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Development of Wide-Area Radiation Monitor Using an Optical Fiber

Naoki KAWATA, Naoya HIRABAYASHI*, Toshiro ITOGA, Takako MIURA,
Masatoshi KATO, Takeshi YAMAUCHI, Mamoru BABA, Akira YAMADERA,

Cyclotron and Radioisotope Center, Tohoku University, Aoba, Aramaki, Aoba-ku, Sendai, Miyagi, 980-8578, Japan

We have developed a method for radiation distribution measurement by combining an optical fiber of wave-length shift type with plastic scintillators, and studied its properties to apply as a wide-area radiation monitor. The detector employs two photomultipliers in both ends of the fiber and locates the radiation position by using the difference of light arrival time from scintillators.

We tested the detector with gamma-rays and neutrons concerning with the position-response and pulse-height response of the detector. From the experiment, we confirmed the proper operation of the detector and position response with spatial resolution of 30-60 cm.

KEYWORDS: Wide-area radiation monitor, coupling of fiber and scintillator, position sensitivity

I. Introduction

Measurement of spatial distribution of radiation is required to confirm the safety and proper operation of nuclear facilities, i.e., nuclear reactors, accelerators, nuclear fuel plants, and fusion study facilities. It is desirable to measure the radiation distribution in real time. A means of spatial distribution is divided into two categories. One is distributing many radiation detectors separately. In this case, a large number of detectors and electronic devices, and therefore a large capital investment is required[2),3)] The other one is using position sensitive detectors to measure radiation intensity in each point. By using the position sensitive detector, it is expected that the measurement can be done over a wide-area in real time with a relatively simple system. In particular, the use of optical or scintillating fiber will be useful because it provides information not only on the position of radiation emission but also on the type of radiation and energy.

In this study, we have studied a method of radiation distribution measurement by combining an optical fiber with plastic scintillators, and studied its property to apply as a wide-area radiation monitor such as radiation area monitor or beam loss monitor for accelerators. In this method, several scintillators are placed around the location of interest and their outputs are led to a wavelength-shift fiber coupled to two multipliers in both ends. From the difference of light arrival time to the photomultipliers and the magnitude of the signal, we know the positions and light intensities of the radiation.

In this method, we can vary the sensitivities and the selectivity of radiation types by changing the scintillator type and its size. Further, by using the combination, the sensitivity for the radiation will be higher than the case of using scintillating fibers alone owing to large size of the scintillator.

II. Principle of wide-area radiation monitor

A schematic view of the detector is shown in **Figure 1**. Several scintillators are placed in the location of interest and their light outputs are lead to a wavelength-shift fiber coupled to two photo-multiplier tubes in both ends.

When radiations enter and interact with the scintillators, generated scintillation photons go to both ends of the fiber, and the arrival time difference in both ends of the fiber provides the information on which scintillator is lighting.

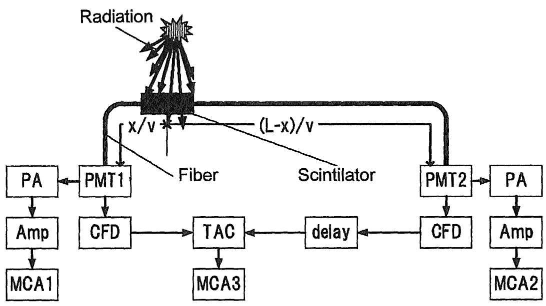

Fig. 1 Principle of wide-area radiation monitor

The fiber outputs are connected to photo-multiplier tubes (PMT) (Hamamatsu H1949 assembly), constant-fraction discriminators (CFD), and time-to-amplitude converters (TAC). When the radiations are incident on the scintillator placed x m from the start PMT, the difference of light arrival time to both photomultipliers is given by

$$\Delta t = \{(L - x)/v + T_d\} - x/v = (L - 2x)/v + T_d, \quad (1)$$

Therefore,

$$x = \{v(T_d - \Delta t) + L\}/2, \quad (2)$$

where, v:velocity of light in the fiber, L:length of optical fiber, and T_d:delay time.

The present detector has the following advantages which are inherent in detectors using an optical fiber;

1. light mass, compact, and flexible structure,

2. suitability for wide-area monitoring,

* Corresponding author, Tel. +81-22-217-7806, Fax. +81-22-217-7809, E-mail: hiraban@cyric.tohoku.ac.jp

3. tolerance to electromagnetic field owing to the utilization of light signal.

In addition, the detector can measure radiation distribution continuously over a wide area.

III. Coupling of fiber with scintillator

In this study, the fiber is coupled with the scintillators through a hole in the scintillator[1] as shown in **Figure 2**, and photons emitted in the scintillators are transmitted into the fiber. To improve the light transmission, we used a wavelength-shift fiber (WSF) for an optical fiber coupled to the scintillators. WSF absorbs lights and then re-emits lights with different wavelength to 4π solid angle. By using WSF, therefore, the transmission efficiency of photons from the scintillator becomes higher compared with the use of normal optical fibers.

In this study, NE102A plastic scintillators and BCF-92 WSF (Bicron) was used. **Figure 3** shows the wavelengths of the lights emitted from NE102A, and the absorption and emission efficiency of BCF-92. The peak of light from NE102A is around 423 nm which is close to the wavelength of absorption of BCF92 about 410 nm. Therefore, the transmission efficiencies of the scintillation light are high for this combination.

Besides, by changing the scintillator type and its size, it is possible to vary the sensitivities and selectivity of radiation types. Further by using the coupling, the sensitivities for the radiation can be higher than the case of using scintillating fibers alone owing to the larger size of the scintillator. Actually, scintillators are covered with teflon and aluminum case for light shading and light connectors are jointed to the end of WSF to connect the plastic fibers. By the way, a detector module is fabricated for flexible utilization.

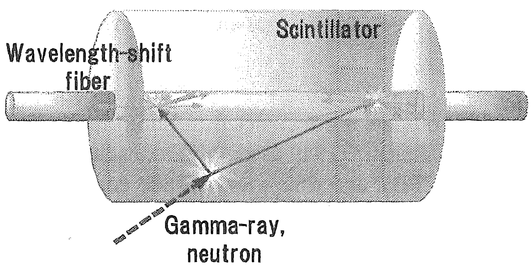

Fig. 2 Coupling of scintillators with fiber

IV. Experiment and result

Figure 4 shows a schematic view of the scintillator and WSF used in this experiment. The scintillator was a rectangular parallelepiped one with a Teflon coating. The fiber was 5.5 m long and 1 mm in diameter. By changing the positions of scintillators along the fiber, we measured the position responses of the detector for gamma-rays from a ^{137}Cs source and 15 MeV neutrons.[4] The pulse-height response was also studied to find the optimum operating condition of the detector.

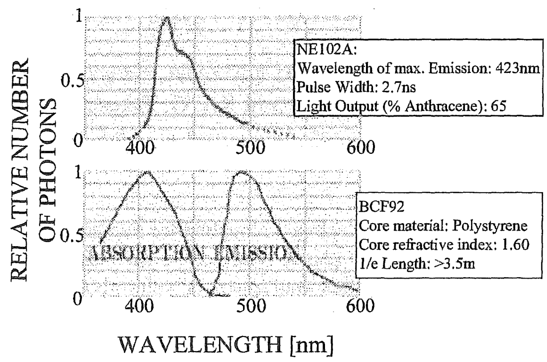

Fig. 3 Comparison of wavelengths

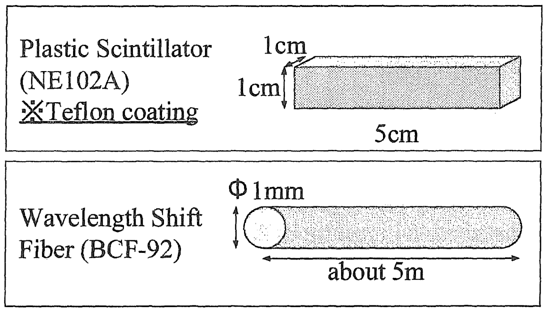

Fig. 4 A size of the scintillator and fiber

1. Pulse height distribution for ^{22}Na gamma-ray

Figure 5 shows a pulse height distribution of the detector for ^{22}Na gamma-rays (0.511 and 1.27 MeV) detected by NE102A coupled directly to the PMT. Two Compton edges are shown apparently. On the other hand, as shown in **Figure 6** no peaks can be seen if the WSF is inserted between scintillator and PMT. As the cause of this loss of pulse-height information, the following processes may be concern:

1. attenuation of lights between the scintillator and the WSF,
2. shift of light wavelength in WSF, and
3. transportation of shifted light along the fiber.

2. Pulse height distribution for 15 MeV neutrons

Figure 7 shows the pulse height distributions for 15 MeV neutrons with WSF of 1 m to 5 m from the start PMT. In the case of 1 m, an edge-like structure can be seen around 3,000 channel, but such structure disappears at 5 m. As the transportation length becomes longer, the pulse height distribution was deteriorating, which suggests that the main cause of the loss of pulse-height information is in the attenuation in the fiber itself.

The results of IV.1. and IV.2. indicate the pulse-height response of the detector is not as good as expected to device position information, if WSF is inserted between scintillators and PMT. Therefore, the wide-area radiation monitor in the present configuration should employ the time-of-flight information for position determination in place of the pulse-height information.

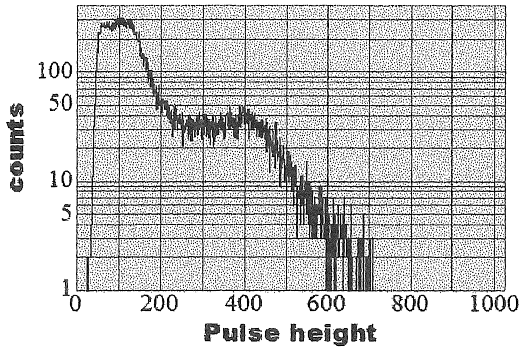

Fig. 5 Pulse height distribution of ^{22}Na without WSF

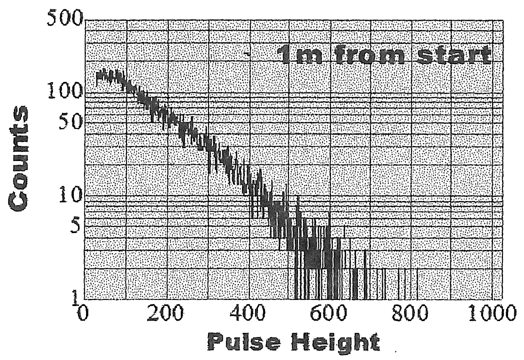

Fig. 6 Pulse height distribution of ^{22}Na with WSF

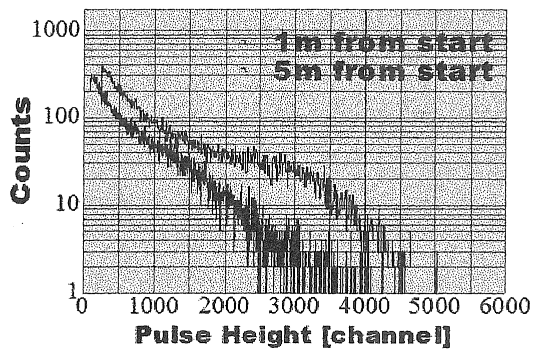

Fig. 7 Pulse height distribution of 15 MeV neutrons with WSF

3. Position response for gamma-ray

By using a ^{137}Cs gamma-ray source, position response was measured in 1 m step from 1 to 5 m. **Figure 8** shows the result of the response test. Five peaks are clearly observed corresponding to the scintillator position. A position resolution was about 60 cm because the time resolution was 3.2 ns in FWHM for a ^{137}Cs source. (Cf. equation(1),(2)).

In the fiber, lights are attenuated exponentially with the distance. Because of the attenuation, counting rates for each peak were different and decreased with the distance from the start PMT. The output light of the plastic scintillator for 661 keV gamma-ray from ^{137}Cs is small, and then the measurement was done by setting a pulse height bias near the threshold of CFD. Correspondingly counting rates for each peak become smaller with the distance from the start PMT.

This resolution was not so high. It is probably due to the attenuation and dispersion in time of scintillating photons during the transportation between the scintillator and the fiber or within the fiber itself.

Figure 10 shows the response measured for two points simultaneously by the method shown in **Figure 9**. Two peaks are observed clearly and this experiment shows that detection in plural points could be possible.

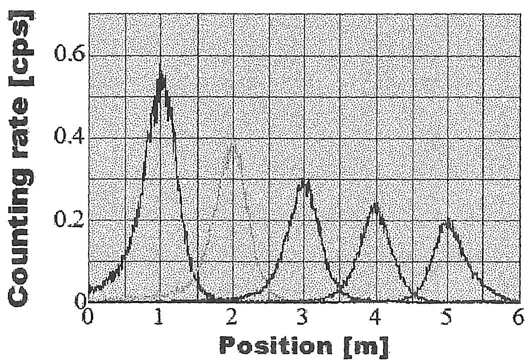

Fig. 8 Position response for ^{137}Cs

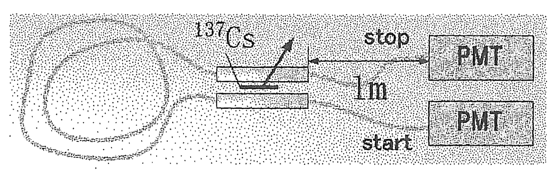

Fig. 9 Schematic view of 2 points detection

4. Position response for 15 MeV neutrons

Figure 11 shows the position response of the detector for 15 MeV neutrons obtained by the D-T reactions using the Tohoku University Dynamitron accelerator. For this measurement, the scintillator was moved in 1 m step from 1 m to 5 m in the same way as the experiment for ^{137}Cs gamma-ray. Five peaks were observed clearly around each position.

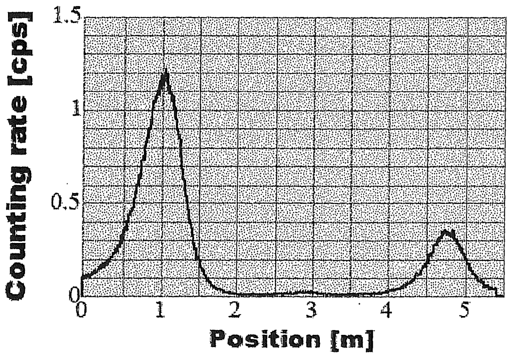

Fig. 10 Response of two points detection

The position resolution improved to 40 cm probably because the light output for 15 MeV neutrons was about ten times as large as that for ^{137}Cs gamma-ray of 661 keV. Furthermore, in contrast with the ^{137}Cs case, the counting rates for the neutrons are almost independent of the position owing to high light output for 15 MeV neutrons and low pulse height bias.

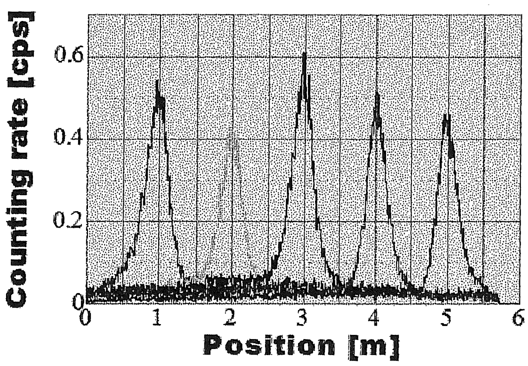

Fig. 11 Position response for 15 MeV neutrons

5. Detector response for five scintillators

The above detector was extended to five scintillators and tested for 15 MeV neutrons. The results indicated the position response can be obtained reasonably so long as the counting rate is not too high to avoid chance coincidence between two PMTs

V. Summary

1. We have fabricated a position sensitive detector as the wide-area radiation monitor using a combination of scintillators and WSF. By changing the size of the scintillator, the sensitivity for radiations can be varied. Light transmission efficiency can be improved by using WSF.
2. We showed the radiation point can be known from the difference of light arrival times (time-of flight) to both ends of the fibers.
3. From the above, the fiber detector can be used as the wide-area radiation monitor, while there is a room of improvement.

For realization of the monitor, the transmission length of the lights should be made longer by using silica fibers whose attenuation length is far longer than that of plastic fibers. Besides, there is possibility to detect only neutrons by using a ZnS(Ag) scintillator and so on to make radiation identification.

References

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