The Auxiliary Radiation Detector System for Monitoring Radiation Level of the Spent Fuel Pool – 14157

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ABSTRACT

U.S. NRC pointed that the lack of information on the conditions of the fuel in the Fukushima spent fuel pools was a significant problem in monitoring the course of the accident and contributes to a poor understanding of possible radiation release and to confusion about the need and priorities for support equipment. The report recommended enhancing instrumentation for the spent fuel pool. The lack of information on the conditions of the fuel in the Fukushima spent fuel was mainly due to a prolonged loss of AC power. According to the recommendation by the NRC report, the monitoring system should be equipped with the capability to monitor the key environmental variables even if the AC power to the system is lost for a long time such as several days. This study is to suggest an auxiliary radiation detector system to check if the emergency occurs in the spent fuel pool by monitoring the radiation level on the water surface in the spent fuel pool. The auxiliary radiation detector system could be operated using a low-voltage DC power against the long-lasting loss of AC power to the main radiation level monitoring system.

To meet the qualification, the fiber-optic sensors, which consists of light-generating probe such as scintillators for radiation dosimetry, plastic optic fiber, and light-measuring device such as PMT, might be considered. The fiber-optic sensor has many advantages such as remote and stable transmission of signals, real-time readout, high-resolution measurements, no corrections for temperature, pressure and humidity, and no interference by electromagnetic waves. The radiation sensor is separated the scintillator from the PMT, and the gap connected by an optic fiber. The optic fibers for transmitting the signals were also estimated for various geometrical conditions.

INTRODUCTION

Fukushima-Daiichi power plant which is known as the worst nuclear accident such as Chernobyl and Three Mile Island nuclear accident occurred severe accident that core melt due to natural disasters caused by the earthquake and tsunami and safety of power plant and restoration work are going until now by reason of unsatisfactory action for follw-up steps due to the fault information at the time of the accident [1].

Unit 4 at the time of the 2011 nuclear accident was not running operation but top of containment building collapsed by hydrogen explosion. As a result, until recently, Unit 4 has been progressed wreckage removal and installation work for the cover of the building for decommissioning. In August, NRA, Japan approved decommissioning plan, but it has not been determined fuel damage manual of unit 4.

As a warning for unanticipated variables such as Fukushima Daiichi power plant, NRC recommended strengthening of monitoring system for the spent fuel pool to nuclear operators [2] and in Korea, standard technical specifications for power plant of Nuclear Safety and Security Commission specified that emergency generator of power plant is power supply when off-site power was cut and is a necessary safety device for supply coolant to power plant. Also, 1 out of 2

of the emergency generator should always be operated in order to ensure safety of nuclear power plant.
Generally, environmental (space) radiation level in the surrounding area of the spent fuel spool has been measured by using fixed type radiation detector system, but if necessary, dose rate of water surface of the pool has been measured by using portable radiation detector as workers approach to the key measurement point. The fixed type-radiation instrumentation was installed in the spent fuel pool has been using AC power. For key parameter (radiation level, temperature, water level) has been measuring using active control instrument of AC power, if AC power is lost, the main control room are not able to recognize changed conditions of key parameter.

If AC power is lost, especially, owing to blackout of the spent fuel pool, radiation level of pool' water surface is difficult to measure by reason of the risks. The risk is to be exposed to radiation because workers should get directly to measurement point.
Likewise, a fault of accident action due to blackout of AC power is proven through Fukushima Daiichi nuclear accident. Even though blackout of main power and emergency generator began, it is required development of auxiliary monitoring system of DC power to notice changes of the spent fuel pool. For this purpose, first, we have started development of a remote and real-time monitoring system for radiation level of the spent fuel pool. The possibility of distributed optical fiber sensing technology was proven by the monitoring of large nuclear infrastructures such as reactor containment buildings, nuclear waste repositories and reactor primary circuits [3]. The optic fiber has number of key advantages: intrinsic insensitivity to magnetic fields and electromagnetic interference, small size and ability to perform distributed radiation measurements along one single fiber using optical time domain reflectometry techniques [4]. The typical applications of the optic fiber technology include local dose deposition measurements and distributed hot-spots dose monitoring in nuclear waste storage facilities [5, 6]. Also, the optic fiber sensing method have been studied for remote radiation dose monitoring applications [4]. The development of optic fiber radiation sensors has been mostly driven by medical applications such as in vivo real-time dosimetry [7].
In this paper, radiation sensor base on an optic-fiber was designed and was described experiment result and possibility of a remote transmission.

METHOD

1. Material Selection and Characteristic Study of Optic fiber and Scintillator

The radiation sensor for a remote measurement, based on optic fiber, is made for checking radiation level of the spent fuel pool. The optic fiber radiation sensor is composed with radiation sensing probe, transmitting optic fiber, data acquisition instruments.
The optic fiber radiation sensor that has over 10m separation distance can measure radiation level of the spent fuel pool multiply without sensor holders which is fixed in the spent fuel pool.
In the study, we choose the best suitable scintillator for measuring gamma ray from the spent fuel pool and performed performance evaluation depending on the optical fiber length.

To detect gamma ray, by comparison with organic scintillator which is unsuitable for detection efficiency low density gamma ray, as the sensing probe of the optic fiber radiation, inorganic scintillator has been selected. It is composed of elements with high atomic number, by choosing the transmitting optic fiber which is advantageous for detection of gamma radiation because of the high density and for very long distance monitoring and inorganic scintillator which is easy to combine with something and has no deliquescence.

Lyso ($Lu_5Y_2SiO_5$), chosen from in the study, has higher scintillation efficiency than others and is easy to transmit light through optic fiber because its index of refraction is close to a refractive index of the optic fiber. Experimental lyso scintillator has diameter of 3mm, length of 20mm.

Table Ⅰ is summarized character of an inorganic scintillator, considered in the study.

Table Ⅰ. The character of an inorganic scintillator

scintillator	BGO	YSO:Ce	Lyso:Ce
Density(g/cm^3)	7.13	4.44	7.40
Melting point(℃)	1,050	1,980	2,050
Light yield(%) (*relative to NaI:Tl)	21	120	85
Peak wavelength(nm)	480	430	402
Decay time(ns)	300	70	40

To transmit the light sensed by radiation through scintillator, the plastic optic fiber was used to transmitting fiber. The optic fiber using for optical communication usually has used for the glass optic fiber (GOF) which is made by high purity glass based on quartz as basic resource of existing optics component because of outstanding optical properties, environmental safety, thermal resistance of the glass. However its thermal resistance is better than the plastic fiber in the environment near the spent fuel pool, but excluded considering the measurement of water surface in the spent fuel pool. Besides, the optical glass is not only easy to break, difficult to make manufacturing shape and can't be made as infinite shape but also there is a considerable problem that light-connecting technology needs to be used for cheap price.

To solve this problem, replacement of optical material using the high polymer material has been done sharply. Among the uses of optical material, Plastic optic fiber (POF) is the most useful material in the field. The plastic optic fiber(NY02, Edmund optics) with diameter 3mm, used in the study, is consist of the core made of polymethyl-methacrylate(PMMA) and the cladding made of florine polymethyl methacrylate(F-PMMA). Table I shows properties of the transmitting plastic optic fiber.

Table ⅡII. Properties of the transmitting plastic optic fiber

Plastic optic fiber (NT02, Edmund optics)	
Core	PMMA
Clad	Fluorine-PMMA
Numerical Aperture	0.50
Operating Temperature	-55℃ ~ +70℃
Minimum Radius of Band	25×outer diameter

2. Experimental setup

A light-measuring device composed with radiation sensor probe, transmitting plastic optic fiber, photomultiplier tube (PMT), amplifier (AMP) and multi channel analyzer (MCA).

A main amplifier is the Canberra Amplifier model 2012 and a power supply (C3830, Hamamatsu) was used to supply electric power and pre-amplifier, safely and simultaneously. A multi channel analyzer (Ortec trump-8k-32+Maestro32) system was used as a data acquisition device.
Physical properties of photomultiplier-tube (PMT) and experimental setup for performance assessment of a remote radiation sensor using lyso scintillator and plastic optic fiber is table Ⅲ and fig.1, respectively.
A photomultiplier-tube (H5211A, Hamamatsu) used for measurement has response wavelengths of 300-650nm as head-on type.
The sensor for radiation detection was fabricated by attached between the optic fiber and scintillator using epoxy resin. To analysis experimental results on the length of transmitting optic fiber, the sensor for radiation detection was fabricated 1, 3, 5 and 10m of length, respectively. Also, during the measurement, a bending angle of the radiation sensor on the length was equally for the purpose of the same for bending loss of the transmitting optic fiber.

Table Ⅲ. Properties of photomultiplier

Parameter	Description
Wavelength, nm	300-600
Peak wavelength, nm	420
Cathode	Bialkali
	22
Dynode	L
	10
Rise time, ns	1.5

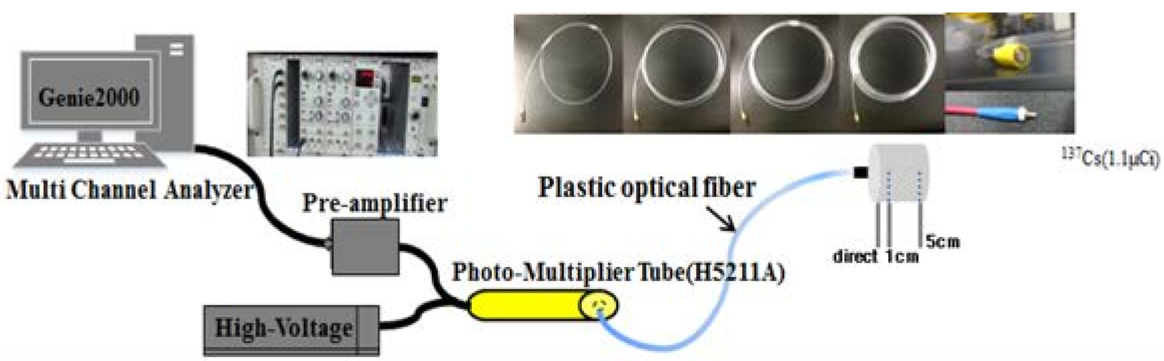

Fig. 1. Experimental Setup.

RESULTS

Fig.2 is the pulse height spectra of radiation sensor on the length of the transmitting optic fiber, which were attached directly to the sensor for Cs-137 source. The reproducibility evaluation is measured 4 times to the length of the transmitting optic fiber. With the change in length, the pulse height spectra were similar, but fig. 4(a) shows that the efficiency of the 1m optic fiber was higher than others. On the other hand, in the reproducibility evaluation, the sensor of the 10m length is measured the smallest standard deviation. The measurement were analyzed that 10m remote detection from the radiation is enough available as the radiation sensor. Fig. 5 shows the pulse height spectra and total counts using average on the length of the transmitting optic fiber. Just like the reproducibility evaluation, the comparison between 1m of the transmitting optic fiber and others showed that 1m of the transmitting optic fiber was approximately 25-40% higher than others.

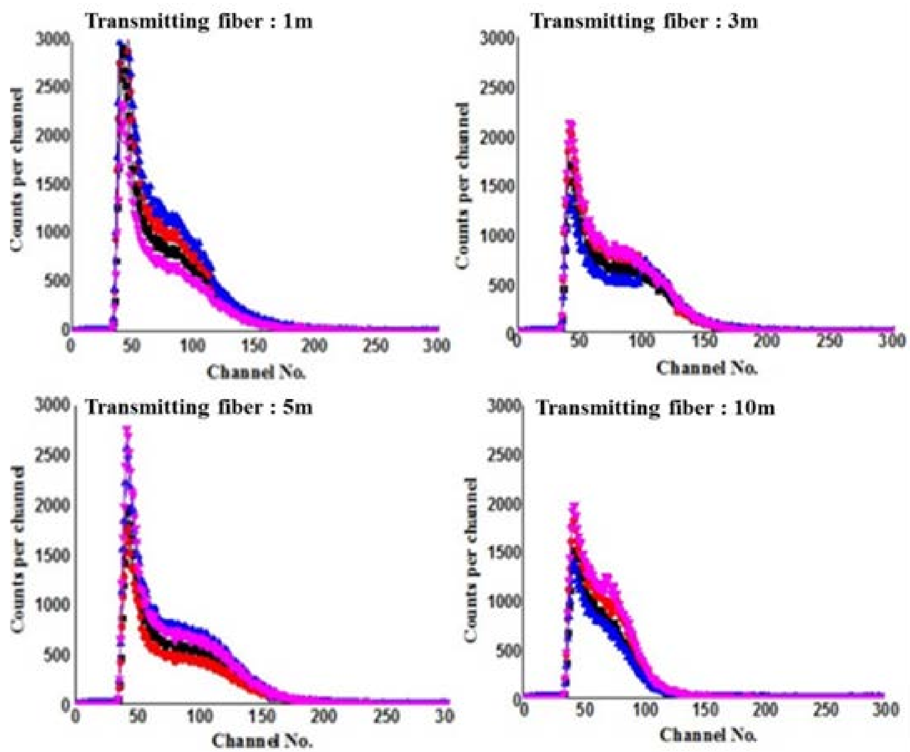

Fig. 2. The reproducibility evaluation of radiation sensor on the length of the transmitting optic fiber.

Fig.3 is the pulse height spectra on the distance between the radiation sensor and the source, which were connected to the distance of 1, 5, 0cm with 1m of transmitting optic fiber. The reproducibility evaluation is measured 4 times to the distance between the radiation sensor and the source. The spectra of 4 sensors on the distance revealed similar shape, but fig. 4(b) shows that the efficiency of the 1cm distance between the radiation sensor and the source was higher than others. In the reproducibility evaluation, the sensor of the 0cm distance is measured the smallest standard deviation. The reason was that transmission loss occurred to the distance. . Fig. 6 shows the pulse height spectra and total counts using average on the distance between the sensor and the source. The comparison between the distance of 1cm and others showed that the distance of 1cm was approximately 16-20% higher than others. In this case, if the

radiation sensor is located collinearity for the source, the signal detection efficiency decreased because the reaction area of the scintillator is relatively small.
In reviewing the results, the detection efficiency should be willing to consider loss on the connection and polishing between the scintillator and source.
From now on, we will develop the radiation sensor using photodiode is powered by DC power replacing photomultiplier tube.

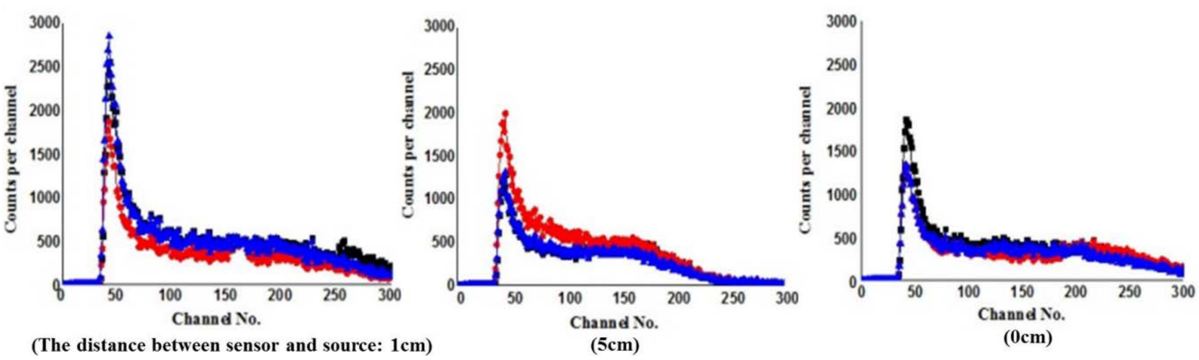

Fig. 3. The reproducibility evaluation on the distance between the radiation sensor and the source.

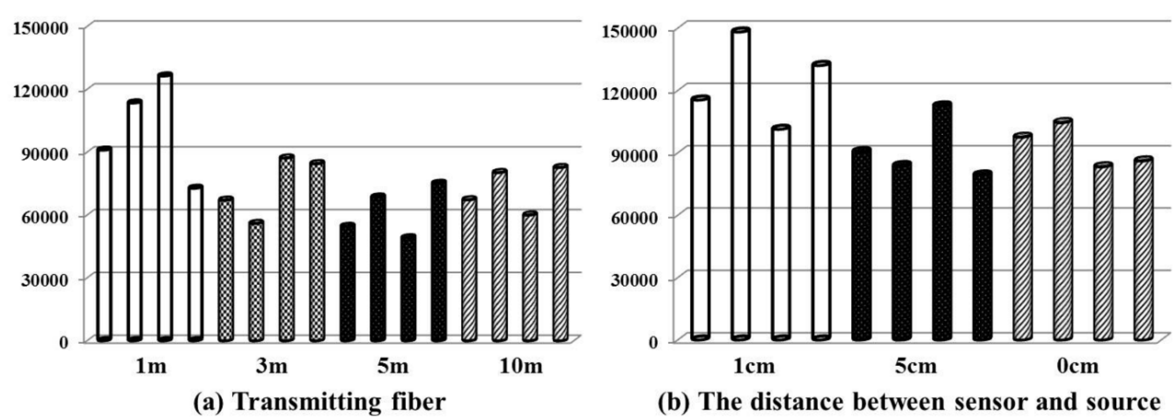

Fig. 4. Total counts of the radiation sensor (a) on the length of transmitting optic fiber and (b) on the distance between the radiation sensor and the source.

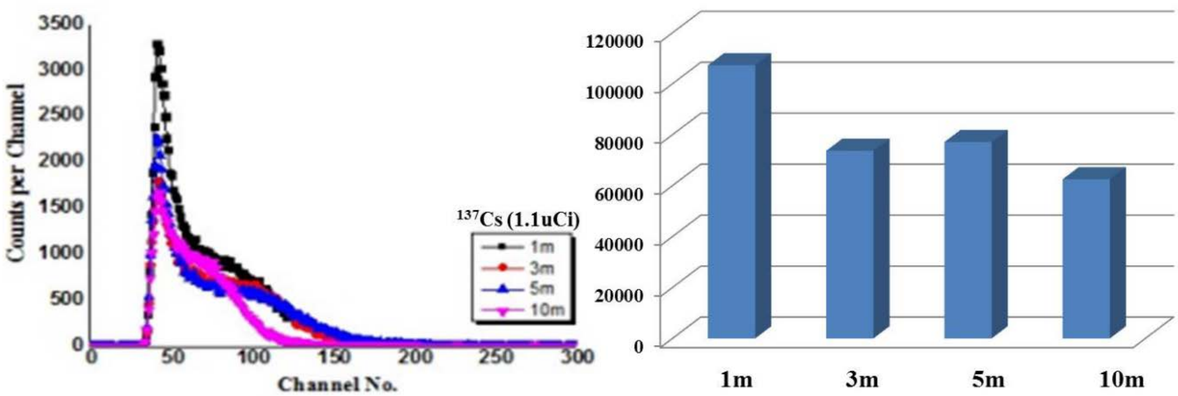

Fig. 5. The pulse height spectra on the length of the transmitting optic fiber.

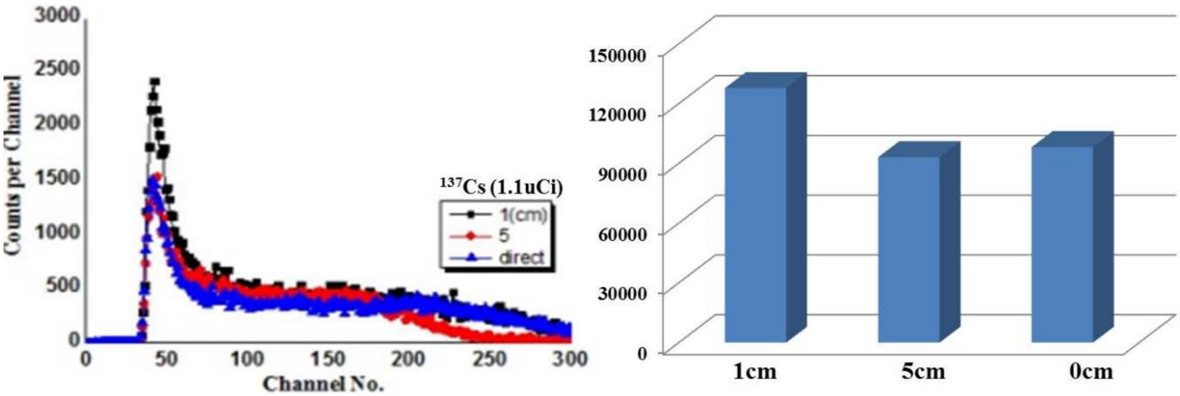

Fig. 6. The pulse height spectra on the distance between the radiation sensor and the source.

CONCLUSION

A remote radiation sensor was developed using an inorganic scintillator and plastic optic fiber, was tested to discuss the possibility for the detection of the spent fuel pool. The detector was tested for Cs-137 sources and compared with change in length of the transmitting optic fiber and in the distance between the sensor and the source. In this study, it was possible to measure the radioactive level remotely in the spent fuel pool using the optic fiber and an inorganic scintillator. This auxiliary radiation detector system have a merit to crosscheck the main radiation level monitoring system at the same time and minimize the possibility to misjudge the situation in the spent fuel pool. The auxiliary radiation detector system is expected to enhance the instrumentation capability of the spent fuel pool.

REFERENCES

[1] CHARLES MILLER et al., "Recommendations for enhancing reactor safety in the 21st century," U.S. Nuclear Regulatory Commission (2012).

[2] C. H. Park et al., “An auxiliary system to monitor the key environmental variables in spent fuel

pool at the loss of power accident", International High Level Radioactive Waste Management Conference (2013).

[3] A.F. Fernandez et al., "Radiation-tolerant Raman distributed temperature monitoring system for large nuclear infrastructures", IEEE Trans. Nucl. Sci. 52, p. 2689-2694 (2005).

[4] A. Fernandez Fernandez et al., "Real-time fibre optic radiation dosimeters for nuclear environment monitoring around thermonuclear reactors", Fusion Engineeering and Design 83, p. 50-59 (2008).

[5] H. Bueker et al., "Fiber optic radiation dosimetry for medical applications, in: A. Katzir(Ed.), Optical Fibers in Medicine V, vol.1201, SPIE, p. 419-429 (1990).

[6] V. M. M. Decreton, P.Borgermans, "Potential benefit of fibre optics in nuclear applications-the case of decommissioning and storage activities, in SPIE(Ed.) , Optical Fibre Sensing and Systems in Nuclear Environments, vol. 2425, p. 2-10 (1994).

[7] B.Brichard, A.F.Fernandez, H. Ooms, P. Borgermans, F. Berghmans, "True dose rate enhancement effect in phosphorous-doped fibre optic radiation sensors, in: J.M. Lopez-Higuera, B. Culshaw(Eds.), Second European Workshop on Optical Fibre Sensors, vol. 5502, SPIE, p. 184-187 (2004).

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