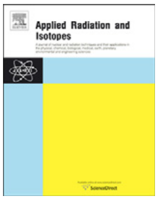
Applied Radiation and Isotopes 69 (2011) 711–715

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Development and characterization of the integrated fiber-optic radiation sensor for the simultaneous detection of neutrons and gamma rays

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ARTICLE INFO

Article history:
Received 3 October 2010
Received in revised form
21 December 2010
Accepted 6 January 2011
Available online 13 January 2011

Keywords:
Integrated fiber-optic radiation sensor
Detection
Thermal neutrons
Gamma rays

ABSTRACT

Sometimes, detection of thermal neutrons in the presence of gamma rays is required. This study developed and characterized an integrated fiber-optic radiation sensor for the simultaneous detection of thermal neutrons and gamma rays in a mixed radiation field. The performance of the integrated sensor was verified by measuring the distributions of thermal neutrons and gamma rays released from a nuclear fuel rod at the Kyoto University Critical Assembly. The experimental results show that the integrated sensor produced similar distribution patterns to those of thermal neutrons and gamma rays released from a fuel rod.

1. Introduction

The remote detection of thermal neutrons in the presence of an intense field of gamma rays is sometimes required in monitoring spent fuel storage, radioactive waste containers and special nuclear materials. The ideal detector in such a situation would be able to discriminate against gamma rays in the detection process. Although conventional neutron detectors, such as BF3 and ^{3}He gas proportional tubes, can be used for slow neutron detection, there are problems with these counters, such as no easy and accurate way of measuring the neutron contribution separately.

In this study, an integrated fiber-optic radiation sensor (FORS) for the simultaneous detection of thermal neutrons and gamma rays in a mixed field of neutron and gamma rays was developed. The integrated FORS consists largely of converters for neutron detection, organic scintillators, optical fibers and light-measuring device.

Scintillators can be categorized into organic and inorganic scintillators according to their constituents. They are selected and used as the sensing probe of a FORS according to the characteristics of the radiation to be detected. Converters are used for neutron detection, and consist of a sensing probe of the FORS along with scintillators. The optical fiber guides the light signals generated from the scintillators to a light-measuring device. The optical fiber has several advantages in detecting and transmitting light signals: long-distant signal transmission, real-time measurement and no disturbances from temperature, pressure and electromagnetic waves (Bartesaghi et al., 2007; Frelin et al., 2005; Becks et al., 2000; Aoyama et al., 1999; Beddar et al., 2001). Photo-multiplier tubes (PMTs) are used widely to detect scintillation light.

To discriminate against gamma rays in a mixed radiation field of neutrons and gamma rays, it is essential to discriminate the light produced by neutrons from those by gamma rays. In this study, two FORSs were fabricated. One was for the simultaneous detection of thermal neutrons and gamma rays using converters and scintillators. The other was for the detection of gamma rays using only scintillators. The neutron contribution was then measured from the difference between the two scintillation lights from the two sensors. In addition, a third FORS for the detection of Cerenkov radiation generated in the optical fiber was added to the integrated radiation sensor.

2. Experimental material and method

^{6}LiF was used as the converter to detect thermal neutrons. The organic scintillator BCF-20 (Saint Gobain) with a cylindrical shape was used as the scintillator for detecting alpha particles generated from the converter. BCF-20 emits scintillation light with a wavelength of 492 nm from the interaction between low-energy X-ray, gamma ray and particles. BCF-20 consists generally of core and cladding like an optical fiber. To increase the sensitivity of

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doi:10.1016/j.apradiso.2011.01.009

sensors in this study, the cladding was removed because it limits the efficiency of detecting alphas from ^{6}LiF.

Fig. 1 shows the structure of the fiber-optic neutron and gamma sensor using ^{6}LiF and BCF-20. The commissure between the organic scintillator and optical fiber was polished with polishing pads to remove bends and scratches. The sensing probe was coated with a black jacket to minimize the noise due to outside light. The sensor in Fig. 1(a) was 5 mm in length with the ^{6}LiF converter enclosing the organic scintillator. Since the ranges of alpha and triton generated through ^{6}Li(n,α)^{3}H reactions in ^{6}LiF are just microns (2.7 MeV triton: 12 μm, 2 MeV alpha: 6.6 μm), the thinner ^{6}LiF layer is, the higher the efficient for detection of neutron is. The structure of the fiber-optic gamma sensor shown in Fig. 1(b) is the same as that of the fiber-optic neutron and gamma sensor except for the converter.

Cerenkov light should be considered in radiation detection using the FORS. Generally, Cerenkov light is produced by charged particles that pass through a transparent medium, such as a plastic optical fiber (POF), with a velocity greater than that of natural light (Fontbonne et al., 2002). Although the wavelength of Cerenkov radiation is quite broad, the peak is in the visible range from 400 to 480 nm. Therefore, it always causes problems in detecting the real light signal that is generated in scintillation on a fiber-optic sensor tip for dose measurements (Lee et al., 2007a, 2007b; Arnfield et al., 1996; Clift et al., 2000; de Boer et al., 1993). The intensity of Cerenkov radiation varies according to incident angle and field size of the radiation. Since the incident angle and field size of radiation are undefined, a method to remove Cerenkov radiation generated in the optical fibers themselves should be applied. A third background sensor, which is a dummy fiber without an organic scintillator, was employed to apply the subtraction method used in this study. In this method, the real scintillating light can be obtained by subtracting the Cerenkov light generated in the dummy fiber, as shown in Fig. 2.

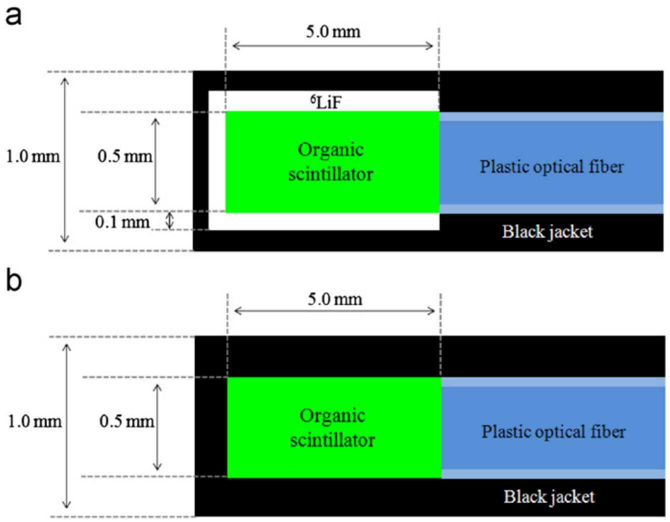

Fig. 1. Structure of the fiber-optic neutron and gamma sensor using ^{6}LiF and BCF-20.

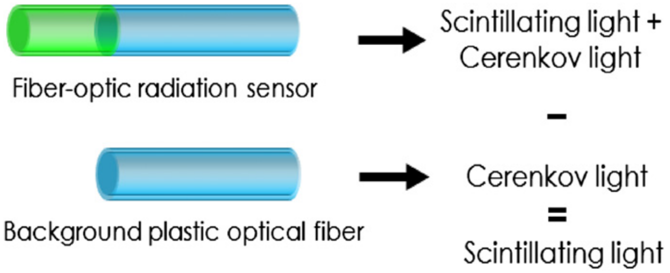

Fig. 2. Principle of the subtraction method to remove Cerenkov light.

Prior to integrating the three sensors into one, the cross-talk of optical fibers that are part of the sensors should be considered. Fig. 3(a) shows the experimental setup to measure the cross-talk of optical fibers due to the integration of sensors. Three optical fibers with a 1 m length were piled up and only one optical fiber was exposed to a LED light source with a 470 nm wavelength. The light from the other optical fibers were measured and the light leaking from optical fiber was determined using a PMT. Fig. 3(b) shows the measurement results, which indicate that 2% and 4% of the light had leaked. Since a 1 m optical fiber was used in this study, the leaked light would increase with an increase in length of the optical fiber. Hence, it is not appropriate to integrate each sensor using bare optical fibers. To minimize the impact of cross-talk between them due to the integration of optical fibers, an optical fiber with a jacket was used in the same experiments, as shown in Fig. 4(a). Fig. 4(b) shows that little of the leaked light was detected.

The diameter of the sensor to be fabricated should be <3 mm because it would be inserted into the small gaps between fuel rods. To minimize the error due to the spatial location of sensor, a 0.5 mm diameter optical fiber with a 0.25 mm thick jacket (SH-2001, Mitsubishi Ltd.) was used in the fabricating sensor. Fig. 5 shows the integrated FORS for the detection of neutron and gamma rays.

As a light-measuring device, a position sensitive photomultiplier tube (PS-PMT, H7546, Hamamatsu photonics INC, as shown in Fig. 6) was used. Using this device, the amplification or multiplication of the scintillation light was achieved and the maximum sensitivity was in the range of visible light. The measurable wavelengths of the PMT ranged from 300 to 650 nm, and the peak wavelength was approximately 420 nm. The amplifier was made and used to amplify the electrical signals. The voltage, which is the final output, was measured using a DAQ device (NI USB-6251, National Instruments).

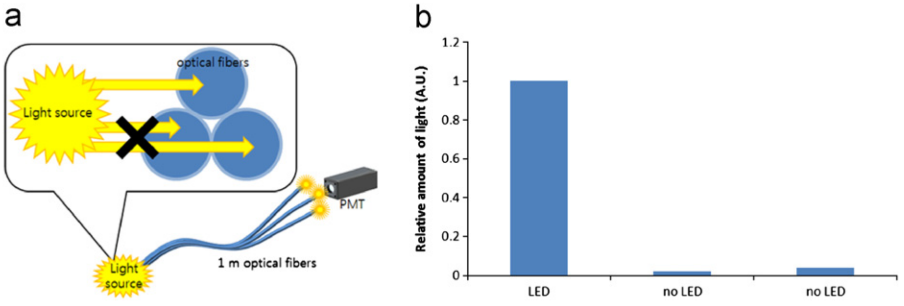

Fig. 3. Measurement of cross-talk with the bare optical fiber.