THE RESPONSE OF 2D TL FOILS AFTER DOSES OF Co-60 GAMMA-RAY, 6 MV X-RAY AND 60 MeV PROTON BEAMS APPLIED IN RADIOTHERAPY*

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(Received July 29, 2013)

A Two-dimensional Thermoluminescence Dosimetry (2D TLD) system has been developed at the Institute of Nuclear Physics (IFJ PAN) in Kraków, Poland. The system consists of TLD foils and of a TL reader equipped with a $200 \times 200\,\mathrm{mm}^2$ heater and a CCD camera. The foils contain LiF:Mg,Cu,P powder mixed with ETFE polymer pressed at high temperature. The CCD camera is able to read out 2D images of TL light in real time, and the re-usable foils are flexible, mechanically stable and water-resistant. We have determined the response of our 2D TL foils after doses of Co-60 gamma-ray, 6 MV X-ray and 60 MeV proton radiotherapy beams, over the range between 1 and 30 Gy, as required in clinical dosimetry. In measurements, performed at the German Cancer Research Center (DKFZ), at the Heidelberg Ion-Beam Therapy Center (HIT) and at the IFJ PAN, we compared the dose response of our foils with those of Kodak® EDR2 and Gafchromic® EBT films. We find both the sensitivity (signal per dose) and the characteristic (saturation) dose of our 2D TL foils to be higher than those of the EDR2 and EBT films, for all beam modalities tested.

DOI:10.5506/APhysPolBSupp.6.1021
PACS numbers: 78.60.Kn, 87.57.uq, 87.63.lj, 87.53.Bn

1. Introduction

Several types of radiation (beam modalities) are now being applied in cancer radiotherapy using external beams. The objective of radiotherapy — to deliver the prescribed dose to the tumour volume while sparing the

* Presented at the Symposium on Applied Nuclear Physics and Innovative Technologies, Kraków, Poland, June 3–6, 2013.

neighbouring healthy tissue, remains valid, but the presently available delivery techniques, such as the Intensity Modulated Radiotherapy (IMRT), the Gamma-Knife system or ion beams, now enable much higher dose gradients to be achieved, thus permitting the dose to the tumour volume to be escalated without consequences to the healthy tissues. The most common radiotherapy beam modality are megavolt X-ray beams produced by medical linear accelerators. Co-60 radiotherapy units are simple and reliable, yet the present use of Co-60 gamma-rays is often in gamma-knife units. The highest dose gradients can be achieved by proton and carbon ion radiotherapy beams. In the clinical dosimetry of such beams, for Quality Assurance (QA) purposes, the ability to visualise and verify dose distributions becomes important, hence the increasing use of photographic films, specially prepared for radiotherapy (such as the Kodak® EDR2) or dye-films (such as the Gafchromic® EBT).

At the IFJ PAN, a Two-Dimensional Thermoluminescence Dosimetry (2D TLD) system consisting of TL foils and large-area reader equipped with a CCD camera was developed for 2D dosimetry in radiotherapy [1–3]. The potential advantage of such a TLD system is that the TL foil may be used repeatedly and be calibrated before use.

The typical dose per fraction in external beam radiotherapy is 2 Gy (for a total of 60 Gy in 30 fractions), however, in some cases higher doses are applied per fraction, *e.g.* in proton radiotherapy of *ocular melanoma*, where four fractions of 13.63 Gy (15 CEG) each, are typically delivered. Therefore, we decided to investigate the response of our 2D TL foils after doses of Co-60 gamma-rays, of 6 MV X-rays and of 60 MeV protons applied in ocular radiotherapy, over the range 1–30 Gy, against the dose response of Kodak® EDR2 photographic film and Gafchromic® EBT dye film.

2. Materials and methods

2.1. 2D Thermoluminescence Dosimetry system

TL foils were prepared from a mixture of LiF:Mg,Cu,P (MCP-N) TL phosphor and polyEthyleneTetraFluoroEthylene (ETFE) polymer pressed at high temperature [1]. Foils thus produced are flexible and mechanically stable, water-resistant and reusable. Foils are typically 0.3–0.4 mm thick and are cut to $200 \times 200\,\mathrm{mm}^2$ sheets. After their readout foils are annealed at 245°C for 20 min to remove the remaining TL signal.

Of importance in ion beam dosimetry is the relative water-equivalent range of our TL foils, R_{rel} defined as

$$R_{\mathrm{rel}} = \frac{\Delta r}{d}\,, \tag{1}$$

where Δr is the shift of the Bragg peak position caused by the beam traversing the TL foil of thickness d inserted into the beam [4]. In measurements using 200 MeV protons at the HIT (using the method of Jäkel *et al.* [5]), we found $R_{\rm rel} = 1.644\,(0.051)$, while $R_{\rm rel} = 1.656\,(0.006)$ was obtained from our FLUKA code simulation. Further simulations showed that the measured value can be extrapolated to energies relevant to this work.

Our large-area reader [3] was equipped with a Hamamatsu 1024×1024 pixel camera and $200 \times 200\,\mathrm{mm}^2$ heater. It has been improved, compared to the previous version [3, 6, 7] with respect to heating performance and control systems. The elements of the reader, such as the heater, camera, cooling and save protection systems are now controlled by a FATEK PLC controller and a PC with dedicated FlatView code prepared using National Instruments LabVIEW system design software. Data acquisition controller and image processing have also been implemented in this software. The standard readouts conditions are as follows:

- temperature rate: 0.64°C/s, linear up to temperature target values,
- temperature target: 250°C (inside the heater), $\sim 240\,^\circ$C (detector),
- camera exposure time: 500 s, starting from 60°C.

Following its recent upgrade, the reproducibility of the large-area reader has been improved. For $20 \times 20\,\mathrm{cm}^2$ TL foils the repeatability, tested in 20 measurements was found to be within 2%, which is comparable to that of an earlier prototype laboratory 2D TL reader able to read $5 \times 5\,\mathrm{cm}^2$ TL foils [3].

2.2. Irradiation

Irradiation and the readout were performed at the DKFZ, HIT and IFJ PAN. For irradiation, foils were stacked between phantom slabs. Co-60 gamma-ray irradiations were made in a PMMA phantom at 5.8 mm of Water-Equivalent Depth (WED). Irradiations with 60 MeV proton beam were performed at 13.7 mm of WED also in PMMA phantom, in the plateau region of the Bragg Peak, giving the proton energy at this depth around 35 MeV. 6 MV X-rays irradiations were performed in a RW-3 phantom at 51.3 mm of WED.

3. Results and discussion

3.1. Dose response

The measured dose response of LiF:Mg,Cu,P foils after their irradiation with 6 MV X-rays, Co-60 gamma-rays and 35 MeV proton beam is plotted in Fig. 1. Fitting the experimental curves with the equation

$$f(D) = N\left(1 - \exp\left(-\frac{D}{D_0}\right)\right), \tag{2}$$

where D_0 represents the characteristic dose [2] was not reliable and could be replaced by the low-dose (for data below 15 Gy) approximation in the way of

$$f(D) = \frac{N}{D_0} D \qquad \text{for} \quad D \ll D_0 . \tag{3}$$

N in the equations denotes a normalisation coefficient. Indeed, the dose range of our measurements is quite low with respect to the value of $D_0 =$ 233 Gy [8] or $D_0 = 243 \pm 9$ [9], measured for MCP-N (LiF:Mg,Cu,P) detectors exposed to Cs-137 gamma-rays, therefore, Eq. (3) applies. Values of D_0, determined from our measurements, plotted in Fig. 1 were 256 Gy, 270 Gy and 283 Gy for Co-60, 6 MV X-rays and 35 MeV protons, respectively.

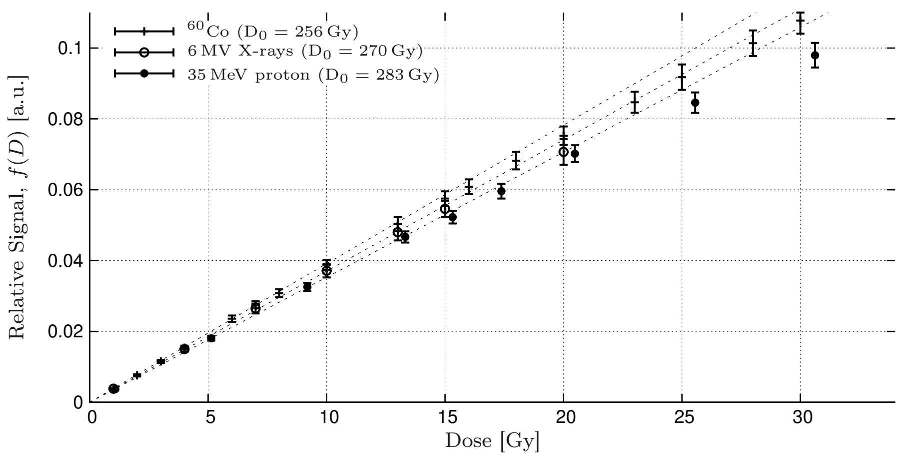

Fig. 1. Relative response of TL foils for different radiation types.

It has been shown earlier [10, 11] that the efficiency (related to *e.g.* Co-60 gamma-rays) of MCP-N TL material significantly depends on radiation type. However, since the saturation dose (or D_0) is much higher than our studied dose range, we expect that such foils can be applied for QA in eye melanoma proton therapy. For the dose of 13.63 Gy (15 CGE) per fraction, typically applied at the IFJ PAN [12], the deviation of the foil response from linearity, over the dose range from 1 to 15 Gy is 2.4% which can be corrected for.

The measured dose response of our TLD foils as well as EDR2 and EBT films is presented in Fig. 2. For EDR2 films, which are now routinely used in clinical dosimetry, the manufacturer recommends that the dose range should not exceed 4.5 Gy and the dose response saturates around 7 Gy. The response of EBT2 films saturates at about 2 Gy [13]. Therefore, the much broader useful dose range of our 2D TL foils makes them more advantageous than photographic or dye films presently used in QA in clinical dosimetry, especially in the case of ocular proton radiotherapy performed at the Bronowice Cyclotron Centre (CCB) of the IFJ PAN in Kraków.

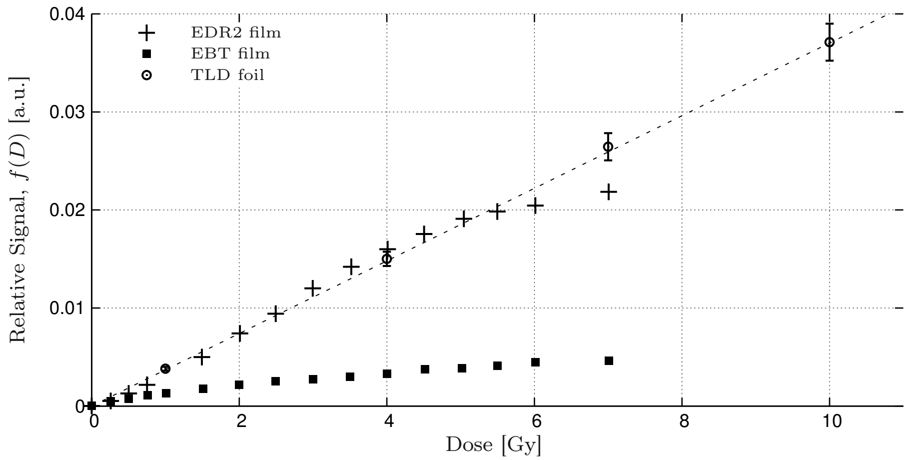

Fig. 2. Response of TLD foils, EDR2 and EBT films [13] relative to 6 MV X-ray doses.

4. Conclusion

The linear dose response of the IFJ PAN-developed 2D thermoluminescence dosimetry system with LiF:Mg,Cu,P foils, which extends to approximately 15 Gy, makes this system a promising tool for QA of radiotherapy units. In several applications, these foils could replace the currently used photochromic EDR2 or EBT films.

We acknowledge support by the Foundation for Polish Science — MPD program, co-financed by the European Union within the European Regional Development Fund.

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