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Test of a Miniature Fiber-optic Gamma-ray Dosimeter Using Alanine Pellet Dosimeters in a ^{60}Co Irradiation Chamber

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1. Introduction

A fiber-optic dosimeter is constructed with a small piece of GSO scintillator optically attached to a low attenuating plastic optical fiber. This dosimeter model can offer several good properties such as remote measurability and superior spatial resolution. Also, GSO(Gd_2SiO_5) scintillator has an excellent radiation hardness of about 10^6 gray[1], which makes it suitable for being used as a radiation dosimeter in high radiation fields.

A number of studies have been conducted on the dosimeter model based on the fiber-optic scintillator concept. Beddar et al. proposed a miniature dosimeter with a combination of plastic scintillator and silica fiber for the dosimetry of small field in stereotactic radiosurgery.[2] Nowotny reported a tissue equivalent dosimeter model with LiF:W scintillator head attached to a plastic optical fiber. [3] Eiji Takada investigated the radiation distribution measurement with optical fibers in high radiation field [4]

In this work, we present the result of our study on a fiber-optic dosimeter with a GSO scintillator piece attached to a low attenuating plastic fiber and a current-type PMT. The PMT current measured is considered to be proportional to the radiation dose absorbed in the scintillator. The dosimeter model was tested in a ^{60}Co irradiation chamber with an activity of about 6000Ci. The measured current distribution is compared with the MCNPX-simulated results and the dose rate distribution measured with Alanine pellet dosimeters (ES200-2106) supplied by Bruker BioSpin. A dose rate calibration factor, which can be effective for the measured dose rated range, is estimated from the measured dose rate and the measured PMT current.

2. Methods and Results

2.1 Dosimeter Model

As shown in Fig. 1, the dosimeter model is composed of scintillator, light guiding optical fiber, current-type PMT module, data acquisition unit (DAU) and PC.

The density of GSO is 6.71g/cm^3, light yield is 20% that of NaI(Tl). Its radiation hardness for photons amounts to about 10^6Gy. The scintillator piece, having a size of $4.9\times4.9\times10$mm^3, is polished with a series of polishing media including 0.5μm alumina powder as the final medium. It is then wrapped with a Teflon tape as a reflector to reduce light losses. The light guiding optical fiber, which is a product (PGR-FB3000) of Toray Industries, Inc., has 3mm diameter and 10m length. Light attenuation of the fiber is less than 0.2db/m for wavelengths between 400-600nm. Both ends of the plastic fiber are also polished with the same alumina powder. One end of the fiber is optically jointed to the scintillator tip with optical cement. The scintillator and fiber assembly is then covered with a thermally-shrunk black tube to block the ambient lights. The other end of the fiber is couple to the PMT module using a FC connector and PMT fiber adaptor. The gain of the PMT module (Hamamatsu H6780-4) is controlled between 10^2 and 10^6 by adjusting the anode control voltage between 0.25 and 0.9 volt.

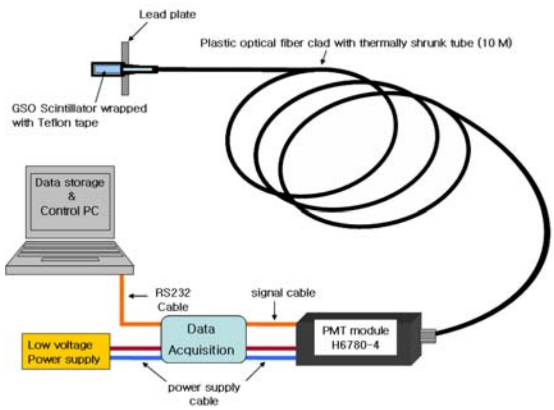

Fig. 1 Schematic of the fiber-optic scintillator dosimeter system

The PMT module is coupled with the data acquisition unit (Hamamatsu C8908), which is connected to the PC. The PMT current is obtained from the collected electric charge divided by the user-specified charge integration time. Each current datum is repeatedly written in a text file for the user specified time.

2.2 Measurement and MCNPX Simulation

The dosimeter system was tested in a ^{60}Co irradiation chamber with an activity of about 6000Ci. The scintillator/fiber assembly was inserted into the irradiation chamber. Measured distance was from 40cm to 100cm from the source with a 20cm interval, and measuring time was 60 seconds at each point. The PMT gain control voltage was adjusted to 0.3 volt. The effect of the Cerenkov radiation generated in the fiber core was significant in this case since the light guide fiber was also exposed to the gamma rays. In order to eliminate the Cerenkov radiation effect, a dummy fiber of the same kind and length but without the scintillator was also inserted into the chamber together with the dosimeter assembly. The current from the dummy fiber was subtracted from the dosimeter current to obtain the net current.

MCNPX simulations were performed, using the F6 tally option, to calculate the energy deposited in the scintillator for the measured source and dosimeter arrangements. Alanine pellet dosimeters were also used to measure the dose rates at the same points. The Alanine dosimeters were read at Advance Radiation Technology Institute at Jeongeup.

2.3 Results

In order for the dosimeter to properly work, the PMT current should be proportional to the deposited energy in the scintillator as well as the dose rate measured with the Alanine dosimeters. We compared the normalized distributions of the PMT current, the calculated energy deposition and the dose rate measured with Alanine dosimeters. Normalizations were performed with respect to the largest values, i.e., the values obtained at the position nearest to the source.

Fig. 2 shows the normalized distributions of the PMT current, the calculated energy deposition, and the Alanine-measured dose rate. The reference values at 40cm was 3.98×10^{-7}A for the PMT current measured, $8.34\text{x}10^{11}$ MeV for the calculated energy deposition and 6 Gy/min for the Alanine-measured dose rate. The three distributions nearly coincide with each other and the deviations are less than 5% at all positions. The PMT current distribution better agrees with the Alanine-measured dose distribution than with the distribution of the calculated energy deposition. The range of dose rate measured with the Alanine dosimeters was from 1.18 to 6 Gy/min.

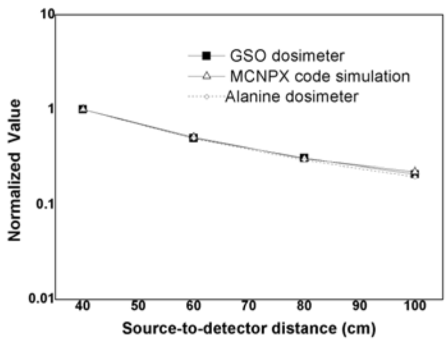

Fig. 2 Normalized distributions of the PMT current, deposited energy and the dose rate measured with Alanine dosimeters

Fig 3 shows variation of the conversion factors (Gy/min/A) determined from the Alanine-measured dose rates divided by the measured PMT currents. The conversion factor can be used to convert the PMT current directly into the absorbed dose rate. The conversion factor is $1.49\text{x}10^7$ Gy/min/A at 1.18Gy/min and $1.51\text{x}10^7$ Gy/min/A at 6Gy/min, and the calibration factor was determined as $1.5\text{x}10^7$ Gy/min/A by taking an average of the conversion factors. With this calibration factor, the dose rate measured with the fiber optic dosimeter model almost agrees with the Alanine-measured dose rate. The errors are less than 1% for the dose range considered.

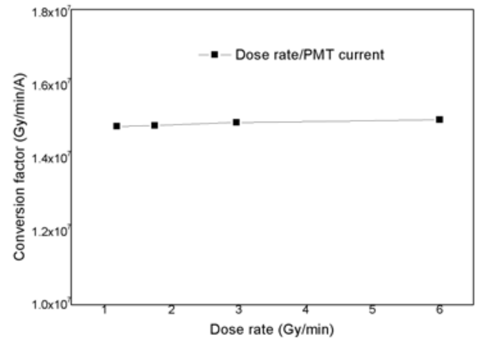

Fig. 3 Estimated conversion factors for the fiber-optic dosimeter to gain the absorbed dose rate from the measured PMT current

3. Conclusions

A fiber-optic dosimeter model, with a small piece of GSO scintillator attached to one end of a low attenuation plastic optical fiber and a current type PMT optically coupled to the other end, was constructed for remote measurement in a strong gamma ray fields. The dosimeter model was tested in a ^{60}Co irradiation chamber of about 6,000Ci. The normalized distribution of the measured PMT current well coincides with those of the MCNPX-calculated deposited energy and the dose rate measured with Alanine pellet dosimeters. A calibration factor, which can be used to convert the measured PMT current into the absorbed dose rate, was determined from the measured data. It is found that with a single calibration factor of $1.5\text{x}10^7$ Gy/min/A, the dosimeter model can measure the gamma ray dose rate in the dose range 1~6 Gy/min with negligible errors (less than 1%).

REFERENCES

[1] Peter Kozma, Petr Kozma, Radiation Resistance of Heavy Scintillators to Low-Energy Gamma-Rays, Radiation Physics and Chemistry,Vol.71, P 705-707, 2004.
[2] A.S. Bedda, T. J. Kinsella, A. Ikhelf, and C. H. Sibata, A miniature scintillator-Fiberoptic-PMT Detector System for the Dosimetry of Small Fields in Stereotactic Radiosurgery, Transactions on Nuclear Science, Vol.48, NO 3, June 2001.
[3] R Nowotny, LiF:W As a Scintillator for Dosimetry in Diagnostic Radiology, Physics in Medicine and Biology, Vol.49, p.2599-2611, 2004.
[4] Eiji Takada, Atsushi Kimura, Yoneichi Hosono, Hiroyuki Takahashi and Masaharu Nakazawa, Radiation Distribution Measurements with Optical Fibers in High Radiation Fields, Nuclear Science Symposium, Vol.2, P 791-795, 1999.