Development of the Fiber-Optic Sensor with a Large Surface Area to Measure Radioactive Contamination in Soil at Nuclear Facility Site

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Abstract: Once decommissioning of a nuclear facility is completed, it shall be confirmed if its site meets the site release criteria. For this the residual radioactivity in the site should be measured and assessed. This paper developed and characterized the fiber-optic sensor with a large surface area for measurement of radioactivity in soil at nuclear facility site, which is less time-consuming due to ease of measurement. The fiber-optic sensor consisted of a radiation sensing probe including scintillator panel and light guide and a transmission optical fiber. The light measuring system was assembled combining it with photomultiplier tube, pre-amplifier, multichannel analyser and display. Several measurements using the light measuring system showed that, as for measuring time for measurement of cesium-137 source, 1,800 sec was the optical measurement duration, and as for reflector, aluminium foil was the best.

1 INTRODUCTION

Once decommissioning of a nuclear facility is completed, it shall be confirmed if its site meets the site release criteria for site release or clearance of items from regulatory control. For this, the residual radioactivity in the site should be measured and assessed.

The residual radioactivity assessment consists of (1) taking samples from contaminated area, (2) measurements of radioactivity in the samples and (3) statistical analysis of the measurement data. The appropriateness of taking samples is a key factor in determining the assessment's reliability.

Radioactivity in soil is commonly measured by using a small portable radiation detector or in-situ gamma spectroscopy, which takes a long time. Therefore, this paper developed and characterized the fiber-optic sensor with a large surface area for measurement of radioactivity in soil at nuclear facility site, which is less time-consuming due to ease of measurement.

2 EXPERIMENTAL SETUP

To identify what types of radiation are emitted from soil at nuclear facility site, related documents and radiation survey records of TRIGA research reactor site in Korea were examined. In the middle of decommissioning of nuclear facilities, cesium-137, cobalt-60, iodine-129, -131, and thorium are usually radionuclides of main concern. (Lawrence E. Boing, 2013). TRIGA site radiation survey records showed that cesium and cobalt were main radionuclides in soil at the site as shown in Table 1. (Gyenam Kim, 2003). Based on the examinations, cesium-137, gamma emitter, was selected as a representative radionuclide to be detected by using the fiber-optic sensor developed in this paper.

Table 1: Main radionuclides in soil at TRIGA site.

Radionuclide	Radioactivity(Bq/kg)
Co-60	644.4 ± 42.6
Cs-134	88.7 ± 4.1
Cs-137	88.7 ± 4.1
Sr-90	<9.7
Cr-51	<5.9
Fe-59	<4.2

LYSO:Ce was selected as scintillator suitable for measuring gamma ray emitted from cesium-137. Its characteristics are listed in Table 2(Chan Hee Park et al, 2014). As shown in Fig.1, sensing probe of the fiber-optic sensor was rectangular solid shape, made

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of LYSO:Ce crystal with the size of 105 mm (length) × 91 mm (width) × 3 mm (height).

Table 2: Characteristics of scintillator LYSO:Ce.

Density (g/cm^3)	Wavelength peak(nm)	Light yield(%) *relative to NaI:Tl	Effective Znumber	Decay time (ns)
7.20	420	73-75	65	42

Light guide that guides lights emitted due to interactions between scintillator and radiation was attached to top-side of the scintillator. Before fabricating the light guide, the optimal mixing ratio between epoxy-resin YD-128 (Kukdo Co., Korea) and hardener D-230 (Kukdo Co., Korea) was determined to be 5:1, in terms of transmittance, light self-absorbance and hardness, referring to Table 3 (Chan Hee Park, 2013). Using the mixture, the light guide was fabricated with a rectangular solid shape consistent with size of the scintillator for easy to combine scintillator with light guide. Its size was 105 mm (length) × 91 mm (width) × 30 mm (height), as shown in Fig. 1.

Table 3: Properties change according to mixing ratio between YD-128 and D-230.

YD-128 + D-230	Transmittance	Self - absorbance	Hardness
50.0g + 10g	1	5	Excellent
47.5g + 12g	3	3	Excellent
45.0g + 14g	4	2	Good
42.5g + 16g	2	4	Good
40.0g + 18g	5	1	Bad

The fiber-optic sensor was fabricated by embedding the transmission optical fiber in the light guide before it solidified. To minimize the light loss due to incomplete connection between them, the transmission optical fiber was submerged into a depth of 10mm at the centre of the light guide.

The transmission optical fiber used in this paper was commercial-grade plastic multimode fiber (Edmund Optics Co. ESKA® acrylic fiber optics). The core of the optical fiber was made of poly-methyl methacrylate (PMMA) and the cladding was made of a fluorine series polymer. The length of the transmission optical fiber was determined to be 1m considering the distance to measurement site from source. The optical fiber was coated with double layers of heat shrinkable tube to block lights from the outside.

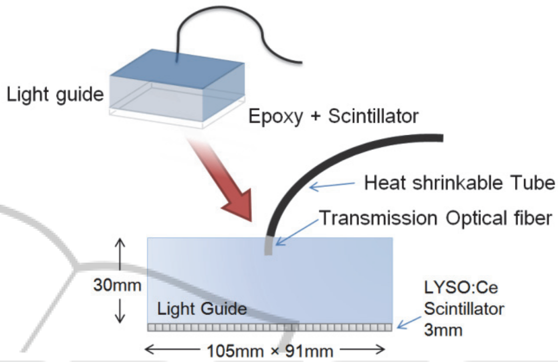

Figure 1: Sensing probe of the fiber-optic sensor.

In this study, reflector was used to block lights from the outside and prevent lights generated by interactions between scintillator and radiation from escaping from the light guide. The 4 types of reflector were considered: Dupont's TYVEK-1025D; TYVEK-1056D; aluminium foil and Teflon tape. (W.Bugg, 2014). The surfaces of scintillator and light guide were wrapped with the reflector.

The light-measuring system used in this paper consisted of a radiation sensing probe, transmission optical fiber, photomultiplier tube (Hamamatsu, R1924A) that converts optical signals into electrical signals, pre-amplifier (Hamamatsu, Amplifier Unit C319) that amplifies electrical signals, multichannel analyser (MCA) that analyse amplified signals and display that shows transmitted signals. The Genie 2006 was used to analyse the electrical signals. The experimental setup is shown in Fig.2.

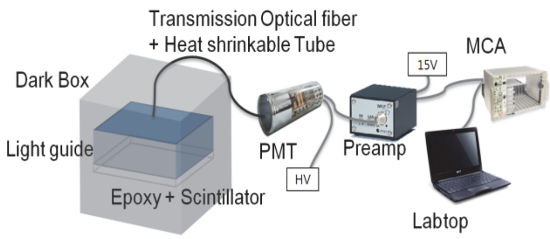

Figure 2: Experimental setup.

3 RESULTS

First, several measurements were made and analysed using the light-measuring setup shown in Fig. 2 to find the optimal measuring time. As measuring time increases, more radiation is counted, but more background radiation is also accumulated. Hence, the measuring time should be optimized. Measurements of gamma radiation from cesium-137 source (1 μCi) were made for the three different measuring times: 600, 1,000, and 1,800 sec. The measurement results without reflector were depicted in Fig. 3 to Fig. 5.

The net counts, dividing total counts by measuring time, were compared. The net counts in counts per second were 663 for 1,800 sec, 390 for 1,000 sec, and 414 for 600 sec, respectively, as shown in Fig.6. The net counts for the case of 1800 sec were the highest. Based on the comparison, measuring time for the fiber-optic sensor developed in this paper was chosen to be 1,800 sec.

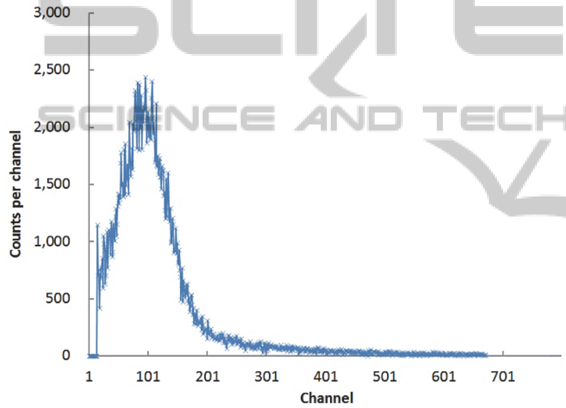

Figure 3: Measurements results for 600sec.

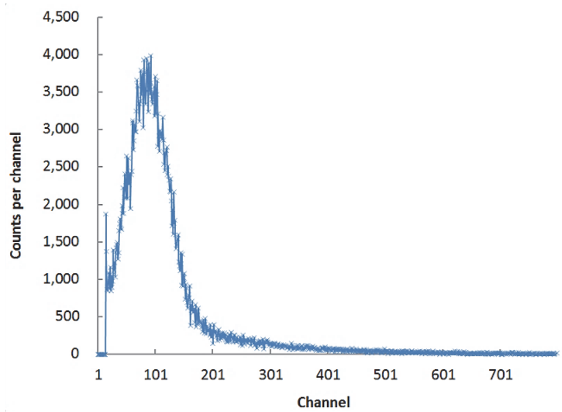

Figure 4: Measurement results for 1000sec.

To improve detection efficiency of the fiber-optic sensor, it is necessary to collect the optical signals, that is, lights generated by interactions between radiation and scintillator as much as possible as well as to reduce loss of the optical signals. For this, reflector was used as described before. To find the best reflector, measurements of cesium-137 source were made for the 4 different reflectors: Dupont's TYVEK-1025D; TYVEK-1056D; Aluminium Foil and Teflon tape. The reference measurements were the measurement without reflector.

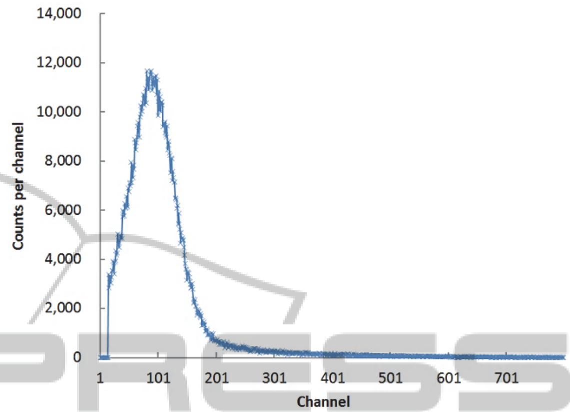

Figure 5: Measurement results for 1800sec.

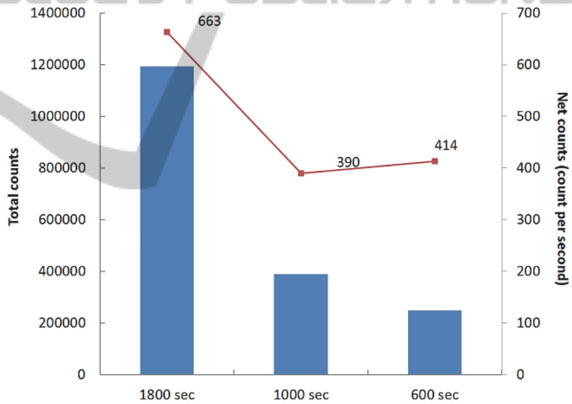

Figure 6: Total counts and net counts (counts per second) for the three different measuring times.

Tyvek 1056D and 1025D are commonly used as reflector. The light guide was surrounded by two layers of both reflectors. The measurements with Tyvek 1056D were higher, but the measurements with Tyvek 1025D were lower than the reference measurements. As for Aluminium Foil, common household aluminum foil was used. The light guide was covered with 3 layers of Aluminium Foil with the thickness of 18μm. The measurements with Aluminum Foil reflector were about twice as high as the reference measurements. Teflon tape is also common reflector material. The measurements with Teflon tape were lower than the reference measurements. Measurements for the four different reflectors are shown in Fig. 7 to Fig.10.

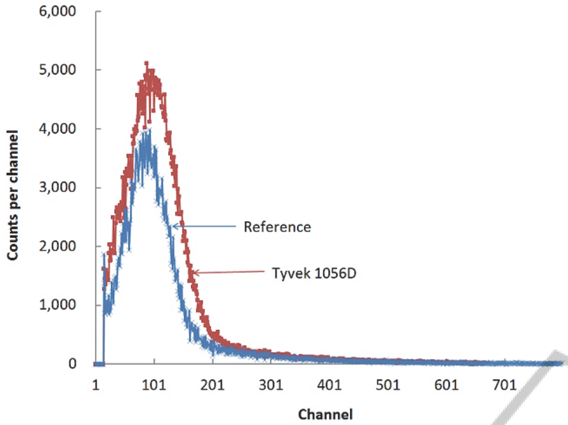

Figure 7: Comparison between measurements with Tyvek 1056D and the reference measurements.

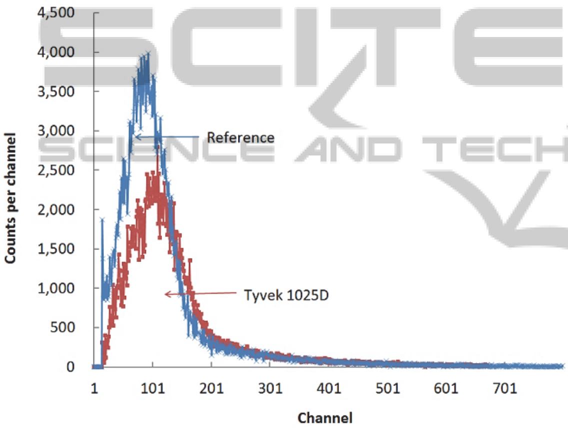

Figure 8: Comparison between measurements with Tyvek 1025D and the reference measurements.

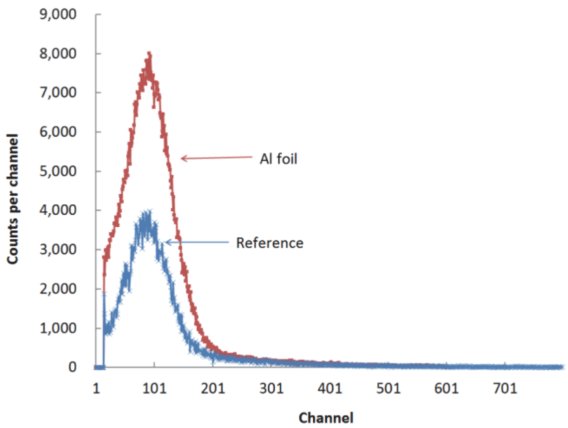

Figure 9: Comparison between measurements with Aluminum Foil and the reference measurements.

Measurements with the four different reflectors showed that the Aluminum Foil was the best reflector in terms of detection efficiency of the fiber-optic sensor.

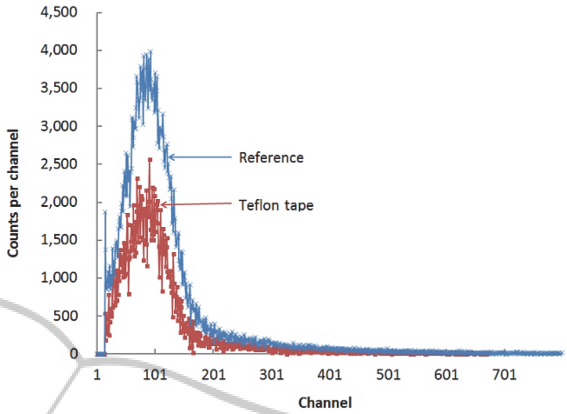

Figure 10: Comparison between measurements with Teflon tape and the reference measurements.

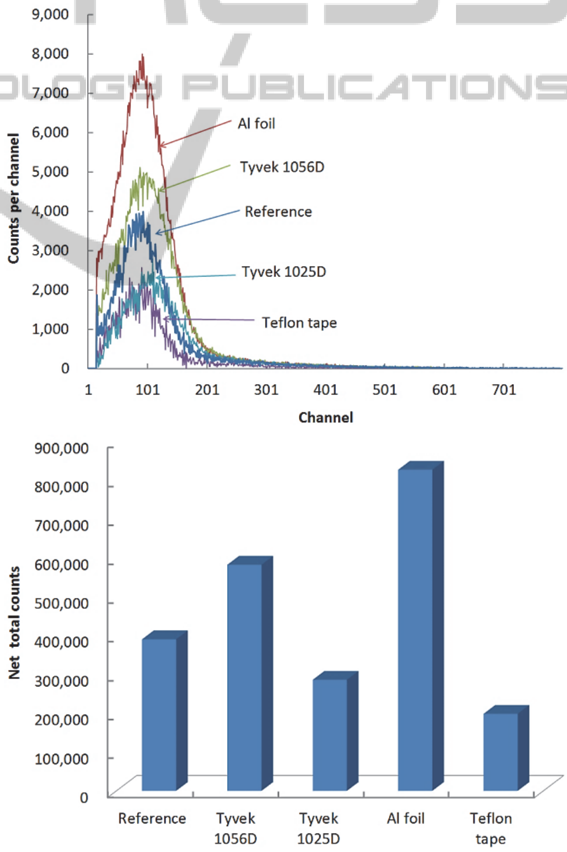

Figure 11: Comparison of measurements with the four different reflectors.

If the total count for the reference measurements is regarded as 1, normalized counts for the 4 different reflectors are shown in Table 4.

Table 4: Normalized counts for the 4 different reflectors.

Reflector	Normalized count
Reference	1.000
Tyvek 1056D	1.492
Tyvek1025D	0.733
Aluminum foil	2.119
Teflon tape	0.508

4 CONCLUSIONS

This study developed and characterized a fiber-optic sensor with a large surface area to measure radioactive contamination in soil at nuclear facility site.

The fiber-optic sensor consisted of a radiation sensing probe including scintillator panel, light guide and a transmission optical fiber. It was fabricated by embedding the transmission optical fiber in the light guide. The light measuring system was assembled combining it with photomultiplier tube, pre-amplifier, multichannel analyser and a display unit.

The light measuring system was used to measure gamma radiation from cesium-137 source. Several measurements were made to characterize the fiber-optic sensor with a large surface area. They showed that as for measuring time, 1,800 sec was the optimal measurement duration, and as for reflector, aluminium foil was the best.

This fiber-optic sensor is expected to be useful in measuring gamma radiations resulting from the radioactive soil at nuclear facility site, along with the experimental results such as the best reflector and measuring time. To improve the detection efficiency of the fiber-optic sensor, the best geometry of light guide should be studied.

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