Feasibility study of fiber-optic radiation scanning sensor based on Cherenkov radiation

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1. Introduction

Among the various advanced reactor designs, the sodium-cooled fast reactor (SFR) stands out as the most promising type within the fourth generation of nuclear reactors. These reactors employ liquid sodium as a coolant, effectively acting as a heat sink to absorb and dissipate the heat generated in the reactor core. Due to the potential risks associated with the interaction between liquid sodium and water vapor, it is crucial to have sensors capable of diagnosing and assessing damage to the reactor vessel—the most critical component for ensuring the safety and reliability of these designs. However, the opacity of liquid sodium limits the use of traditional optical in-service inspection techniques, which are commonly employed in conventional light water reactors (LWR). Additionally, conventional monitoring systems face significant challenges in the harsh conditions of a sodium fast reactor, characterized by high temperatures and intense radioactivity.

One promising monitoring system is a fiber-optic radiation sensor based on the Cherenkov radiation principle. When energetic charged particles pass through the optical fiber, they produce a light signal known as Cherenkov radiation. Radioactive sodium, activated by neutron irradiation, emits high-energy gamma rays with energies of 1.369 and 2.754 MeV, which can generate Cherenkov radiation within the optical fiber. Generally, the number of photons produced is proportional to the intensity of gamma-rays incident on the optical fiber. In this study, we propose a scanning system based on the measurement of Cherenkov radiation to detect liquid sodium leakage.

2. Method and Results

2.1 Method

Cherenkov radiation occurs when a charged particle travels through a medium at a velocity surpassing the phase velocity of light in that medium. It has been proven that the intensity of Cherenkov light emission is proportional to the absorbed dose in the medium [1]. Hence, through the measurement of the difference in emission of Cherenkov radiation, it becomes possible to assess the variation in dose within that region of interest. This enables the detection of potential cracks in the reactor vessel.

In this study, we fabricated an array of fiber-optic sensors by coupling polyimide coated optical fibers (Optran UV, Ceramoptec) with SiPM (S13361-3050AE-04, Hamamatsu Photonics Ltd) and DAQ (DT5702, CAEN) to measure Cherenkov radiation generated from optical fibers induced by high-energy gamma-ray. We fabricated the PCB board to bias the SiPM and acquire its signal, as shown in Fig. 1.

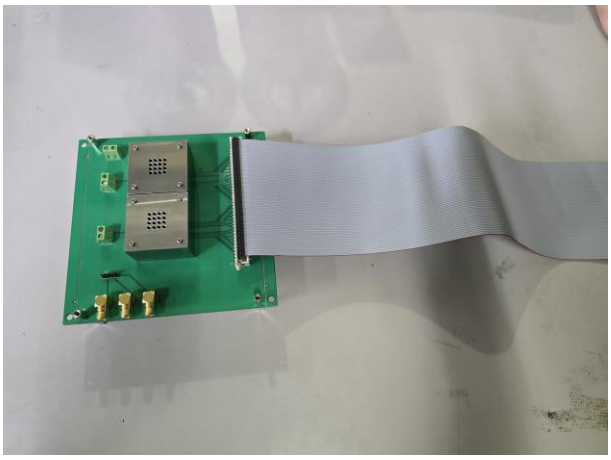

Fig. 1. PCB board for SiPM

The array of fiber-optic sensors is evaluated by measuring Cerenkov radiation induced by ^{60}Co gamma source that emits high-energy gamma-rays with energies of 1.17 and 1.33 MeV. The gamma source was collimated into 5 and 10 mm slits using stainless steel bricks to make dose variations, as shown in Fig. 2. The fabricated sensor was affixed to a linear actuator to quantify the amount of Cherenkov radiation generated at each location.

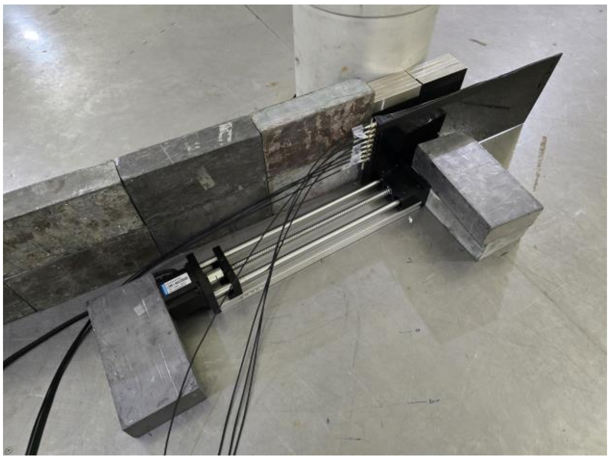

Fig. 2. Experimental setup

2.2 Results

Fig. 3 shows the measured amount of Cherenkov radiation at each step of linear actuator during a 120-second measurement period. To evaluate the difference in emission of Cherenkov radiation, subtraction method was applied using two optical fibers of different lengths.

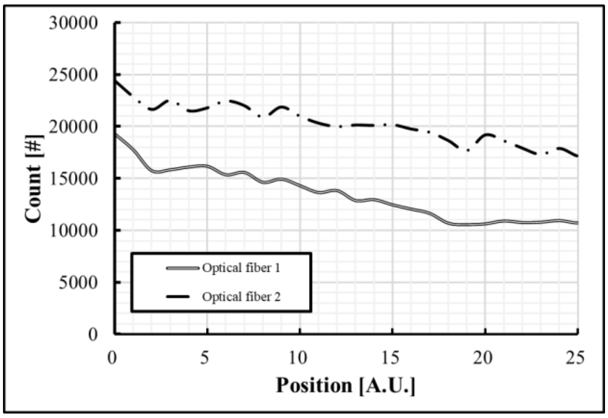

Fig. 3. Measured amount of Cherenkov radiation at each position

To determine the difference in Cherenkov emission from the slit, we applied a subtraction method to compare the light intensity between the two fibers. Fig. 4 and 5 show the Cherenkov measurements with the subtraction method applied, measured at 5 mm and 10 mm slits.

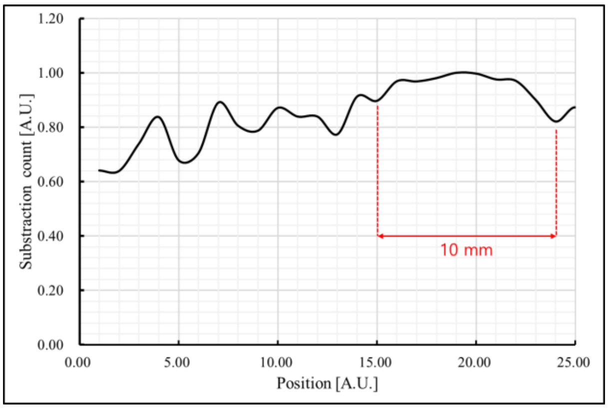

Fig. 4. Subtracted result (10 mm)

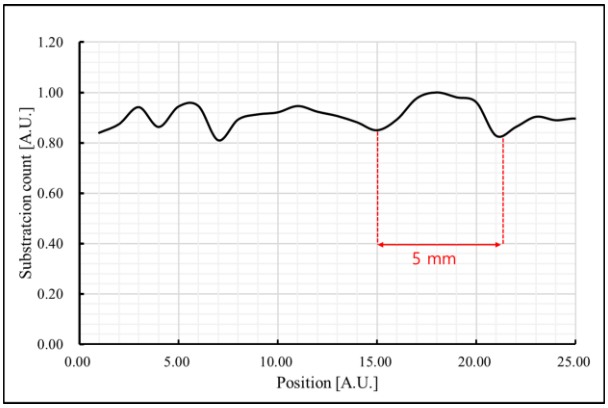

Fig. 5. Subtracted result (5 mm)

3. Conclusions

In this study, we fabricated a fiber-optic radiation scanning sensor based on Cherenkov radiation to measure the dose variance caused by transmitted gamma rays. We confirmed that the sensor is capable of detecting the presence of 10 mm and 5 mm slits.

Future studies will be conducted to evaluate the resolution of the fabricated sensor by maintaining a fixed position for the slit and minimizing source impact through increased slit distance.

ACKNOWLEDGMENT

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