Test of a Fiber Optic-Based Dosimeter with LYSO Scintillator tip in Low Dose Range

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1. Introduction

Due to its excellent remote measurability and high spatial resolution, the fiber optic-based radiation dosimeter has been extensively explored for its usability in medical applications [1,2]. In previous work [3,4], we reported the result of our investigation on feasibility of a photon dosimeter constructed with a BGO($Bi_4Ge_3O_{12}$) or GSO(Gd_2SiO_5), CWO($CdWO_4$) or LYSO(Cerium-doped Lutetium Yttrium Orthosilcate) scintillator piece attached to a plastic optical fiber to be applicable to a high dose rate field (10~2000 Gy/h) formed by ^{60}Co source with an activity of 2.0 TBq (5,400 Ci). The dosimeter with the LYSO scintillator tip had generally shown good dosimetric characteristics: sensitivity and linearity of the dosimeter reading. In this paper, we report test result of the same dosimeter in a relatively low dose rate field formed by a ^{137}Cs standard source with an activity of 37 MBq (1 mCi). We have investigated linearity of the dosimeter reading (dosimeter current) with respect to the dose rate measured with an OSL (Optically Stimulated Luminescence) dosimetry system. A single current-to-dose rate conversion function is obtained from the linear fit function between the dosimeter current and the OSL dose rate, and this conversion function is used to convert the dosimeter current into dose rate. Errors are estimated in the measured dose rate range.

2. Materials and Experimental Methods

2.1Materials

As shown in Fig. 1, the dosimeter model is composed of two trains of a light guiding plastic optical fiber and a current-type PMT: sensor train and dummy train. The sensor train has an LYSO piece attached to one end of the fiber, but the dummy train does not. The other end of each fiber is coupled to a current-type PMT by an FC-type connection.

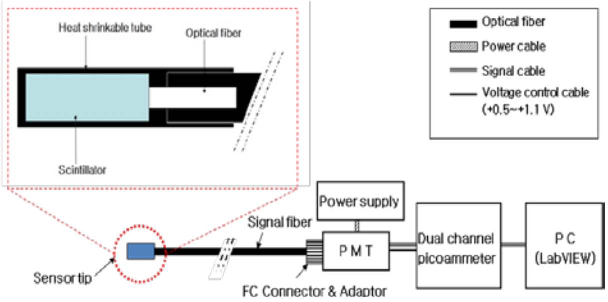

Fig. 1. Schematic diagram of the dosimeter model

The fiber is clad with a black heat shrinkable tube to block the ambient light. The purpose of the dummy train is to eliminate the effect of the Cerenkov light generated in the fiber core in a strong radiation field. The PMT currents from both trains are simultaneously measured with the dual channel picoammeter (Keithley 2502). The LYSO was purchased as polished in a cylindrical shape of ϕ 5m×10mm from Omega Piezo Technology. The scintillator is enclosed in a black heat shrinkable tube. The light guiding optical fiber, which is a product (PGR-FB3000) of Toray Industries, has 3mm diameter and 10m length. The PMT (H10721-210) is a product of Hamamatsu Photonics. The PMT gain is controlled between 10^3 and 10^7 by adjusting the anode control voltage between 0.5 and 1.1V. The picoammeter has a variable voltage source in each channel so that it can be used for the gain control voltage of the PMT. The output currents from the picoammeter are sent through a GPIB cable (KUSB-488A, Keithley) to the PC, where the net PMT current is calculated by subtracting the dummy train current from the sensor train current in the LabVIEW program. This net PMT current is taken as the dosimeter current. The picoammeter actually measures the electric charge accumulated during a user-specified time interval, and convert it into current by dividing the accumulated charge by the user-specified time. Thus the current is actually an average electric charge accumulated per unit time. We set 120 measuring time intervals for a minute. The PMT control voltage was set to 1.1V for the maximum gain of 10^7. The OSL dosimetry system, provided by LANDAUER, consists of the microStar nano dot dosimeters and Reader. The sensor size is small enough to practically represent a dot. Since the OSL dosimeter had been calibrated with ^{137}Cs source to measure absorbed dose rate in mGy/h, we used a ^{137}Cs standard source of 37 MBq (1 mCi).

2.2 Experimental Methods

In order to confirm the accuracy of the OSL dosimetry system, we measured the absorbed doses for 1h, 2h, ...10h, at 1cm from the source. Fig. 2 shows an excellent linearity of the dosimeter reading as a function the measuring time. In order to test the constructed dosimeter model, the dosimeter currents were measured at 1.5, 3.5, 5.5, 7.5, and 9.5 cm from the source. The measuring time was 1 minute at each point. 3 measurements were made at each point and averages of them were used for evaluation. The absorbed dose rates were measured at the same points with the OSL dosimetry system, and these values were taken as reference dose rates.

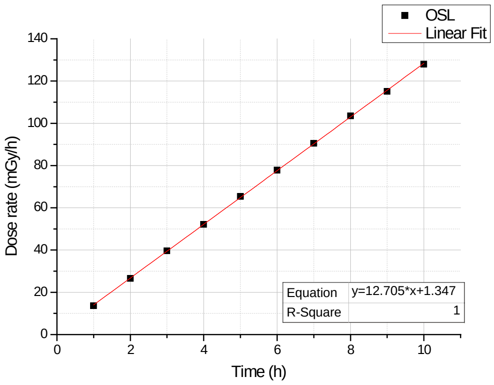

Fig. 1. Linearity of OSL dosimeter reading at 1cm from the source as a function of the measuring time

3. Results

Fig. 3 shows variation of the dosimeter current with respect to the reference dose rate. The solid line represents a linear fitting of the dosimeter current to the reference dose rates. The fit function obtained by ORIGIN 8 graphing program is expressed in the form of I=a·D + b, where I is the dosimeter current (μA), D is the reference dose rate (mGy/h), a and b are fitting parameters. The fitting parameters were obtained as 3.05x10^{-7} and 1.59x10^{-7}, respectively. The correlation factor (R-square) was obtained as 0.99974.

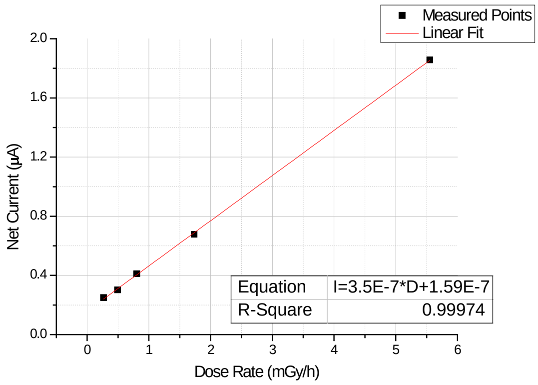

Fig. 3. Linear fitting of dosimeter current with respect to the reference dose rate measured with the OSL dosimeter

For the purpose of evaluating the accuracy of our dosimeter model, we derived a single calibration function for the whole dose range, which would be used for the conversion of the dosimeter current into the dose rate. The calibration function was obtained from the fit function by a simple transformation to the form D=α·I + β, where α and β were calibration constants, computed to be 3.28x10^{6} and -0.521, respectively. Using this calibration function, we converted the dosimeter currents into the dose rates at all points. Table 1 compares the dose rates measured with the OSL dosimeter and our dosimeter model. The relative errors shown are estimated by the formula: $Error(\%) = \frac{D-D^*}{D^*}\times 100$, where D and D* represent the converted and reference dose rates, respectively.

It can be seen that the relative errors are increasing as the dose rate decreases. They are small at higher dose rates (closer points to the source), but there is no consistency in the direction of the error vector.

Table 1: Comparison of the reference and converted dose rates

Position (cm)	Reference Dose rate (mGy/h)	Converted Dose rate (mGy/h)	Error(%)
1.5	5.55	5.56	-0.17
3.5	1.73	1.70	2.15
5.5	0.81	0.83	-2.44
7.5	0.49	0.47	5.21
9.5	0.27	0.30	-12.71

4. Conclusions

A fiber optic-based dosimeter model with an LYSO scintillator tip employing current-type PMTs was constructed to measure the gamma-ray dose in low dose range. Linearity of the dosimeter reading was evaluated in a low doer range using a commercial OSL dosimeter as reference dosimeter. A single calibration function was obtained. Using this calibration function, accuracy of the dosimeter model was evaluated. The relative errors are increasing as the dose rate decreases. There is no consistency in the direction of the error vector.

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