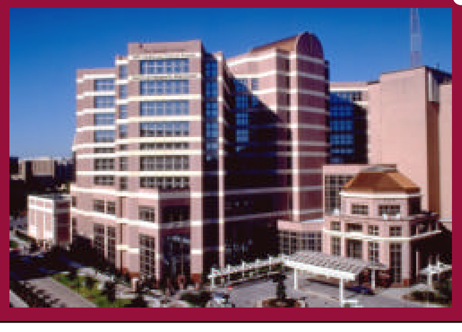

"Energy dependence of a TLD system for characterizing low energy brachytherapy sources"

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1. Introduction

Low-energy brachytherapy sources, such as ^{125}I and ^{103}Pd, are being used with increasing frequency for interstitial implants in tumor sites such as prostate. Due to their low-energy photon emissions (effective energy 29.7 keV and 21.6 keV, respectively), the radiation will predominantly interact via photoelectric interaction, delivering the required radiation in a localized area and hence reducing unnecessary exposure to surrounding normal tissue.

The most extensive measurements to evaluate dose distribution around low-energy brachytherapy sources have been performed using LiF thermoluminescence dosimetry systems, which consist of Solid Water™ phantoms and LiF TLDs. However, the use of LiF TLD system for the dosimetry of low-energy brachytherapy sources has its limitations. The use of Solid Water™ requires the determination of build up correction factors to provide a correction for total dose rate between solid water and liquid water materials in the geometry of the phantom.

In an effort to reduce the complications introduced by the use of Solid Water™ as a phantom material for the characterization of low-energy brachytherapy seeds a new LiF TLD system has been developed at the Radiological Physics Center (RPC). This new LiF TLD system will allow measurements for the determination of dose distribution around low-energy brachytherapy sources to be performed directly in water.

It is well known that direct measurement of LiF TLD response to low-energy radiation must be performed with caution since LiF TL materials exhibit significant energy dependence. In this work, the energy correction factor, K_E, of the system has been determined as the ratio of the corrected thermoluminescence (TL) response over dose for low-energy photons relative to ^{60}Co γ rays.

2. Methods and Materials

The determination of the energy dependence factor, K_E, is performed using two different methods. The first method uses TL response measurements, and in the second one, Burlin's cavity theory is implemented.

2.1. Experimental determination of K_E

The absorbed dose, D, in LiF is calculated from the TL signal measured by the reader as,

$$D = T\,S\,K_L\,K_F\,K_E, \qquad (1)$$

where, T is the TL reading per unit mass for a single sample; S is the system calibration factor; K_L is the dose response linearity correction; K_F is the fading correction; and K_E is the energy correction factor (Kirby et al). The system calibration factor, S, is defined as the inverse of the TL response of the TLD system per unit dose under standard irradiation (^{60}Co beam) conditions.

$$S = \frac{D_{Co-60}}{\left(T\,K_L\,K_F\right)_{Co-60}}. \qquad (2)$$

The energy dependence correction factor, K_E, is normalized to unity for ^{60}Co, so it is not included in Eq. (2). Substitution of Eq.(2) into Eq.(1), yields the following expression for the energy correction factor,

$$K_E = \frac{\left(T\,K_L\,K_F\,/\,D_{LiF}\right)_{Co-60}}{\left(T\,K_L\,K_F\,/\,D_{LiF}\right)_{X-rays}} \qquad (3)$$

2.2. Cavity theory

For an ordinary calibration procedure with ^{60}Co beam, measurements are taken by introducing the TL material into water and irradiated to a fixed exposure. The dose given to TL material, D_{LiF}, can be determined as (Attix),

$$\bar{D}_{LiF} = \left(d\,\bar{S}_w^{LiF} + (1-d)\left(\frac{\overline{\mu_{en}}}{\rho}\right)_w^{LiF}\right) x \left(\frac{\overline{\mu_{en}}}{\rho}\right)_{air}^{w}, \qquad (4)$$

where $\bar{S}_w^{LiF}$ and $\left(\frac{\overline{\mu_{en}}}{\rho}\right)_w^{LiF}$ are the mean ratio mass collision stopping power and the mass energy absorption coefficients of LiF, water and air at the energy of ^{60}Co. For the dosimeters used in this work, *d*, a parameter related to the attenuation of electrons entering the cavity and build up of electrons inside the cavity, was determined to be 0.21.

For the irradiation with low energy X-rays the dosimeters measurements area taken in air. At low energy, *d* happens to be 0.001, so the cavity is large compared with the average range of secondary electrons. The absorbed dose to LiF is,

$$\bar{D}_{LiF} = \left(\frac{\overline{\mu_{en}}}{\rho}\right)_{air}^{LiF} x\, D_{air}. \qquad (5)$$

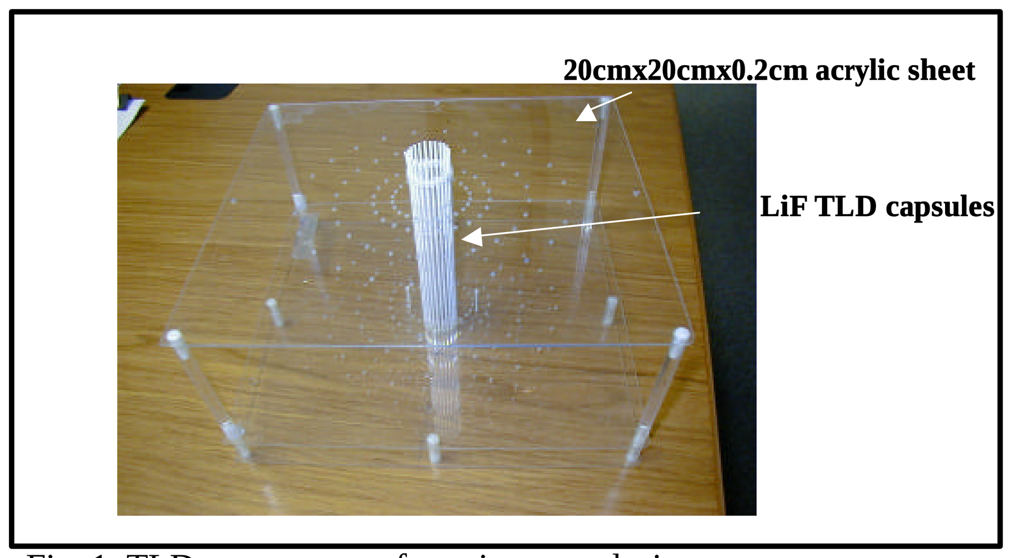

Fig. 1 TLD system setup for anisotropy dosimetry.

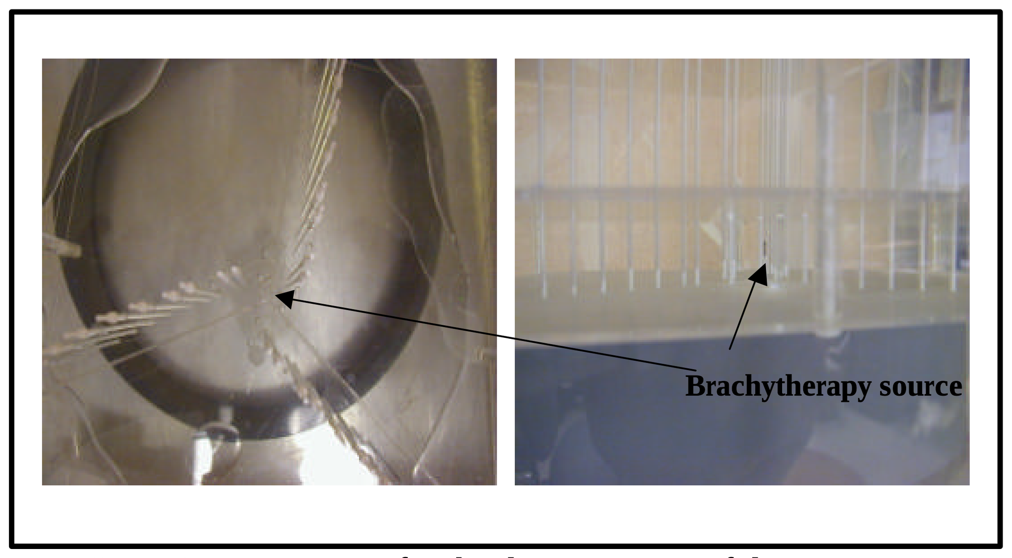

Fig. 2 TLD system setup for the determination of dose rate constant and radial dose function.

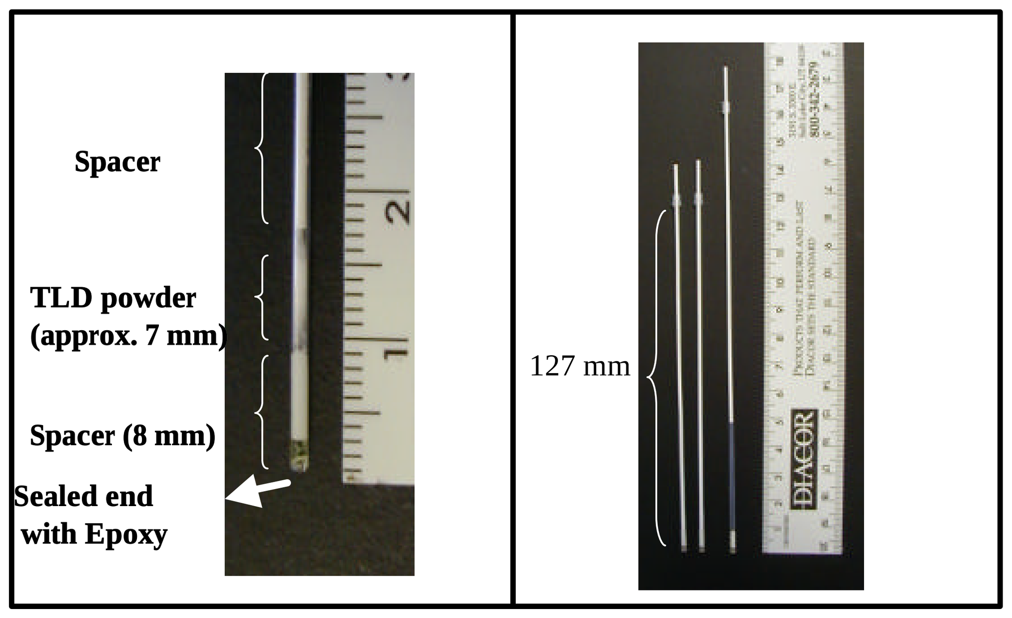

Fig. 3 TLD capsules.

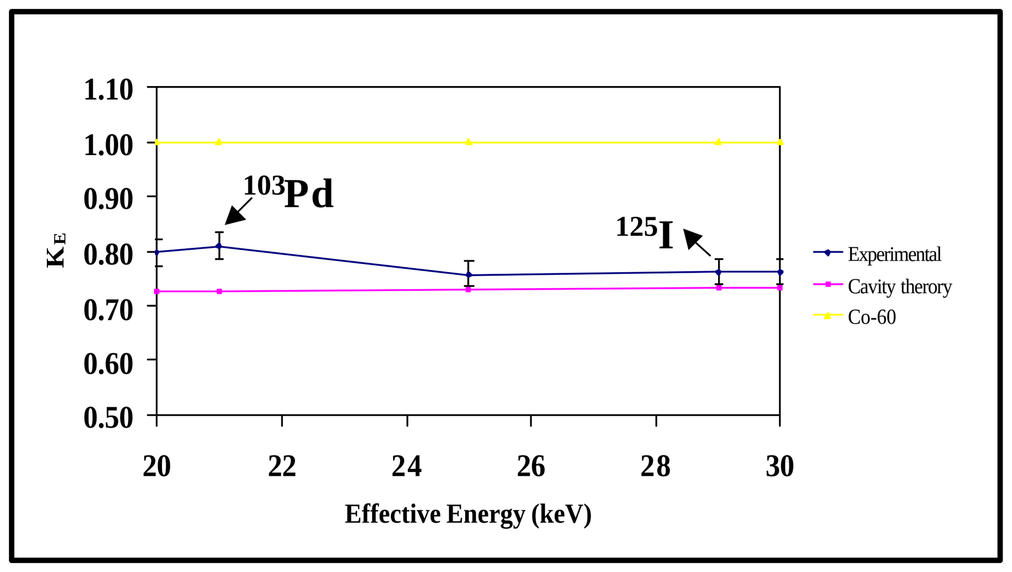

Fig. 4 Energy correction, K_E, factor as a function of energy

3. Experimental procedure

3.1. LiF TLD System

The detector system consists of N51-A capsules hold by three main acrylic sheets (20 cm x 20 cm x 0.2 cm), Figure 1 and Figure 2. The N51-A capsules are constructed using glass tubing, inner diameter of 1.4 mm, outer diameter of 1.8 mm, length of 127 mm, Figure 3.

The capsules are filled with TLD-100 (LiF:Mg, Ti) disposable powder from Harshaw Chemical Company. The dimensions of the TLD-100 powder are approximately 1.4 mm diameter and 6.0 mm length.

3.2. ^{60}Co g irradiation

An "El Dorado 8" ^{60}Co unit has been used to irradiate the LiF TLD samples according to the AAPM TG-51 protocol (Almond et al). A total of fifty capsules were irradiated at a depth of 5.0 cm. The absolute dose determined with an ion chamber at the irradiation depth was 3.0 Gy.

3.3. X-ray irradiation

The low-energy radiation of low energy brachytherapy sources such as, ^{125}I and ^{103}Pd (average energy of 28.7 keV and 20.7 keV, respectively) was simulated using soft X-rays from a RT 50 – Contact Therapy Apparatus (Philips Orthovoltage X-ray therapy unit), Figure 6. For effective energies between 20 keV-30 keV, irradiations were carried out in air following AAPM TG-61 protocol (Ma et al.). For each effective energy, a total of 50 capsules were irradiated given a dose of approximately 3.0 Gy.

4. Results

Table 1 and Figure 7 show, for given operation conditions, the values for the energy correction factor, K_E, estimated from cavity theory and from measurements for the dosimeters irradiated at low energies (20 to 30 keV).

kV	mm Al	E_{eff} (keV)	K_E, cavity theory	K_E, measured
50	0.67	20	0.728	0.80 ± 0.02
50	0.80	21	0.728	0.81 ± 0.03
50	1.10	25	0.730	0.76 ± 0.03
50	1.80	29	0.732	0.76 ± 0.03

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

5. Discussion

The measured values of K_E (approximately 0.78 ± 0.02) are more comparable to the values determined using cavity theory for the effective energies of 25 keV and 29 keV. When minimum filtration was used, low energy photons may have been attenuated by the dosimeter's encapsulation material. When more filtration was added, the low energy portion of the spectrum is filtered out and the values for K_E obtained by the two methods are compatible.

6. References

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