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Dose–response and intrinsic efficiency of thermoluminescent dosimeters in a 15 MV clinical photon beam in a liquid water phantom

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ABSTRACT

This paper compares the performance of $CaSO_4$:Dy and LiF dosimeters irradiated with a 15 MV photon beam of a clinical linear accelerator to 0.1–10 Gy in a liquid water. The dose–response curves are linear up to 5 Gy. The average TL sensitivity of $CaSO_4$:Dy is 26 and 287 times higher than the sensitivities of LiF:Mg,Ti and microLiF:Mg,Ti, respectively. $CaSO_4$:Dy has an intrinsic efficiency 71% and 94% higher than the intrinsic efficiencies of LiF:Mg,Ti and microLiF:Mg,Ti, respectively.

1. Introduction

An important requirement in radiation therapy is that cancerous tissues are irradiated uniformly and precisely to the radiation dose prescribed by the oncologist. The objective of radiotherapy dosimetry is to determine the absorbed dose to the patient by calibrating the radiation beam. This is important because keeping the dose variation within ±5% is crucial for reducing the risk of sequelae or recurrences. An effective and accurate calibration of the radiation beam ensures knowledge of the radiation dose delivered to the patient, supporting overall efforts towards successful radiotherapy. The small size, high sensitivity and linearity of response over a wide range of useful doses are some of the advantages of thermoluminescent dosimeters used for this purpose (Metcalfe et al., 2007; Nelson et al., 2010).

Thermoluminescent dosimeters (TLD) have been used for a long time (Eggermont et al., 1971; Gooden and Brickner, 1972; Hufton, 1984). Due to the high sensitivity of thermoluminescent materials and a possibility of constructing robust detectors of various shapes and sizes, thermoluminescence dosimetry has become a useful tool in radiation oncology, particularly for measurements in regions of high dose gradients (Duch et al., 1998; Venables et al., 2004). Optimization of dose distribution in patients is essential for controlling the risks associated with exposure to radiation (Kron, 1999). A research performed in the United States revealed that about 50% of hospitals and 90% of academic institutions used thermoluminescence for in vivo dosimetry (Kron, 1999).

The most common thermoluminescent material used in radiotherapy is lithium fluoride (LiF), usually in the form of TLD-100 marketed by Harshaw (Olko et al., 2006; Livingstone et al., 2010; Nelson et al., 2010). Another thermoluminescent material, calcium sulfate doped with dysprosium ($CaSO_4$:Dy), has a linear dose response over a wide range from micrograys to grays (Campos and Lima 1987). Due to its high sensitivity, $CaSO_4$:Dy has been used in radiation protection dosimetry for a long time (Campos, 1983; Campos and Lima 1987), and recent studies have evaluated its performance in photon and electron beams used in radiation therapy (Nunes and Campos, 2008; Matsushima, 2010; Bravim et al., 2011). This dosimeter is manufactured and marketed by the Dosimetric Materials Laboratory of the Center of Radiation Metrology at IPEN.

In radiation therapy, dose measurements in tissue-equivalent phantoms are more accurate than measurements in the air (McKeever, 1985). The aim of this study was to evaluate the TL response of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to doses from 15-MV clinical photon beams in a liquid–water phantom.

2. Materials and methods

Before irradiation, 200 $CaSO_4$:Dy TL dosimeters used in this study were heated at 300° C for 3 h in a VULCAN furnace (Model 3-550 PD). Sets of 80 microLiF:Mg,Ti and 160 LiF:Mg,Ti TL dosimeters were preheated at 400° C for 1 h in the same furnace and then at 100° C for 2 h in a FANEN furnace (Model 315-IEA 11200). Three cycles of heat pretreatment, irradiation in air with a ^{60}Co gamma-radiation source (656.4 MBq) under electron-equilibrium conditions and TL reading were carried out. The individual and average TL responses of the dosimeters were measured with a

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Harshaw TL reader (Model QS 3500). Based on the results of these measurements, the dosimeters were sorted in five groups according to their sensitivity.

A Varian Clinac 23EX linear accelerator operating at 15 MV was used. Five dosimeters of approximately identical sensitivity were positioned in water at the depth of 5 cm in a PMMA phantom ($40.0 \times 40.0 \times 40.0\ \text{cm}^3$). The dosimeters were irradiated to doses from 0.1 to 10 Gy. The field size at the water surface was $10 \times 10\ \text{cm}^2$, and the source–surface distance was 100 cm. TL readings were performed 24–32 h after the irradiation. Each value quoted in this paper is the average of measurements of five $CaSO_4$:Dy, LiF:Mg,Ti or microLiF:Mg,Ti dosimeters of the same sensitivity group, and the error bars represent the standard deviations of the mean (1σ). The intrinsic efficiency (IE) is defined as

$$\mathrm{IE} = \frac{A}{m}, \tag{1}$$

where A is the slope of the linear least-squares fit provided by Origin 7.0 and m is the mass of the dosimeter.

3. Results

Fig. 1 shows responses of the dosimeters to doses in liquid water at the depth of 5 cm. The dependences of the responses on dose are linear in the range from 0.1 to 5 Gy. Fig. 2 confirms supralinear deviations at doses beyond 5 Gy. This behavior is similar to what was observed with a 6-MeV electron beam in Solid Water^{TM} and PMMA phantoms (Bravim et al., 2011). The TL sensitivities of $CaSO_4$:Dy dosimeters ranged from 17.41 ± 0.25 to $22.61 \pm 0.06\ \mu\text{C Gy}^{-1}$. In the case of LiF:Mg,Ti, the sensitivity varied from 0.6543 ± 0.0036 to $0.7565 \pm 0.0036\ \mu\text{C Gy}^{-1}$, and in the case of microLiF:Mg,Ti, the range was from 0.0612 ± 0.0009 to $0.0737 \pm 0.0008\ \mu\text{C Gy}^{-1}$.

The intrinsic efficiencies of the $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters in the 15-MV clinical photon beam and the liquid–water phantom were $1.30 \pm 0.13\ \mu\text{C Gy}^{-1}\ \text{mg}^{-1}$, $0.3677 \pm 0.3819\ \mu\text{C Gy}^{-1}\ \text{mg}^{-1}$ and $0.0712 \pm 0.0075\ \mu\text{C Gy}^{-1}\ \text{mg}^{-1}$, respectively. As for the response reproducibility, the relative standard deviations of readings of the replicate dosimeters were found to be within 1.25%, 0.812% and 2.08% for the $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters, respectively.

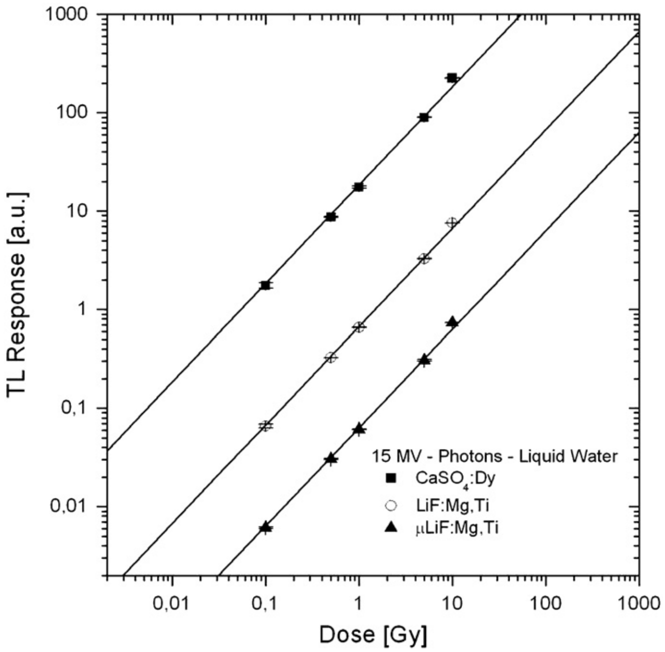

Fig. 1. Dose–response curves for the $CaSO_4$:Dy and LiF:Mg,Ti TL dosimeters.

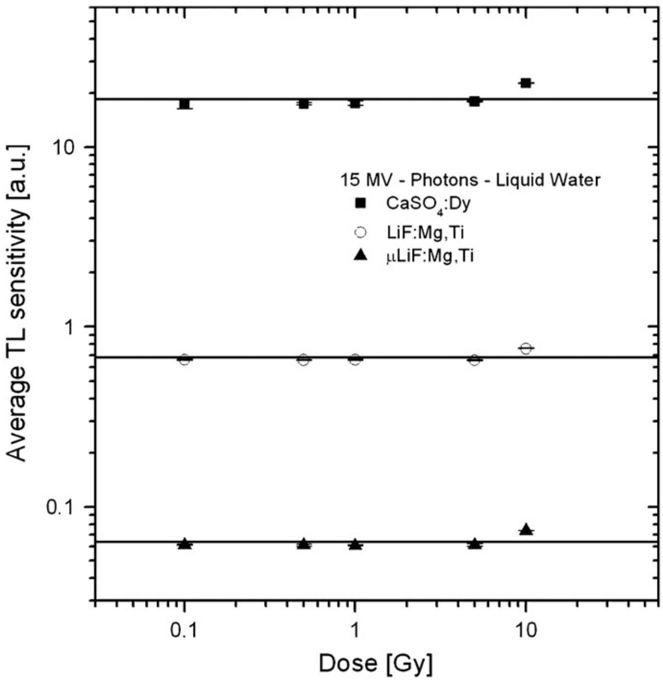

Fig. 2. Average TL sensitivity of the $CaSO_4$:Dy and LiF:Mg,Ti TL dosimeters.

4. Conclusions

The dose-response curves were found to be linear in the photon dose range from 0.1 to 5 Gy. The dependence is supralinear at higher doses. The $CaSO_4$:Dy dosimeters are 26 and 287 times more radiation-sensitive than the LiF:Mg,Ti and microLiF:Mg,Ti dosimeters, respectively. The intrinsic efficiency of $CaSO_4$:Dy is 3 times higher than that of LiF:Mg,Ti and 18 times higher than that of microLiF:Mg,Ti.

As the $CaSO_4$:Dy dosimeters produced by the Instituto de Pesquisas Energéticas e Nucleares/IPEN respond to doses in the same way as LiF:Mg,Ti and microLiF:Mg,Ti, but have higher sensitivity and intrinsic efficiency, they can be a viable alternative in radiotherapy dosimetry.

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