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

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1. Introduction

Among advanced reactor design, sodium cooled fast reactor (SFR) is the most promising reactor-type in the 4th nuclear reactor design [1]. These reactors utilize liquid sodium as a coolant, serving effectively as a heat sink to absorb and dissipate heat generated in the reactor core. To mitigate potential hazards arising from the interaction between liquid sodium and water vapor, there is a necessity for sensors capable of proactively diagnosing and assessing damage to the reactor vessel, the paramount component ensuring safety and reliability in these reactor designs. However, opacity of the liquid sodium as a coolant restricts the application of optical in-service inspection techniques traditionally used in conventional light water reactors (LWR) [2]. Moreover, conventional monitoring systems encounter heightened difficulties in the demanding conditions of a sodium fast reactor, marked by elevated temperatures and intense radioactivity [3].

A fiber-optic radiation sensor based on the Cherenkov radiation principle is one of the promising monitoring systems. As energetic charged particles traverse the optical fiber, they produce light signal known as Cerenkov radiation. Since radioactive sodium, activated by neutron irradiation, emits high-energy gamma rays with energies of 1.369 and 2.754 MeV, it can produce Cerenkov radiation in an optical fiber. The number of generated photons is proportional to the intensity of gamma-rays incident on the optical fiber. In this study, we proposed a monitoring system based on measuring Cerenkov 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 directly proportional to the absorbed dose in the medium [4]. Hence, through the measurement of the difference in Cherenkov radiation produced, it becomes possible to assess the variation in dose within that specific region. This enables the identification of potential defects 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 MPPC module (C13368-3050EA-16, Hamamatsu Photonics Ltd) to detect Cherenkov radiation generated from optical fibers induced by high-energy gamma-ray. 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 1, 5, and 10 mm slits using lead bricks to induce dose variations, as shown in Fig. 1. The fabricated sensor was affixed to a linear actuator to quantify the amount of Cherenkov radiation generated at each location.

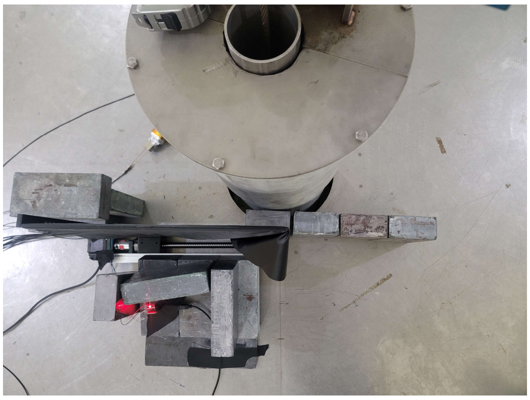

Fig. 1. Experimental setup

2.2 Results

Fig. 2 shows the measured amount of Cherenkov radiation at each step of linear actuator. The influence of an isotropic cylindrical gamma source resulted in an upward-trending in generation of Cherenkov radiation.

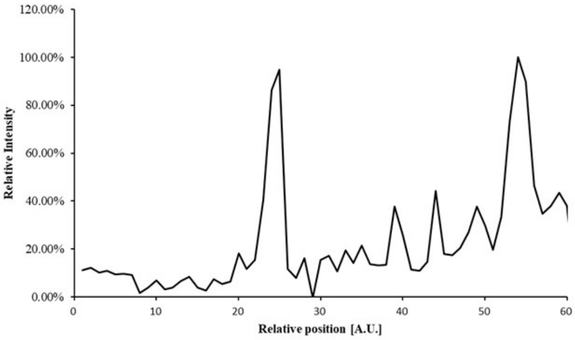

Fig. 2. Measured amount of Cherenkov radiation at each

position

In order to verify the impact of an isotropic cylindrical gamma-ray source, the experimental setup without lead bricks was replicated in Monte Carlo N-Particle (MCNP) simulations. In each position, the simulation computed energy deposition resulting from the interactions of optical fibers with gamma-rays. Fig. 3 shows the energy deposition at each position calculated by the MCNP code.

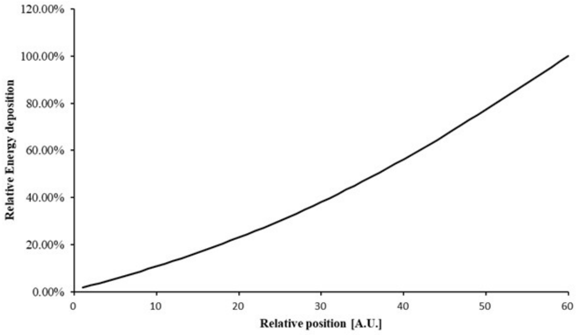

Fig. 3. Computed energy deposition in each position

Based on the MCNP results, we calibrated the effect of an isotropic cylindrical source in the measured data as shown in Fig. 4. The calibration curve was derived into a quadratic function using the MATLAB curve fitting toolbox.

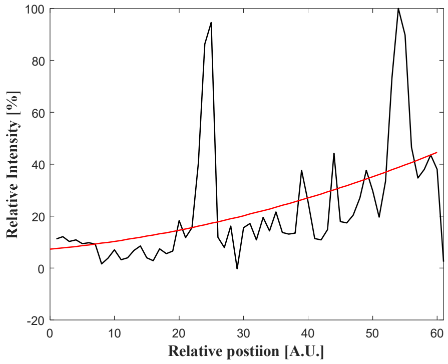

Fig. 4. Derived calibration curve for the measured Cherenkov radiation

Fig. 5 shows the calibrated result, following the truncation of the influence caused by an isotropic cylindrical gamma-ray source. From the result, we verified that utilizing the manufactured sensor to measure the quantity of Cherenkov radiation allows us to pinpoint locations with a higher penetration of gamma rays.

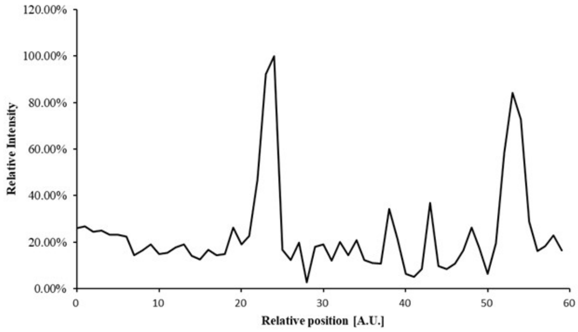

Fig. 5. Calibrated result

3. Conclusions

In this study, we fabricated a fiber-optic radiation sensor based on Cherenkov radiation to measure the dose variance caused by transmitted gamma rays. We have validated that the manufactured sensor is capable of measuring the presence of a 5 mm slit.

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.

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