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Thermoluminescence Responses of TLD–100 Subject to Low Dose Irradiation

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ABSTRACT

The increasing use of radiation especially low radiation in everyday life demands an evaluation of the performance of dosimeter in the respective environment. The present work is concerned with the investigation of the thermoluminescence (TL) response of TLD-100 in a low radiation dose environment. Ten Harshaw TLD-100s were collected from Health Physics Division, Atomic Energy Centre, Dhaka, Bangladesh and irradiated at different low dose radiation such as 46.82μGy, 93.82μGy, 140.73μGy, 187.54μGy and 234.1μGy with ^{90}Sr/^{90}Y Irradiator and read-out by Harshaw 4500 TLD Manual Reader. Following the reading, detection limit, linearity, variation of standard deviation, and coefficient of variation were investigated. After that, the same TLDs were irradiated at a dose of 140.46μGy and fading test was incorporated for 7 days. TLD-100 upon low dose irradiation showed a good linear response (Coefficient of Determination, $R^2 \sim 1$) as well as a lower detection limit (D_L). The value of D_L has been found 40μGy. Standard deviation and coefficient of variation form a decreasing pattern with increasing low radiation. For a very short time period like 7 days, TLDs showed an irregular response. These investigations help conclude that TLD-100 can be used for low dose environments with proper calibration and correction factor calculation.

Keywords: Ionizing Radiation, Thermoluminescence, Dose-Response, Limit of Detection.

1. Introduction

The widespread use of ionizing radiation in the medical sector, national security system, smoke detector, food irradiation, and in the industrial field enhance the possibility of getting exposed by occupational individuals which leads to various health hazards among them. To maintain proper radiation protection in these fields, individual monitoring system attracts the attention of researchers to develop proper dosimeters to monitor the workers. This will help in maintaining the dose limit within the recommended value. Personal dosimeters are worn by workers when they are exposed to radiation to make sure that the reference limit is not exceeded. Although extremely accurate active radiation detectors are now available, TLDs are small, inexpensive, and if the correct material is chosen, also tissue equivalent. They can be used to detect photons, beta particles, and slow neutrons, and with appropriate filters, can be used to determine shallow and deep doses. Their prime advantage is long-term deploy-ability, possible due to a power source being unnecessary until readout.When ionization chamber measurements are impractical for in vivo dosimetry, it can be replaced by TLD. For being small, it can be inserted into an anthropomorphic or water phantom for dosimetry. Also they can be used to measure point doses with greater precision in volume as their active volume can be made very small as compared to ionization chamber [1]. TLD-100 is the most common dosimeter, used almost everywhere in radiation monitoring. It has become popular because of several properties, such as tissue equivalence, relative low fading and the possibility to manufacture the material with acceptable reproducibility [2-4].In order to optimize radiation protection in clinical radiation treatment, TLD is the most versatile dosimetry tools. In this consideration, TLD technique is the most important technique in radiation oncology [5,6]. To be confident that the radiation level does not exceed the defined level, one must ensure first that the dosimeter can detect the low dose as much as possible. If the detectors are not well calibrated and cannot detect small ranges of dose, then radiation monitoring will not be accurate. Many researchers worked on the different characteristics of TLD [7-15]. All the researches were in the mGy range i.e. limited to high radiation dose. In addition to high doses of radiation, a very low dose of radiation usually in the μGy range is used in clinical and diagnostic centres as well as in industrial sites for manufacturing steels and sterilizing foods. So, the detection of low doses with high accuracy and precision is foremost needed [16]. So performance and characteristics of TLD-100 should be studied to be assured about the detection & measurement. The objectives of the present work, hereby, are to detect the detection limits of the dosimeters, study the most important property, linearity, in terms of dose, investigate whether the standard deviation decrease with increasing low dose and observe the fading of detectors for low dose in a short time period. In short, our goal is to investigate the TL behaviour of TLD-100, under a low dose environment so it can be assured that TLD-100 is eligible for low dose detection. Later on this paper materials and methodology of this study are described followed by results and discussion and conclusion.

2. Materials and Methods

In this study, ten LiF:Mg,Ti, commercially known as TLD-100, were irradiated in BICRON 90Sr/90Y Irradiator (Model 2210), shown in Fig. 1, with five different doses of 46.82μGy, 93.82μGy, 140.73μGy, 187.54μGy and 234.1μGy in ten consecutive cycles. Then the dosimeters were read-out using HarshawModel-4500 TLD Manual

Reader. Every reading was followed by another reading for background dose measurement. Before starting every different dose of irradiation, TLDs were annealed at the same reader. For fading test, ten dosimeters were used. Before irradiation, they were annealed using the reader and then irradiated at a dose of 140.46µGy. After that, they were stored in the tight opaque box at room temperature of 24 °C. Readings were taken at the following post-irradiation time: 19 hrs, 42 hrs, 71 hrs, 93 hrs and 164 hrs[17, 18].

Fig. 1. Irradiation of TLD-100s in Two Groups

Table 1. Time Temperature Profile of TLD-100 [18]

PREHEAT	
Temp. (°C)	50
Time (sec)	0
ACQUISITION	
Max. Temp. (°C)	300
Time (sec)	13.33
Rate (°C/sec)	25
ANNEAL	
Temp. (°C)	300
Time (sec)	5

Although oven baking annealing is not possible for card type TLDs, pre-reading was incorporated to move out the defects. At first, the TLD-100s were annealed using a reader at 300°C for 5 seconds. After irradiation, reading was taken in the reader with a 10minutes time gap between exposure to radiation and reading. The Time Temperature Profile (TTP) of TLD-100 material, shown in Table 1, is set on the Reader.

3. Results and Discussion

3.1 Lower Detection Limit

The lower limit of detection is defined as the lowest dose that can be detected with an acceptable confidence level [19], which is defined as 3 times the standard deviation of the reading at zero doses, is expressed in units of absorbed dose. Detection thresholds for the TLDs were calculated from the following expression:

$$D_{Limit} = 3\sigma_{BKG} \times \Phi_{Calibration} \quad (1)$$

where σ_{BKG} is the standard deviation at zero doses and $\Phi_{Calibration}$is the calibration factor for determinated dose.

The calculated average detection limit was 40µGy. But a closer look suggests that a more accurate average detection limit will be 30µGy as 70% of the sample showed a detection limit near 30µGy. Ben-Shachar B., 1996, found minimum measurable dose for TLD-100 was 16.4µGy from the relative standard deviation vs Dose graph where the relative standard deviation was 20% [12].

3.2 Linearity

The most expecting property of a dosimeter is its linearity. In the case of the dosimeter, it requires that the measured dose (µSv) will be changing according to the given dose (µGy). Fig. 2 shows the linearity of TLD-100 used in the present study. All the TLD-100s showed good linear behaviour in terms of different doses. The coefficient of Determination (R^2)

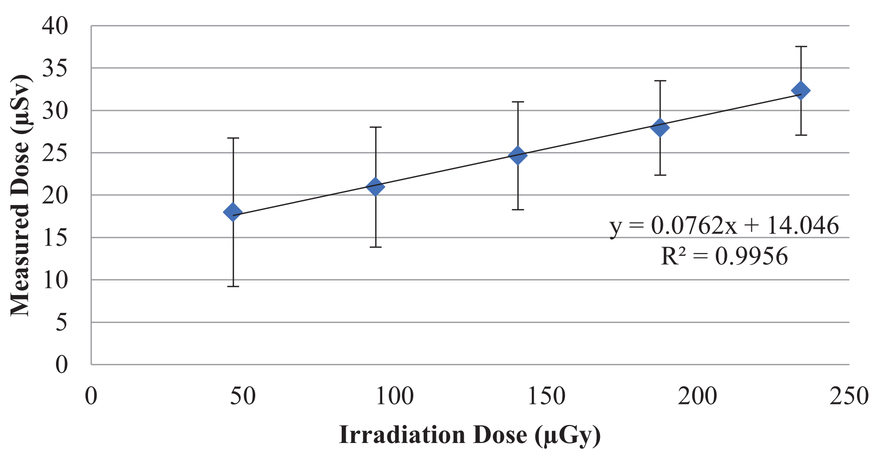

Fig. 2. Linearity of TLD-100 as a Function of Dose

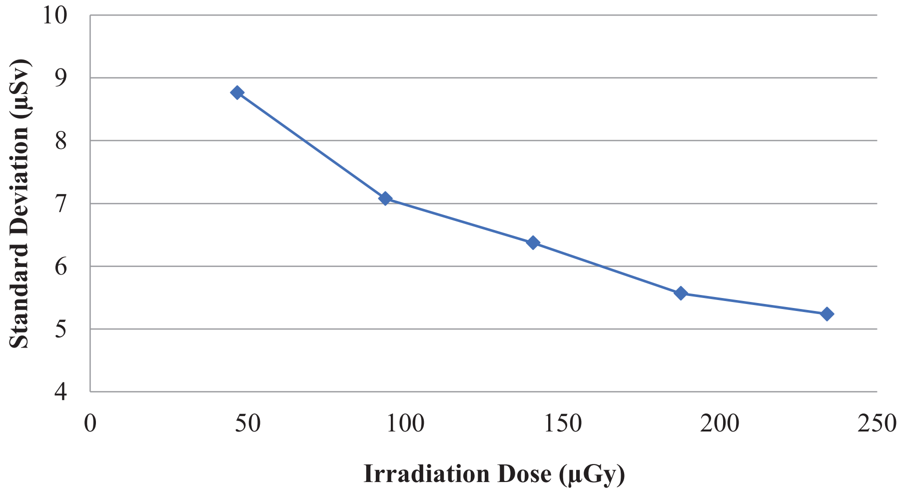

Fig. 3. Variation of Standard Deviation of TLD-100 with Irradiation Dose

ranges between 0.91-0.99. The average Coefficient of Determination also has a value of 0.99. The more this value goes near to 1 the more the linearity approaches. According to Sabar B. et al., below 0.3 mGy, the standard deviation was very high around 40% [14]. But in this case, the standard deviation did not exceed 26% even at the lowest dose. On the contrary, non-linearity was reported by some authors [10, 20, 21] also observed linearity for dose in the mGy ranges where TLD crystals were irradiated with X-ray.

3.3 Standard Deviation & Coefficient of Variation

Fig.3 depicts the change in the standard deviation of TLD-100 with irradiation dose. As the irradiated dose increases, the standard deviation of TLDs decreases. Although in some cases it is noticed that standard deviation increases, only for one TLD, the overall effect has shown a lowering behaviour. In the lowest dose, 46.82μGy, the largest standard deviation was found below 12 μSv. And during the irradiation with 234.1μGy, the standard deviation was around 4 μSv. Ben-Shachar B. etal., 1996 found a standard deviation of (0.3-1.5) % for the dose range (0.075-1.1) mGy were(0.075-1.1) mGy where TLD cards contained three chips of crystal [12]. But in that case, the standard deviation was higher with two chips in the card. The greater observation indicated that the decrease of standard deviation was not that linear. A standard deviation was of 10% in an extremely low dose of about 1μGy was found by Delgado A. et al., although the material was different [11].

The dependency of the Coefficient of variation (CV) on the irradiation dose is shown in Fig. 4. Average CV decreases with increasing dose from 46.82μGyto 234.1μGy. From the value of the Coefficient of Determination, it can be concluded that changing behaviour is almost linear. A coefficient of variation of less than 2% was found by Savva A., for 4380μGy and Fernandez D. et al., calculated CV which was about 4% although named it as repeatability [13,10].

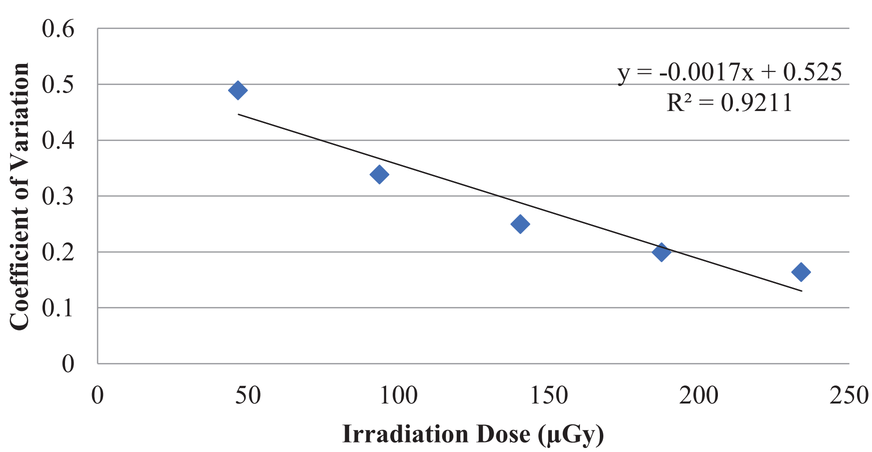

Fig. 4. Change in Coefficient of Variation with Different Dose for TLD-100

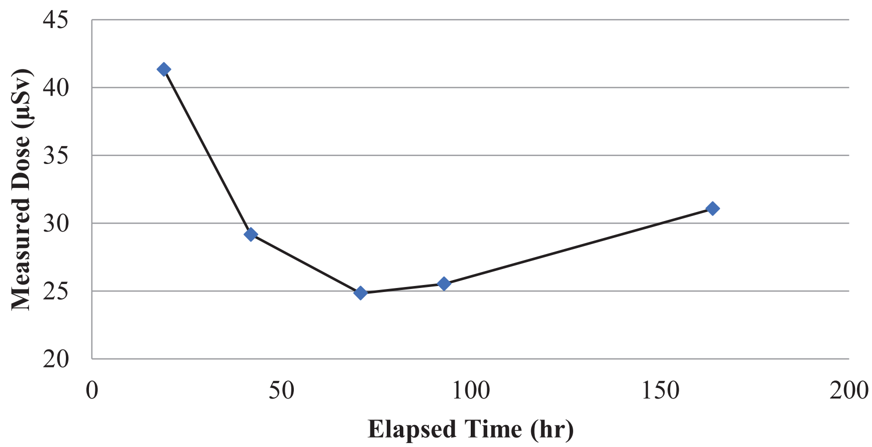

Fig. 5. Fading of TLD-100 from 19 hours to 7 days (164 hours) after Irradiation

3.4 Fading

Fading depends on several parameters such as storage temperature, time, radiation type and annealing procedure. Fading of dosimeters as a function of time was studied in the present work. Fig. 5 demonstrates the fading of TLD 100 within 164 hours after irradiation. From the graphical representation, it can be summarized that TLD-100 shows an irregular response with no fading at all. The fading test was conducted over a week which is a very short time period. Low fading is always expected although over a long time around 3 months, here 1week observation occurred and shows no fading. Other cases where a larger dose was used over a longer period showed very slow fading [10]. As seen from the Figure, the last two points indicate an increasing dose level. So TLDs at first take time to reach in its maximum value then it starts to decrease. With these values, TLDs showed 25% fading over 7 days although in the last time interval it shows increasing behaviour. The irregular increasing and decreasing behaviours can be explained by the number of defects and traps inside the crystal.

4. Conclusion

The thermoluminescence responses of TLD-100s used in the present study, were satisfactory in terms of accuracy and precision since the average standard deviation was 2.19µSv. Littledeviation in the measurement of the lower detection limit was observed. Although the average lower detection limit was found 40µGy, the calculated lower detection limit was 30µGy for 70% of the TLDs. As oven baking was not possible for these card type TLDs, preheating is a must before reuse. For studying the fading characteristics, more time period is required as 7 days fading test does not interpret anything specific. The most important property of TLD-100s which is linearity has proved right even in very low dose irradiation. So in terms of verification of certain and vital characteristics, TLD-100s applicability has been proved justified for low dose detection. Its usage as individual monitoring is expected to be valid. For more reliability other properties of TLD-100 must be studied like energy dependence, angular dependence, etc.

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