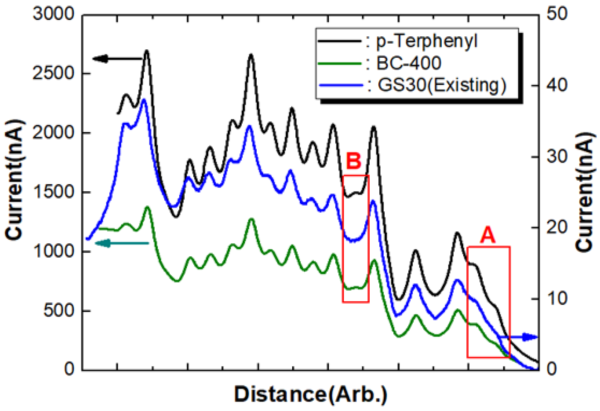

Fig. 4. Comparison of electric current obtained by the three different scintillation materials

4. Conclusions

To improve performance of the OFPS which is used for nuclear safeguards inspection of spent nuclear fuel in Wolsung Heavy Water Reactor, the new scintillation material is determined using MCNP simulation and experiments. This study shows that the optical fiber-based scintillation detector employing a newly applied p-Terphenyl crystal and a bundle type fiber increases largely signal sensitivity and resolution of the OFPS.

The results of this paper would contribute to enhancing efficiency and effectiveness of IAEA and nation safeguards activities because the improved NDA equipment could reduce unnecessary secondary inspection.

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