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A Study on the Response Characteristics of a Fiber-Optic Radiation Sensor Model Based on Cerenkov Principle

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1. Introduction

When the charged particles passing through the transparent medium at speeds greater than the phase velocity of light, Cerenkov radiation is generated within the same medium. In recent year, various fiber-optic radiation sensors using Cerenkov principle have been developed without employing any scintillators for measuring high-energy photon, electron, etc. [1-2].

The main advantages of the optical fibers are the remote transmission of the light signal and immunity to pressure and electromagnetic waves. Therefore, the sensors utilizing the optical fibers can be used in hazardous radiation environments, such as the high-level radiation areas of a nuclear facility [3-4].

The study to be simulated a fiber-optic radiation sensor based on Cerenkov principle and to be analyzed the response characteristics of the sensor. For the aforementioned study, the GEANT simulation toolkit was used. It is able to take into all the optical properties of fibers and is found to be appropriate to realistically describe the response of fiber-optic radiation sensor [5].

2. Simulation and Results

In order to the fiber-optic radiation sensor model simulation was used GEANT4 which is a simulation toolkit package. The software was designed initially for simulating and studying the performance of detector for nuclear and high energy physics experiments [6-8]. And simulation is performed with reference to the method of the previous research [9].

2.1 Physical processes

This models that describe interaction of photons and electrons with materials have been implemented using the GEANT4 toolkit. When gamma ray enters a material, gamma ray interacts with the material through various physical processes such as photoelectric, Compton scattering, pair production. Thus, we have added physical models, including the electromagnetic radiation and the optical reactions (Cerenkov effect, reflection, refraction, etc.).

2.2 The fiber-optic radiation sensor

The fiber-optic radiation sensor was composed of only multimode silica optical fiber (BFH48-1000, Thor Lab.) without employing any scintillator. The core and cladding materials of the fiber consist of pure silica and hard-polymer. The core size of silica optical fiber is 1mm and the numerical aperture is about 0.48. The ends of fiber was attached by a reflector and a detector, respectively. Fig. 1 shows the structure of the fiber-optic radiation sensor.

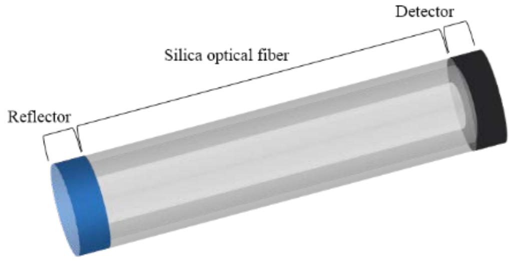

Figure 1. Structure of the fiber-optic radiation sensor

In this simulation, the fiber-optic radiation sensor consists of two silica optical fibers which are divided into a sensing fiber and a reference fiber, and we apply the subtraction method. Two fibers have different lengths, and the length difference between the sensing fiber and the reference fiber is 20cm. Fig. 2 shows the structure of the fiber-optic radiation sensor and subtraction method using the length difference between the two sensors.

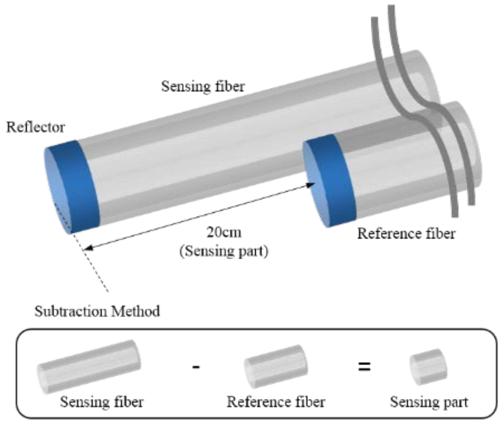

Figure 2. Subtraction method

The fiber-optic radiation sensor was placed at the edge of the radioactive source. To obtain dose distribution, we detected the count difference of the Cerenkov photon generated from the sensing and reference fibers and then Cerenkov photon was obtained by using the subtraction method.

2.3 Simulation results

The virtual experimental area is shielded with a box type of lead housing. The fiber-optic radiation sensor is placed with penetrating side wall. The radioactive source has a point type and is placed at the center. As the radioactive source, we use the ^{60}Co, a radioactive isotope of cobalt. ^{60}Co which has gamma ray emission with decay energy of 1.17 MeV, 1.33 MeV decays to the ground state of ^{60}Ni.

Gamma rays are emitted by the radioactive decay of ^{60}Co, it is irradiated on a fiber-optical sensor the inside area. Then the electron in the optical fiber is traveling through faster than the phase velocity of light, it produces the Cerenkov effect. Cerenkov radiation generated from the optical fiber is guided to the photocathode. Finally, when Cerenkov photons hit the photocathode are recorded in the output file. And then the distribution of Cerenkov photons was obtained using the output file data. Figure. 3 shows the results of the dose distribution according to the y-axis.

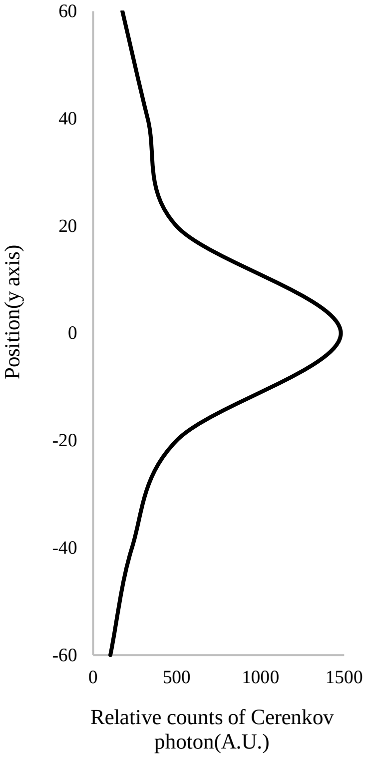

Figure 3. Y-axis distribution of the Cerenkov photon counts by using Monte Carlo simulation.

The fiber-optic radiation sensor, where is close to the radioactive source, are detected the much more Cerenkov photons. The simulation results indicated that the distribution of Cerenkov photon depends on the position of the radioactive source. And then the results of simulation have a similar propensity to the previous research [9].

3. Conclusions

In the recently, the fiber-optic radiation sensor have been developed in nuclear industry. Because sensor can detect gamma ray in harsh nuclear environments. In this study, we analyzed response characteristics of the fiber-optic radiation sensor. We have simulated the Monte Carlo model, for detecting the Cerenkov radiation using the fiber-optic radiation sensor. And the y-axis distribution of Cerenkov photons was obtained using output file. Simulation is performed with reference to the method of the previous research, and then the simulation results exhibited a good agreement with the previous research [9]. As a result, the fiber-optic radiation sensor based on Cerenkov principle can be an effective and convenient sensor tool.

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