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Comparison of Depth Dose Distributions Using Cerenkov Fiber-Optic Dosimeter and Monte Carlo Simulation for HDR Brachytherapy

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Abstract

In this study, we fabricated a Cerenkov fiber-optic dosimeter (CFOD) without any scintillator to measure Cerenkov radiation signals owing to gamma-rays. The relative depth dose (RDD) distributions of Ir-192 HDR brachytherapy source were obtained by using the CFOD based on a subtraction method and the RDD curve was compared with the simulation result of Monte Carlo N-particle extended transport code (MCNPX). Finally, we demonstrated that the CFOD can be used to measure real-time dose information for HDR brachytherapy.

Keywords

Cerenkov Fiber-Optic Dosimeter, Cerenkov Radiation, Gamma-Ray, Relative Depth Dose, HDR Brachytherapy

1. Introduction

In general, high-energy charged particles can produce Cerenkov radiation or light in various kinds of transparent materials [1]. In high-dose-rate (HDR) brachytherapy applications that use various radiation sources with intermediate energies, in the hundred keV range, Cerenkov radiation can be also generated. This Cerenkov radiation is well known as an additional signal for the fiber-optic dosimeters (FODs) using scintillators and thus, it can interfere with the accurate measurement of the dose information as an unwanted light signal. However, Cerenkov light can be of utility for dosimetry because it is one of the various light signals generated from the sensing areas of FODs by the radiation interactions. Radiation-induced light signals including Cerenkov light can be obtained simply using the optical fibers without any scintillating material [2]-[8].

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In this study, we fabricated a novel Cerenkov fiber-optic dosimeter (CFOD) using plastic optical fibers (POFs), a photomultiplier tube (PMT; H12525-01, Hamamatsu Photonics), and a photon-counting unit (C8855-01, Hamamatsu Photonics) to measure the light intensities of Cerenkov radiation induced by gamma-rays. Using the CFOD, the relative depth dose (RDD) distributions of a HDR brachytherapy source were measured and then, the RDD curve was compared with simulation result of Monte Carlo N-particle extended transport code (MCNPX).

2. Materials and Methods

The sensing probe of the CFOD is composed of two identical POFs with different lengths to measure Cerenkov radiation [9]. The length difference of two POFs (i.e., probes 1 and 2) is 10 mm to apply the subtraction method, as shown in **Figure 1**. In general, the subtraction method can be employed for measuring the difference of interest between two sensor signals [10]. In this study, we used two step-index multimode POFs (GH-4002 Mitsubishi Rayon) to generate and transmit Cerenkov radiation signals owing to the gamma-rays emitted from a HDR brachytherapy source. The core material of the POF is polymethylmethacrylate (PMMA) and the cladding layer is made of fluorinated polymer. The refractive indices of the core and the cladding at the design wavelength of 650 nm are 1.49 and 1.402, respectively; thereby the NA is about 0.5. And, the core diameter is 0.98 mm and the cladding thickness is 0.01 mm. The maximum transmission loss of the POF is 190 dB/km when used with 650 nm collimated light.

Ir-192 with a radioactivity of 8.14 Ci is used as a HDR brachytherapy source. The diameter and the length of Ir-192 are 0.6 and 3.5 mm, respectively. Ir-192 emits gamma-rays with the energy range from 50 to 800 keV and the energy peaks at 316 and 468 keV. The average energy of the gamma-rays emitted from Ir-192, which is placed in a sealed stainless-steel capsule, is approximately 397 keV.

Figure 2 presents the experimental setup for measuring the Cerenkov radiation generated from the sensing probe of the CFOD. The sensing probe is located on the center of the Ir-192 HDR brachytherapy source. When the sensing probe is irradiated by the gamma-rays, two Cerenkov radiation signals with different light intensities are generated from the probes 1 and 2 in the sensing probe and then, they are transmitted to the pertinent channels in the PMT via two transmitting optical fibers with a length of 10 m. The output current signals generated from the PMT are converted into the Transistor–transistor logic (TTL) pulses by a photon-counting unit. Finally, the pulse counts are transmitted through a universal serial bus (USB) line to a laptop.

3. Results

Figure 3 shows the light intensities of the real-time Cerenkov radiation signals generated from the sensing probe of the CFOD during the gamma-ray irradiation. The output signal of the probe 1 is higher than that of the probe

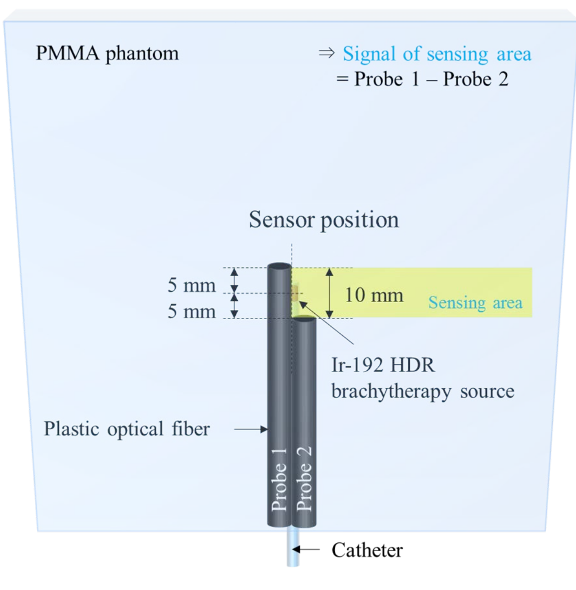

Figure 1. Schematic diagram of the sensing probe of the proposed CFOD without any scintillator.

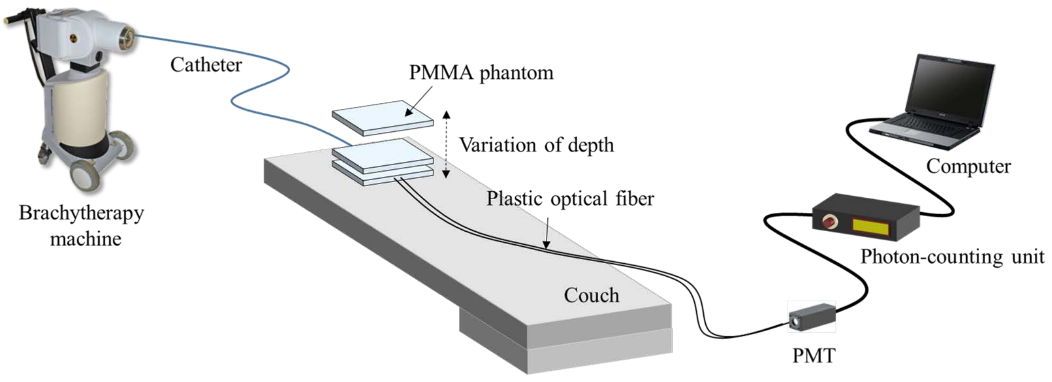

Figure 2. Experimental setup for measuring Cerenkov radiation using the CFOD and the Ir-192 HDR brachytherapy source.

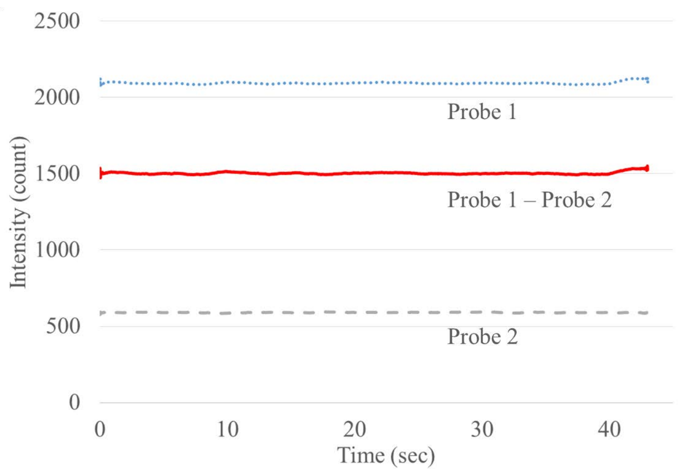

Figure 3. Subtraction method and the light intensities of the real-time Cerenkov radiation signals generated in the probes 1 and 2.

2 because the two probes have the different irradiated length. In this study, the real-time dose information is obtained by measuring the intensity difference of the two Cerenkov radiation signals from the probes 1 and 2, as shown in **Figure 3** [6].

Using the subtraction method that deducts the output signal of the probe 2 from that of the probe 1, we obtained the RDD curve according to the depth variation of the PMMA phantom, as shown in **Figure 4**. The RDD curve in the PMMA phantom falls off sharply to a depth of 20 mm and decreases gently with depth beyond 20 mm. The RDD curve measured by using the CFOD is also compared with the simulation result of MCNPX, which is used to verify the dosimetric response of the CFOD. As experimental results, the RDD curve obtained by using the proposed CFOD is similar to the electron flux distribution calculated by using the MCNPX simulation.

4. Conclusions

In this study, we fabricated a CFOD using two POFs without any scintillator to measure real-time dose information for HDR brachytherapy. By using a sensing probe of the CFOD, Cerenkov radiation signals owing to the gamma-rays emitted from Ir-192 were measured successfully. We obtained the depth dose distribution using a subtraction method and then compared the RDD curve to the electron flux distribution calculated by using the MCNPX simulation.

In conclusion, we demonstrated that the proposed CFOD can be used to measure dose information including RDD distributions. Based on the results of this study, it is expected that the CFOD can give useful dose information for HDR brachytherapy due to its many advantages, including high spatial resolution, real-time monitoring, remote operation, and water or tissue-equivalence.

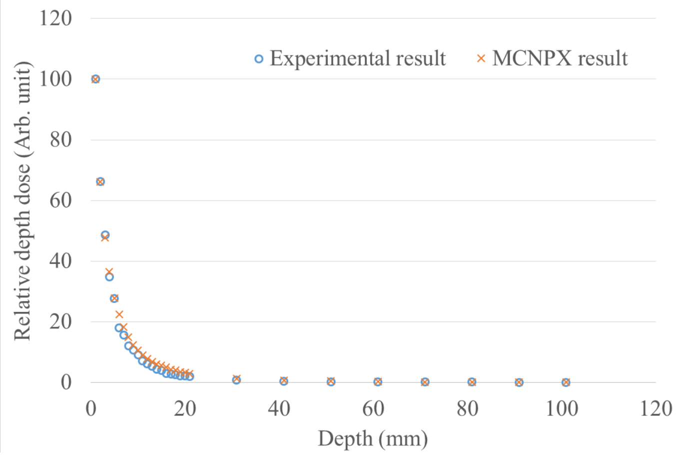

Figure 4. Comparison of two RDD curves obtained by using the CFOD and the MCNPX simulation.

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