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STUDY OF THE RESPONSE AND CALIBRATION PROCEDURES OF LiF:Mg,Ti TLD-100 FOR THE DOSIMETRY OF PHOTON BEAM

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ABSTRACT

To guarantee quality assurance and quality control of the received radiation dose and treatment level, Thermoluminescent Dosimeter (TLD) is frequently employed in personal control and monitoring equipment. TLDs are commonly used to ensure the precise delivery of radiation doses to patients in clinical radiotherapy, diagnostic radiology, personal radiation monitoring, and environmental radiation dosimetry. Even though the manufacturer made all the TLDs in the same batch, their sensitivity varies. This study aims to examine the TLD crystal calibration process, in particular, the crystal sensitivity and linearity of individual TLDs following exposure to radiation at various dosage levels for precise dosimetric radiotherapy purposes. Herein, a batch of twenty (20) LiF:Mg,Ti dosimeters was used for calibration in the air for low dose levels and in tissue equivalent water phantom for high dose. In this method, dosimetry of 20 sets of TLDs was carried out in the air on the skin of Alderson rando phantom and was exposed by ^{137}Cs source to 1 mSv, 2 mSv, 3 mSv, 4 mSv, 5 mSv, 10 mSv, and 20 mSv dose. Again, TLDs were irradiated to ^{60}Co beams following the reference dosimetry for 50 cGy, 100 cGy, 150 cGy, and 200 cGy at reference depth (5 cm) of a water phantom. The uncertainty of the variation of crystal sensitivity of our TLDs is 0.21%. The dose – response linearity of TLDs in both cases showed to be very close to unity having uncertainty within the recommended limit. This finding supports the clinical practice of measuring precise dosages of radiation using TLDs and essential to guarantee the correct delivery of the dose to the patient.

Keywords: *Thermoluminescent Dosimeter (TLD), Dose-response, Dosimetry, Crystal Sensitivity, Calibration, Radiotherapy*

1. INTRODUCTION

Thermoluminescence Dosimeter (TLD), a passive radiation dosimeter, measures the amount of ionizing radiation exposure by sensing the visible light that is released when a sensitive detector crystal is heated. It detects ionizing radiation in ambient radiation dosimetry, personal radiation monitoring, diagnostic radiology, and clinical radiotherapy [1]. Thermoluminescence dosimeters (TLDs) are extensively employed in clinical applications for the purpose of measuring radiation doses due to their physical and dosimetric properties. One such characteristic is the requirement for TLDs to possess (a) small size and be tissue equivalent. This size enables the acquisition of high-resolution point dose measurements on both phantoms and patients [2], (b) it should have strong linearity and be sensitive to a wide range of exposures, such as from a low of roughly 0.2 Gy to a high of 103 Gy [3], (c) it should be unaffected by external factors such as pressure, humidity, most laboratory fumes, etc., (d) by annealing it, it ought to retain its usability with little change in efficiency [4]. The patients receiving radiotherapy are exposed to a high radiation dosage in clinical radiation therapy. TLD is one of the most flexible dosimetry technologies available for maximizing radiation protection while treating patients receiving radiotherapy. Taking all of this into account, the TLD technique stands out as the most significant method used in radiation oncology [5], [6].

Most modern thermoluminescence phosphors are made from lithium fluoride, which has an atomic number $Z_{eff} = 8.2$ and is thus roughly an air or tissue equivalent material [3]. LiF:Mg,Cu,P and LiF:Mg,Ti are examples of TLDs used for distinct purposes. LiF:Mg,Ti TLD is excellent for radiotherapy due to its great sensitivity, small size, and tissue equivalency [7]. There are many variables that can affect the thermoluminescence (TL) response of LiF:Mg,Ti, such as high temperature, pre-irradiation annealing, cooling rate, low temperature annealing, heating rate during readout, and maximum readout temperature [1] . Specifically, TLD-100 dosimeters, based on lithium fluoride doped with magnesium and titanium (LiF:Mg, Ti), have minimal signal fading (5–10% per year) and great radiation sensitivity, making them appropriate for dosage verification in radiation therapy (RT) beams [8]–[11]. Additionally, TLD-100 is commonly used to assess dose distribution due to its wide linear response range (10 μGy–10 Gy)[11]–[14]. Amols et al. reported that the permissible inaccuracy of radiation treatment applications is 3–5%, whereas 22% of reported dosage levels had a 10% error [4]. Therefore, appropriate calibration and application of TLD can reduce these uncertainties to tolerable levels[1]. In 2013, Banaee et al. examined the dose response of the tested TLDs by subjecting them to doses of 50 cGy, 100 cGy, and 200 cGy. They discovered that the dose-response varies depending on the dose level. Before usage, TLDs must be calibrated [15]. The fundamental advantage of TLDs is that they may be measured without an electrometer. TLD dosimetry has been the preferred clinical approach for over 30 years for these reasons. A wide literature describes the physical properties and clinical use of TLDs in conventional radiation therapy[16]–[18]. Despite the same batch, TLDs have different sensitivity. Therefore, determining each TLD's sensitivity is crucial. TLD does not always respond linearly to different doses. The linearity of the TLD response at different doses must be measured in this context [4], [19]. The current study's objective was to examine the dose response linearity of TLDs using the IAEA calibration formalism in tissue equivalent water phantoms for high dose levels and the air for low dose levels[20], [21].

2. MATERIALS AND METHODS

The dose response linearity of TLDs investigated in two different ways. Initially, they are calibrated in air for low dose levels. In this method, dosimetry of 20 TLDs were carried out in the air on the skin of Alderson rando phantom (Phantom Laboratory, Salem, New York) and was exposed by a known ^{137}Cs source to 1 mSv, 2 mSv, 3 mSv, 4 mSv, 5 mSv, 10 mSv, and 20 mSv doses. Reference dosimetry was done by using an ionization Chamber (NE 2575, volume 600 cc) at a refence condition (SSD: 100 cm) and at a height of 30.5 cm. Later, TLDs have been calibrated in tissue equivalent water phantom (300 × 300 × 300 mm, wall thickness is 15mm) at reference depth (5cm) and are irradiated by a known gamma source ^{60}Co teletherapy unit (Best Theratronics, Ottawa, Ontario, Canada). In this case, reference dosimetry was done in IAEA water phantom using IBA FC65-G Farmer chamber (0.65 cm^3) in the reference condition (field size: 10 × 10 cm^2, SSD: 100 cm, Chamber at depth: 5 cm). The experimental measurements were performed by using LiF: Mg, Ti thermoluminescence dosimeters (MTS-100, Mirion technology, Germany). These chips are of size 4.5 mm in diameter and 0.9 mm. TLDs were read out by a RE-2000 TLD Reader (RE-2000, Mirion technology, Germany).

Both the dosimeter and reader are often calibrated to preserve the high-quality performance of a TLD system [22] . TLD calibration consists of four steps[23]:

2.1. Zero dose calibration

The objective of the zero-dose calibration is to measure and document the baseline radiation level of both the material and the reader. Zero dose varies by material, crystal, preparation, use, and total dose they received. For zero dose calibration, all dosimeters in cassette were inserted in the reader and annealed twice at 300^0C for 15 seconds to remove thermoluminescence. Zero dose calibration readout all TLD

2.2. Reader Sensitivity calibration

Different crystal materials and crystals have different reader sensitivity, and even the same crystal material might have different reader sensitivity. In an Alderson Rando phantom, all TLDs were irradiated by a known ^{137}Cs source for a calculated time (2.2 min exposure to 2mSv beam, etc.). Grouped three TLD and irradiated. TLDs were pre-heated in the RE-2000 at 150^0C for 10 seconds to clear fading peaks for reader sensitivity. Read the TLDs sensitivity with glow curves.

2.3. Crystal sensitivity calibration

This compares the radiation sensitivity of dosimeter crystals to calibration crystals of the same material. It is the ratio of the mean count value for a batch of crystals irradiated in the irradiator after subtracting the zero dose to a batch of calibration crystals. Followed by the above reader sensitivity calibration procedures TLDs were irradiated and performed the crystal sensitivity calibration.

(a) **(b)**

Fig. 1: (a) RE-2000 TLD reader with WinTLD system at SSDL, AERE, Bangladesh, (b) Irradiation of TLDs in water phantom by ^{60}Co teletherapy beam.

2.4. TLD irradiation and standard dose calibration

This is calibration factor relates a dose given by the local irradiator to standard dose values. Twenty TLD in three groups (G1, G2, G3) were irradiated by ^{137}Cs to 1 mSv, 2 mSv, 3 mSv, 4 mSv, 5 mSv, 10 mSv, and 20 mSv for low dose calibration. For high doses, they were calibrated in tissue equivalent water phantom. Twenty TLDs in two groups (G1, G2) were set in a plastic plate hole, wrapped in latex to make it waterproof, and placed in a water phantom at 5 cm reference depth. Finally, TLDs were irradiated by ^{60}Co beam to 50 cGy, 100 cGy , 150 cGy and 200 cGy doses following the standard dosimetry (0.41 min for 50 cGy and so on). TLDs were pre-heated by RE-2000 at 150^{0}C for 10 seconds to eliminate TL components in both cases. Standard dose calibration glow curve readout. The calibration factor for individual crystals of every TLD with respect to the standard dose was calculated for each dose level by the following formula.

$$\text{Calibration factor} = \frac{\text{Standard dose}}{\text{TLD dose of specific crystal}}$$

3. RESULTS AND DISCUSSIONS

The aim of the zero-dose calibration is to record the zero-dose level of the material. It is recorded after annealing. Figure 2 shows the variation of zero dose level of twenty sets of TLDs. Our results show that the doses are close to zero. The average zero dose of 20 TLD crystals are 0.010296 ± 0.001442.

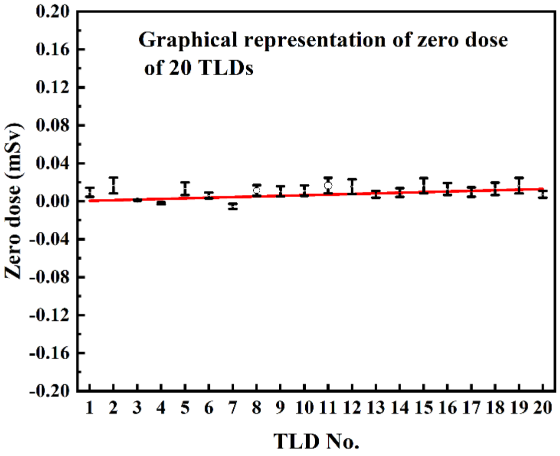


Fig. 2: Graphical representation of zero dose of each TLD-100

Figure 3 shows the variation of crystal sensitivity of TLDs at 2 mSv exposures by the ^{137}Cs source in the same manner as the calibration process in the air. The average crystal sensitivities of TLDs are 1.0215 ± 0. 032232. The uncertainty of the variation of crystal sensitivity of our TLDs is 0.21%.

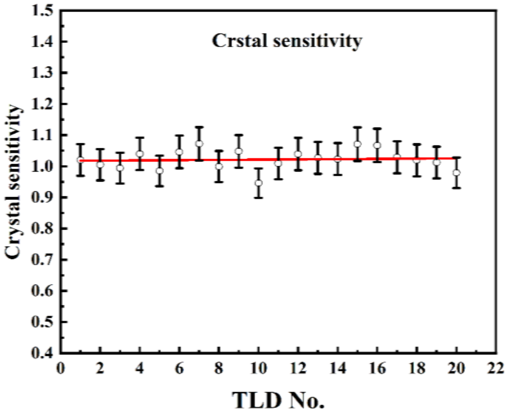
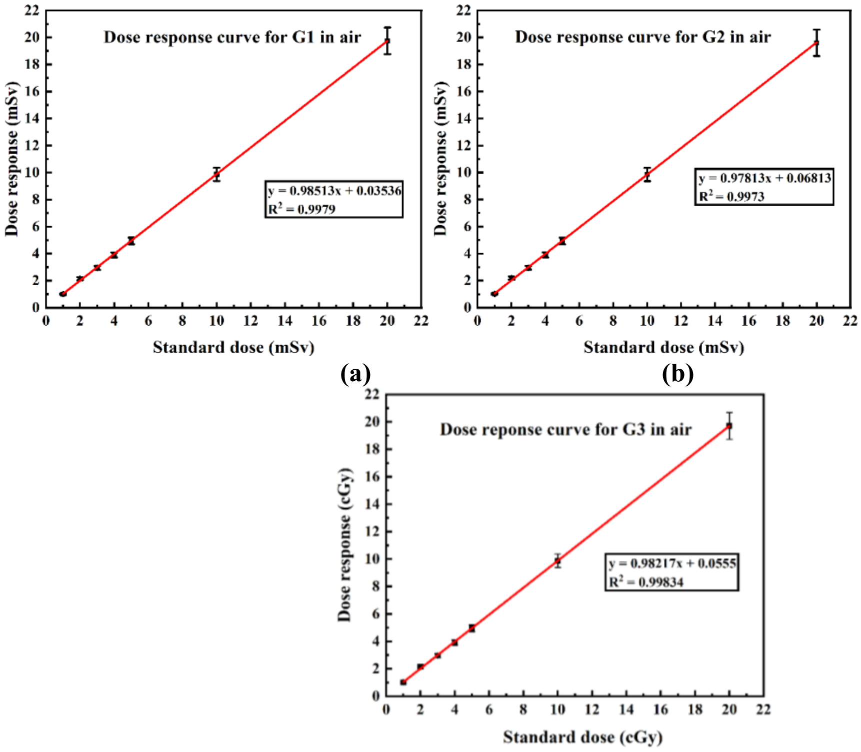


Fig. 3: Variation of crystal sensitivity of each TLD-100



(a) **(b)**

(c)

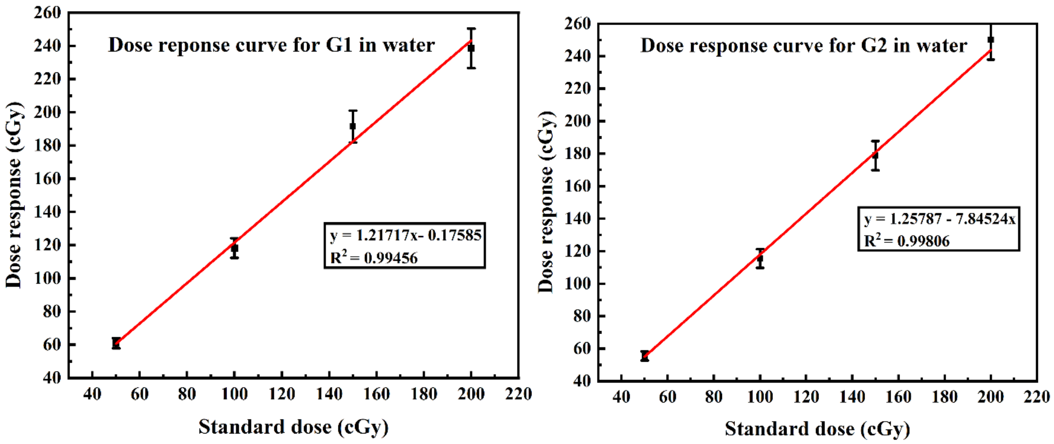
Fig. 4: Dose response linearity graph of each TLD group, exposed by ^{137}Cs in air.

Figure 4’s represents the dose-response linearity graph of the corresponding three TLD group (G1, G2, G3) when irradiated to 1 mSv, 2 mSv, 3 mSv, 4 mSv, 5 mSv, 10 mSv, and 20 mSv doses by a known ^{137}Cs source. These show that a good correlation exists in between the response and the corresponding doses for each of the TLD groups indicates that the dose – response linearity of TLDs is very close to unity. The uncertainty of dose response varies from 0.41% to 4.25% which are within the recommended limit 3-5%[24].

Again, Figure 5 shows the dose-response linearity graph of the corresponding two TLD group (G1, G2) when irradiated to 50 cGy, 100 cGy, 150 cGy and 200 cGy by a ^{60}Co teletherapy beam in water. The dose-response linearity is very close to unity having an uncertainty of 3.67% and 2.84% within the acceptable limit [25]. In both cases, TLDs showed the linear response.

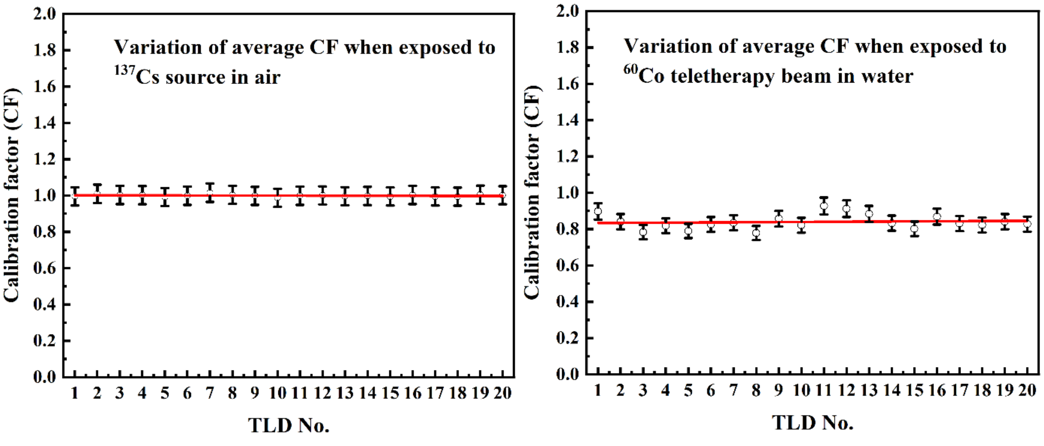
In order to measure the ionizing radiation, it is essential to calculate calibration factor of TLDs at different gamma dose levels. TLD calibration factors are calculated using standard dose and received dose of individual crystals. Figure 5’s represents variation of average calibration factors of TLD-100 in two different cases.

From figures 4, 5 and 6 it was found that, TLDs showed a good linear response as a function of dose in all cases. In low dose level, TLDs response dose were not much deviated from the standard dose. The average calibration factor is very close to 1 and the uncertainty varies from 0.45% to 1.03%. In high dose levels, TLDs response was significantly overestimated from standard dose. The average calibration factor also significantly varies lower to 1. In this case the uncertainty varies from 0.56% to 3.00041% [1], [2], [15], [19], [22], [24].



(a) **(b)**

Fig. 5: Dose response linearity graph of each TLD group, exposed by ^{60}Co in water.



(a) (b)

Fig. 6: Variation of average calibration factors of each TLD, exposed by ^{137}Cs and ^{60}Co.

4. LIMITATIONS

TLDs exhibit varying responses to different types of radiation (such as X-rays, gamma rays, and beta particles) as well as to photon energy. This study is constrained by the use of fixed photon energies from ^{137}Cs and ^{60}Co beams. The calibration curve is developed for a specific type of radiation and applying it to other radiation types without appropriate correction factors could lead to inaccurate results

5. CONCLUSIONS

In the field of radiation, thermoluminescence dosimeters have become standard equipment for verifying dose. However, TLDs must be calibrated with the radiation beams in use before they can be incorporated into the quality assurance methodology [25]. This investigation involved the characterization and calibration of twenty sets of TLDs-100. The TLDs were subjected to irradiate by low dose levels in air and high dose levels in a tissue equivalent water phantom. The findings demonstrated a clear linear correlation between the thermoluminescence response and the administered dose. This paper presents a comprehensive analysis of TLDs-100, so establishing their suitability for implementation in contemporary radiotherapy facilities utilizing photon beams. The precise determination of optimal dose and the calibration of thermoluminescence dosimeters (TLD) are crucial factors that significantly impact the performance of TLDs and the accuracy of absorbed dose measurements, especially in the context of high doses of photon beams.

6. FUTURE WORKS

Future studies should focus on including various types of radiation and photon energies, using X-rays or LINAC. Additionally, the same calculations should be performed using Monte Carlo simulations to improve prediction accuracy and measurement reliability.

AUTHOR'S STATEMENT

This submission complies with ethical guidelines and all authors contributed to this manuscript.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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