Energy dependence of a TLD-100 system for characterizing low energy brachytherapy sources

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1. Introduction

Accurate measurement of the dose distribution around ^{103}Pd and ^{125}I sources in phantom is complicated by strict requirements for precise dosimeter and source geometry and by spectral variation with distance from the source. The most extensive measurements to characterize these low energy sources, as recommended by the AAPM TG-43 (Nath *et al* 1995), have been performed using lithium fluoride thermoluminescence dosimeters (LiF TLDs) in precisely machined water equivalent phantoms. These phantom materials have been designed to match the radiation characteristics as those of liquid water at low photon energies. However, studies based on the analysis of the mass absorption coefficient and mass scattering coefficients indicate material discrepancies (Wallace *et al* 1998).

In an effort to reduce the complications introduced by the use of water equivalent phantom materials for the characterization of low energy brachytherapy sources, a LiF TLD system (Tailor *et al* 2003) has been developed at the Radiological Physics Center (RPC, Outreach Physics, U.T. - M.D. Anderson Cancer Center, Houston, TX). This system allows measurements of dose distribution around low energy brachytherapy sources to be performed directly in a water filled phantom.

Absorbed dose determination with TLDs generally relies on calibration in ^{60}Co γ-ray reference beams. The energy dependence correction factor, K_E, for low energy photon emitters takes into account the difference between the response of the TLD in the low photon beam and in the ^{60}Co γ-ray beam. In this work, K_E was evaluated for LiF powder mini capsules in photon beams of 20 to 29 keV (Philips RT-50). Monte Carlo N-Particle transport code (MCNP Version 4C, Briesmeister 2000) and Burlin's cavity theory (Attix 1986) were used as a comparison with the corresponding experimental data. This low energy radiation study has provided a better understanding of the system behavior and also a more accurate calibration of LiF TLD mini capsules relative to ^{60}Co γ-rays.

2. Equipment

2.1. LiF TLD System

The detector system consisted of TLD mini capsules held by three acrylic sheets (20 cm x 20 cm x 0.2 cm), Fig. 1 and Fig. 2. TLD mini capsules were constructed using glass capillary tubes (Drummond Scientific Company, Broomall, PA 19008). Fig. 3 shows the capillary tubes which have an inner diameter, outer diameter and length of 0.13 cm, 0.16 cm, and 12.7 cm, respectively.

An 0.8 cm long polystyrene rod (Z = 5.6, ρ = 1.04 g/cm^3, Evergreen Scale Models, Woodinville, WA 98072) of a matching diameter was inserted into the bottom end of the capillary and sealed with epoxy. Especially designed tool was used to pour approximately 11 mg ± 0.1mg (~ 0.7 cm long) of disposable TLD-100 powder (LiF:Mg:Ti, Harshaw/Bicron, Solon Technologies, Inc.). The rest of the capillary tube was filled by an 8 cm long polystyrene rod to compact the TLD-100 powder.

2.2. ^{60}Co γ-ray beam

An "El Dorado 8" ^{60}Co unit has been used to irradiate the TLD-100 samples according to the AAPM TG-51 protocol (Almond *et al* 1999). A total of 40 capsules were irradiated at a depth of 5.0 cm in water. The absolute dose determined with an ion chamber (PTW Model N30001, 0.6 cc Farmer type, serial # 1483) at the irradiation depth was 3.0 Gy.

2.3. Low energy X-rays

The low-energy radiation of low energy brachytherapy sources such as, ^{103}Pd ^{125}I and (average energy of 20.7 keV and 28.7 keV , respectively) was simulated using soft X-rays from a RT 50 – Contact Therapy Apparatus (Philips Orthovoltage X-ray therapy unit). For effective energies between 20 to 29 keV, irradiations were carried out following AAPM TG-61 protocol (Ma *et al* 2001). For each effective energy, a total of 40 capsules were irradiated given a dose of approximately 3.0 Gy.

3. Methods

3.1. Experimental determination of K_E

The K_E factor was defined as the ratio of the corrected TL per unit average dose (determined by an ion chamber) in water for ^{60}Co γ-rays and for the low energy x-ray beams as,

$$K_{E,\,\exp} = \frac{\left(T\,K_L\,K_F\,/\;D_{med}\right)_{Co-60}}{\left(T\,K_L\,K_F\,/\,D_{med}\right)_{x\;rays}} \quad . \qquad (1)$$

In Eq. (1), T was the average TL reading per unit mass (mC/mg) for a single sample measured during TLD readout session; K_L was the dose response linearity correction which basically relates TL response and dose; K_F was the fading correction factor which accounts for the decrease in TL response that occurs during the time delay between irradiation and readout session.

3.2. Cavity theory

Using Burlin cavity theory, the K_E factor was determined as determined as the ratio of the mean absorbed doses in TLD and water for irradiations with ^{60}Co γ-rays and the low energy x ray beams respectively. K_E factor was given as,

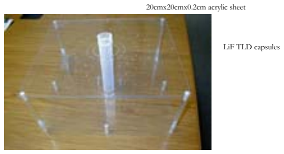

Fig. 1 TLD system setup for anisotropy dosimetry.

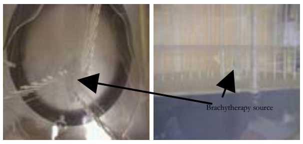

Fig. 2 TLD system setup for the determination of dose rate constant and radial dose function.

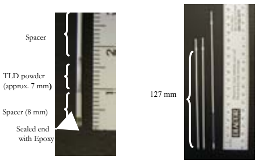

Fig. 3 TLD mini capsules.

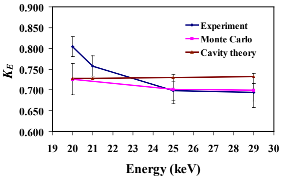

Fig. 4 Energy correction, K_E, factor as a function of energy

$$K_{E,\,cavity\;theory} = \frac{\left(\bar{D}_{cav}\;/\;\bar{D}_{med}\right)_{Co-60}}{\left(\bar{D}_{cav}\;/\;\bar{D}_{med}\right)_{x\;rays}} \quad . \qquad (2)$$

3.3. Monte Carlo Simulations

Using Monte Carlo method, the K_E factor was calculated for a given beam quality as,

$$K_{E,\,MCNP} = \frac{\left(\dot{D}_{LiF}\,/\dot{D}_{H20}\right)_{Co-60}}{\left(\dot{D}_{LiF}\,/\dot{D}_{H20}\right)_{X-rays}} \quad , \qquad (3)$$

where $\dot{D}_{LiF}\,/\dot{D}_{H20}$ is the LiF to water dose rate ratio produced by the two beam qualities. Dose rates were determined in cylindrical TLD mini capsules represented by an inner concentric cylinder of 0.13 cm diameter and 0.7 cm long of LiF powder surrounded by an outer glass cylinder of 0.16 cm diameter (0.015 cm wall thickness) by 0.7 cm long. The MCNP F6 tally, a track length estimate of energy deposition was used to score the MeV/g per of each photon entering the tally cell (detecting volume).

4. Results

Table 1 and Fig. 4 show a summary of the K_E results obtained by cavity theory, experimental measurements and Monte Carlo simulations.

***E* (keV)**	**$K_{E,\,cavity\;theory}$**	**$K_{E,\,experiment}$**	**$K_{E,\,MCNP}$**
20	**0.728**	**0.804 ± 0.034**	**0.724 ± 0.038**
25	**0.730**	**0.698 ± 0.031**	**0.701 ± 0.035**
29	**0.732**	**0.694 ± 0.029**	**0.699 ± 0.041**

Table1 Estimated energy correction factors from cavity theory and different irradiation conditions.

For all irradiations, the average TL response per unit mass (μC/mg) was within ± 2.0 % (1σ) indicating a high level of consistency.

5. Discussion

The K_E factor of a newly introduced TLD-100 system was determined on average within less than 5% discrepancy between experiment, theoretical and computational procedures. The Monte Carlo simulation shows that the total dose contribution due to the photon interactions in the glass encapsulation material (~0.02 cm wall thickness) was negligible (0.6 % at glass/TLD interface and 0.4 % to at the center of the TLD material). The code was also used to determine the effect of low energy photons (as the ones produced by low energy brachytherapy source encapsulation material) on the total dose scored by the TLD. An ^{125}I poly-energetic spectrum was simulated. The results were compared with those from an ^{125}I mono-energetic photon beam. An increase of 0.09 % in total dose was found.

6. References

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