Responses of LiF Thermoluminescence Dosimeters to Diagnostic ^{60}Co Teletherapy Beams

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ABSTRACT

Thermoluminescence Dosimeter (TLD) is used as an ionizing radiation detector in the field of clinical radiotherapy, diagnostic radiology, personal radiation monitoring as well as in environmental radiation dosimetry. The sensitivity of all the TLDs is not the same even though the manufacturer produced them in the same batch. The response of TLD at various doses is also not always linear. In the present study fifty-seven rod shaped LiF TLDs had been irradiated by doses of 50cGy, 100cGy, 150cGy and 200cGy using ^{60}Co teletherapy unit of Dhaka Medical College (Alcyon II, CGR, McV, France). The TLDs were placed in the grooves of a slab phantom and then covered by a 0.5cm thick plexiglass sheet. The phantom was then irradiated in the reference condition (10×10cm^2 field size, 80cm SSD). After irradiation, readout of TLDs was done using a Harshaw TLD reader (Model 3500). Measurements were performed three times for each dose value and their average was taken. For convenience all fifty-seven TLDs were divided into nineteen groups. Grouping was done according to the response of the TLDs for a fixed dose value. In a particular group of TLDs, variation of the response of the dosimeters is the smallest one. The dose (cGy) – response (nC) linearity curve of TLDs for each of the nineteen groups showed to be very close to unity.

Keywords: LiF, Thermoluminescence Dosimeter, ^{60}Co Teletherapy Beam, Slab Phantom

INTRODUCTION

A thermoluminescence dosimeter (TLD) is an inorganic crystal, when exposed to ionizing radiation, emits light in the form of prompt luminescence. The process is illustrated in Figure 1. In this process electrons are released from the valence band to the conduction band by the incident radiation but are then captured at one of the trapping centers. If the distance of the trap energy level below the conduction band is sufficiently large, there is only a small probability per unit time at ordinary room temperature that the electron will escape from the trap by being thermally excited back to the conduction band.

On the other hand, holes can also be trapped in an analogous process. An original hole created by the incident radiation migrate through the crystal until reaching a hole trap with energy somewhat above the top of the valence band. If this energy difference is large enough, the hole will not migrate further and is locked in a place unless additional thermal energy is given to the crystal. The TLD material is, therefore, a function of an integrating detector in which the number of trapped electrons and holes is a measure of the number of electron-hole pairs formed by the ionizing radiation.

After irradiation, the TLDs are placed on a heating device, where temperature is raised progressively. At a temperature that determined by the energy level of the trap or above, the trapped electron can pick up thermal energy, so that they are re-excited back to the conduction band. If the temperature is lower than that required for freeing the trapped holes, the liberated electrons then migrate to the near-trapped hole, where they recombine with the emission of a photon. Alternatively, if the holes are released at a lower temperature, they will migrate to a trapped electron and their recombination also results in an irradiated photon.

The phenomenon of thermoluminescence has been known for years but first discovered by Herman and Hofstadter (Herman and Hofstadter, 1940). TL dating of archaeological and geological samples has been carried out routinely in a number of laboratories (Malik et al., 1973, Aitken, 1975). This phenomenon has been studied by Sir Robert Boyle and Henri Becquerel (Oberhofer and Scharmann, 1981). During the period 1965-1983 several international conferences were devoted to use the thermoluminescence to ionizing radiation detector in the field of clinical radiotherapy, diagnostic radiology and personal radiation monitoring as well as environmental radiation dosimetry.

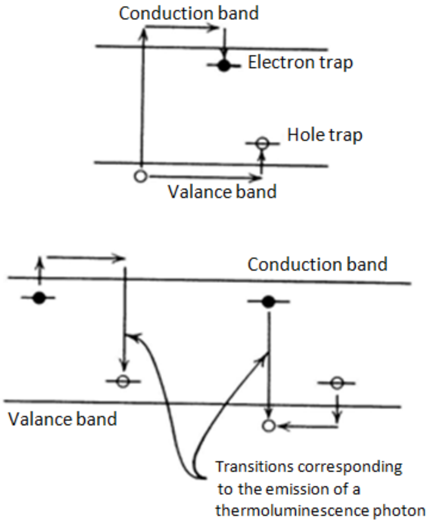


Figure 1: Simplified mechanism of thermoluminescence process

A thermoluminescence dosimeter (TLD) should possess many features such as (a) it should have a small size and should be tissue equivalent, which is useful for a variety of applications in medicine (Yigal and Horowitz, 1984), (b) it should be sensitive to a large range of exposure such as from a low of about 2×10^{-5} rads (0.2μGy) to a high dose of 10^5 rads (10^3Gy) with a good linearity (Knoll, 1989), (c) it should be independent of the environmental agents like humidity, pressure and most laboratory fumes etc., (d) it should be usable many times by annealing with a minimum change of efficiency, and (e) it should have a precision better than 3% for doses in the most important range from 1mGy to 10 Gy (Horowitz, 1984).

In clinical radiation therapy a high radiation dose is delivered to the patients undergoing radiotherapy treatment. In order to optimize radiation protection during the treatment of patients under radiotherapy treatment, TLD is the most versatile dosimetry tools. In this consideration, TLD technique is the most important technique in radiation oncology (Horowitz and Moscovitch, 2013, Olko, 2010).

The sensitivity of all the TLDs is not same even though the manufacturer produced them in the same batch. So it is important to measure the sensitivity of the individual TLD. The response of TLD at various doses is also not always linear. In this regard it is also important to measure the linearity of TLD response at various doses (Attix, 1969, Horowitz, 1984, Massillon-JL et al., 2011, Yigal and Horowitz, 1984).

METHODS AND MATERIALS

TL dosimeters (TLD-100) of diameter 1mm and length 6mm were used for this study. The TLD-100 is made of LiF crystal containing the natural isotope of lithium (7.41% ^{6}Li + 92.6% ^{7}Li) doped with magnesium and titanium (Attix, 1969). Fifty-seven rod shaped TLDs had been used to study their linear response in Co-60 beam energy. The previous irradiation and thermal history can affect the response of the TLD material (Sibony et al., 2014). For these reasons the dosimeter must be annealed (described in detail later) to remove residual effects.

TLD Reader

Reading of the TLD is strongly dependent on the design of TLD readout instrument. In the present study, Harshaw manual TLD reader system (Model 3500) has been used. It economically provides both high performance and high reliability that complies with the latest International Standardization Organization requirement (User's Manual, 1993).

The TLD reader can read one dosimeter per loading with a variety of TL configuration. It can also give readout of TLD powder. The reader consists of two main parts: (i) The TLD Reader Unit and (ii) PC Unit with Software as shown in Figure 2.

Figure 2: Harshaw TLD reader 3500 system

TLD Annealing

To optimize the trap distribution in TL material, it is needed to empty the previously filled high temperature traps before irradiation of TLDs. In the present study, TLDO PTW annealing oven, which is controlled by a programmable microprocessor, has been used. It is specially developed for thermoluminescence dosimetry. Reproducible heating procedures for thermoluminescent dosimeters are essential to maintain constant sensitivity and low background reading. This oven has two different programs. In program-1 the duration of the annealing time is four hours, which heats at 400°C for two hours followed by heating at 100°C for two hours. In program-2 the duration of the annealing time is half an hour, which heats at 100°C for ten minutes and then gradually reduces the temperature to the room temperature. Program-1 is used for annealing of TLDs before irradiation and program-2 is used for preheating after irradiation. TLD annealing oven contains a programmed heating element which produce temperature controlled hot air stream. Figure 3 shows the TLDO PTW annealing oven.

Figure 3: TLDO PTW annealing oven (closed & opened)

Slab Phantom

It is not possible to measure the dose distribution directly in the patient treated under radiation therapy. Data on dose distribution is derived from measurements taken in phantoms made of tissue equivalent materials. Usually the phantom is large enough in volume to provide full scatter for the given beam. These basic data obtained from a phantom are used in dose calculation to predict dose distribution in actual patient. In the present study, a slab phantom was used for calibrating the TLDs.

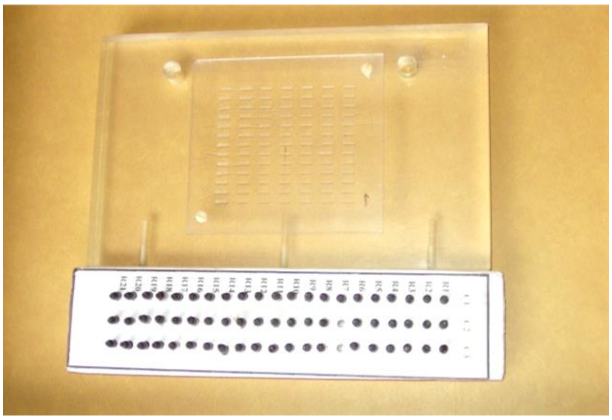


Figure 4: Slab Phantom with TLD Holders

The slab phantom is made of Poly Methyl Methacrylate (PMMA), also known as acrylic or acrylic glass or by the trade names Plexiglass, Acrylite, Lucite, and Perspex. It is a transparent thermoplastic ($C_5H_8O_2$; $\rho = 1.18 g/cm^3$) sheet, a tissue equivalent material, shown in Figure 4. Its dimensions are: length 25cm, thickness 15cm and height 2cm. Cylindrical Grooves (1mm × 1mm × 6mm) were made in the phantom in order to place the rod-shaped TLDs on the central surface of the sheet, which is covered by another 0.5cm thick plexiglass sheet.

Preparation of the TLDs for Calibration

Procedure for the measurement and Dose evaluation using TL dosimeter is a four-step application cycle as described below:

I. Pre-irradiation Annealing of the TL Dosimeters

For annealing the TLDs before irradiation, fifty-seven rod shaped TLDs were placed on two different heating trays into the oven. Each stainless steel tray has 50 circular grooves. The rod TLDs were identified by their arrangements within the grooves. The annealing of the TLDs were carried out by Program-1 of the TLD annealing oven, which heats the TLDs at 400°C for two hours and then at 100°C for two hours. The TLDs were then stored at the room temperature. The thermal treatments of the TLDs were done for the complete bleaching of the previous dose information and re-generation of the specific defect in the crystal.

II. Irradiation of the TL Dosimeters

During irradiation, TLDs were placed in the rod shaped grooves of a slab phantom. The slab phantom was then covered by a 0.5cm thick plexiglass slab, so that the position of the TLDs were at 0.5cm depth from the surface of the phantom i.e., at D_{max} position for ^{60}Co gamma beams. The dosimeters were then irradiated by ^{60}Co gamma ray beam of field size $10 \times 10 cm^2$ at 80cm SSD (Source to the Surface Distance). On receiving the dose from the ionizing beam, the electrons of the crystals (LiF) were trapped in the hole of the crystal. Previously the D_{max} rate of ^{60}Co unit was measured by using secondary standard ion chamber.

III. Post-irradiation Annealing of the TL Dosimeters

The post irradiation annealing of TLDs has been done in order to free the lower trap electrons before readout. Annealing of TLDs was performed at 100°C for 10 minutes using program-2 of the TLD annealing oven. This is, therefore, utilized to minimize the variation of changes in the glow curve due to fading.

IV. Readout of the TL Dosimeters

The dose received by the irradiated TL dosimeters was then measured by a Harshaw TLD reader (Model-3500). For this measurement the TLDs were placed on the planchet (a place with a drawer in the TLD reader unit) of the reader, which is made of stainless steel with a close contact thermocouple. The system is operated with PC installed software TLD Shell Program. The heating and cooling rate of the planchet is controlled by TTP (Time-Temperature Profile). For readout of the TLD, the TLD shell program is maintained by the TTP file, which is given as below:

1. Preheat temperature: 50°C, 0 Sec
2. Acquiring rate of temperature: 10°C/sec
3. Maximum temperature: 260°C
4. Measurement time: 26sec
5. Annealing temperature: 260°C, 0 sec
6. High voltage of Photomultiplier Tube: 824volt

The glow curve is obtained during the readout of the TL dosimeter which results from the charge (nC) collected by the Photomultiplier tube. The measured charge is directly proportional to the absorbed dose. For the determination of charge, which is obtained from the glow curve, software TLD Shell Program version 25282.004 was used. Auto saving of the glow curve was recorded for each dosimeter. The whole TLD reader system requires 15 minutes to warm-up before using it.

For checking the reproducibility of the dosimeters TLDs have been irradiated three times by the same dose and the corresponding charge (nC) was recorded for glow curve of each dosimeter in each time. Sensitivity of each dosimeter has also been measured for four different doses 50cGy, 100cGy, 150cGy and 200cGy. After each of the readouts of irradiated TLDs, the dosimeters were placed in an aluminum tray instead of the stainless steel tray having grooves of the same size of the TLDs. The grooves of the tray were numbered, following the TLD number and the sequence was also maintained for all times. Attention was taken to make sure that the tray was always in the same position inside the oven. After annealing of all the TLDs, dosimeters were withdrawn from the oven. Before irradiation of the TLDs a minimum time of 30min was allowed for the dosimeter to be in thermal equilibrium with its surroundings.

During the readout of the TL-dosimeter, care was taken so that TLDs were placed on the same position of the planchet and the planchet drawer should open and close slowly.

Dose Dependence Calibration Factor

The purpose of TLD calibration is to ensure the consistency and accuracy of TLD reading to a desirable limit. In the present study, all fifty-seven TLDs have been irradiated in a field size $10\times10\text{cm}^2$ at 80cm source to surface distance (SSD) for the doses 50cGy, 100cGy, 150cGy and 200cGy using ^{60}Co gamma ray beam. For every dose value, this process was repeated three times to check the reproducibility of the response of TLDs. Also different values of dose were used to check the uniformity of the response of the TLDs.

The Element Correction Coefficient (ECC_i) of each individual dosimeter was determined with the help of the following formula

$$ECC_i = \frac{\langle TLE \rangle}{TLE} \tag{1}$$

$$\langle TLE \rangle = \frac{1}{m}\sum_{i=1}^{i=m} TLE_i \tag{2}$$

where, $\langle TLE \rangle$ is the average TL efficiency of all the dosimeters for a fixed dose and TLE_i is the TL efficiency of *i*th dosimeter (i = 1, 2, 3, …………, m).

On the other hand, the TLD response (TLR) is proportional to the TLD efficiency (TLE) as,

$$TLR = K \times TLE \tag{3}$$

where, K is the proportionality constant. Hence equation 1 and 2 can be written in the form of

$$ECC_i = \frac{\langle TLR \rangle}{TLR} \tag{4}$$

$$and \quad \langle TLR \rangle = \frac{1}{m}\sum_{i=1}^{i=m} TLR_i \tag{5}$$

Average *ECC* for individual TL dosimeter was obtained by averaging the *ECC* values for each dose.

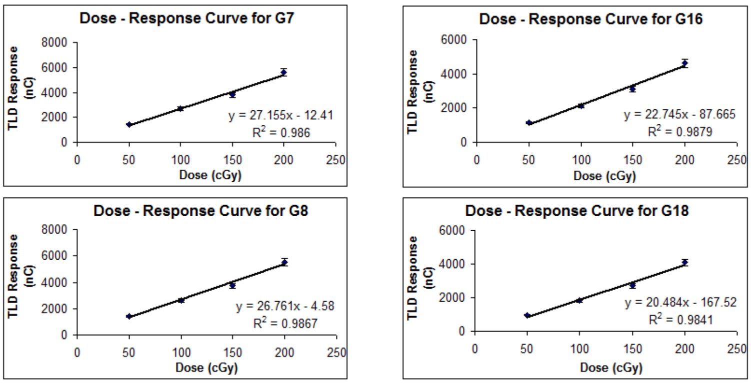
RESULTS AND OBSERVATIONS

Table 1 shows the response (nC) of each group of TLDs at various doses. Figure 5 shows a few representative of the dose-response linearity graph of the corresponding TLD group. Table 2 shows the curve parameters, i.e., the linear curve equation and correlation coefficient for each. These show that a good correlation exists in between the response and the corresponding doses for each of the TLD groups, which is equal to or 0.98 or more. This indicates that the dose – response linearity of TLDs is very close to unity.

Table 1: Response of each group of TLDs at various doses

Group No	**Response of TLDs (nC) for various doses**			
	50cGy	**100cGy**	**150cGy**	**200cGy**
G1	1669.00 ± 30.72	3058.33 ± 118.88	4359.83 ± 111.76	6534.33 ± 208.09
G2	1607.17 ± 22.51	2927.17 ± 127.24	4157.00 ± 72.01	6163.33 ± 212.82
G3	1547.83 ± 27.91	2839.67 ± 125.49	4062.00 ± 78.98	6097.67 ± 203.62
G4	1496.00 ± 46.37	2761.67 ± 134.29	3930.00 ± 129.67	5902.33 ± 229.37
G5	1475.33 ± 32.05	2715.00 ± 105.89	3894.17 ± 58.56	5817.00 ± 193.02
G6	1455.00 ± 48.09	2687.67 ± 119.66	3870.17 ± 166.27	5753.17 ± 257.09
G7	1457.17 ± 22.16	2676.17 ± 110.60	3779.33 ± 86.20	5615.33 ± 113.42
G8	1442.50 ± 14.99	2642.67 ± 94.67	3740.33 ± 65.13	5536.83 ± 193.93
G9	1501.00 ± 81.58	2713.67 ± 164.63	3826.50 ± 230.04	5687.17 ± 324.18
G10	1425.83 ± 46.56	2590.50 ± 87.29	3661.00 ± 52.03	5477.00 ± 150.93
G11	1411.83 ± 62.40	2607.67 ± 134.02	3736.50 ± 105.13	5571.67 ± 232.12
G12	1364.33 ± 17.15	2559.50 ± 132.70	3515.00 ±92.36	5215.50 ± 227.54
G13	1342.17 ± 42.41	2478.83 ± 97.16	3477.50 ± 61.83	5159.17 ± 168.86
G14	1298.67 ± 45.17	2396.17 ± 98.17	3396.17 ± 85.19	5078.83 ± 161.94

G15	1296.00 ± 30.02	2357.33 ± 119.56	3310.33 ± 65.27	4962.17 ± 182.11
G16	1144.17 ± 21.74	2151.33 ± 83.05	3111.50 ± 51.74	4615.00 ± 158.01
G17	1005.40 ± 51.53	1849.67 ± 109.14	2838.50 ± 76.85	4347.83 ± 152.65
G18	971.90 ± 52.42	1809.50 ± 107.31	2702.00 ± 58.51	4088.33 ± 185.48
G19	897.23 ± 44.33	1679.67 ± 76.67	2501.50 ± 144.12	4017.17 ± 115.90



Dose - Response Curve for G7

Dose - Response Curve for G16

Dose - Response Curve for G8

Dose - Response Curve for G18

Figure 5: A few representative sample of the dose-response linearity graph of the corresponding TLD group.

Table 2: Dose – response curve analysis

Group No	Curve equation	R^2
G1	y = 31.80 x – 69	0.98
G2	y = 29.79 x – 10.91	0.99
G3	y = 29.74 x – 81.17	0.98
G4	y = 28.78 x – 74.33	0.98
G5	y = 28.41 x – 75.67	0.99
G6	y = 28.15 x – 77.75	0.99
G7	y = 27.16 x – 12.41	0.99
G8	y = 26.76 x – 4.58	0.99
G9	y = 27.34 x- 14.25	0.99
G10	y = 26.45 x – 17.42	0.98

Group No	Curve equation	R^2
G11	y = 27.22 x – 70.17	0.99
G12	y = 25.02 x – 36.33	0.99
G13	y = 24.90 x – 2.00	0.99
G14	y = 24.68 x – 42.66	0.99
G15	y = 23.90 x – 6.42	0.98
G16	y = 22.75 x – 87.67	0.99
G17	y = 22.03 x – 243.68	0.98
G18	y = 20.48 x – 167.52	0.98
G19	y = 20.36 x – 271. 52	0.97

DISCUSSION

Lithium Fluoride is the most common type of thermoluminescence phosphor used in recent times, having the atomic number $Z_{eff} = 8.2$ which is considered approximately as an air or tissue equivalent (Knoll, 1989) material. LiF is also energy independent from about 100 keV to 1.3 MeV. These kind of dosimeters respond quantitatively to X-rays, gamma rays, electron and photons over a wide range that extends from about 100μGy to 10Gy (Knoll, 1989). For this reason LiF is widely used for the measurement of doses in clinical practices. Dose to a patient, in vivo, is also measurable when the treatment is carried out with 6 MV or 10 MV photons from a Linear Accelerator. The dose at maximum depth is used to irradiate the TLDs in such beams.

In the present study, the group average Element Correction Coefficients (*ECC)* for each group of TLD was taken. This value has been used for the correction of the response for each group of the TLD. The percentage deviation of element correction coefficient (ECC) for each group of the TLD varies from 0.05% to 2.26%.

The calibration factor (CF) of each group of TLD is obtained by dividing the response of the TLD by its corresponding dose. These data can be used to calculate the actual dose from the corrected measured response of the used TLDs for further study of the dosimetry in clinical radiotherapy dose measurement.

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REFERENCES

Aitken, M. J. (1975) *Physics and Archeology,* London, Oxford University Press.

Attix, F. H. (1969) Isotopic Effect in Lithium Fluoride Thermoluminescence Dosimeters. *Phys Med Biol,* 14**,** 147-148.

Herman, R. C. & Hofstadter, R. (1940) Observations on the Dark Current of a Willemite Crystal. *Phys. Rev.,* 57**,** 936.

Horowitz, Y. (1984) Thermoluminescence and Thermoluminescent Dosimetry. *CRC Press, Inc. Boca Raton, Florida,* 1.

Horowitz, Y. S. & Moscovitch, M. (2013) Highlights and pitfalls of 20 years of application of computerised glow curve analysis to thermoluminescence research and dosimetry. *Radiation Protection Dosimetry,* 153**,** 1-22.

Knoll, F. G. (1989) *Radiation Detection and Measurement*, John Wiley & Sons Publisher, USA.

Little, M. P., Vathaire, F., Charles, M. W., Hawkins, M. M. & Muirhead, C. R. (1997) Variations with Time and Age in the Relative Risks of Solid Cancer Incidence after Radiation Exposure. *J Radiol Protec,* 17**,** 159.

Malik, S. R., Durrani, S. A. & Fremlin, J. H. (1973) A comparative study of the spatial distribution of Uranium and of TL-producing minerals in archaeological materials. *Archaeometry,* 15**,** 249-253.

Massillon-JL, G., Ãvila, O. & Brandan, M. E. (2011) Supralinear response of LiF: Mg, Ti (TLD-100) after exposure to 100 keV average energy X-rays. *Radiation Measurements,* 46**,** 1357-1360.

Oberhofer, M. & Scharmann, A. (1981) *Applied Thermoluminescence Dosimetry,* Adam Hilger Ltd, Bristol.

Olko, P. (2010) Advantages and disadvantages of luminescence dosimetry. *Radiation Measurements,* 45**,** 506-511.

Sibony, D., Horowitz, Y. & Oster, L. (2014) The effect of sample/planchet geometry and temperature resolution on the reproducibility of glow curve shapes and precision of dose measurement in LiF-TLD-100 thermoluminescent dosimetry. *Radiation Measurements*.

User's manual (1993) *User's Manual, Model 3500 Manual TLD Reader, Harshaw Bicron Radiation Measurement Products, Publication No. 3500-0-U-0793-005 1.*

Yigal, S. & Horowitz, Y. (1984) Thermoluminescence and Thermoluminescent Dosimetry. *Inc. Boca Raton, Florida,* 3.

Zimmerman, D. W., Rhyner, C. R. & Cameron, J. (1966) Thermal Annealing Effects on Thermoluminescence of LiF. *Health Physics,* 12**,** 525.