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A Photo-transfer Thermoluminescence (PTTL) Study of TLD-100 over a Wide Dose Range

Engin Aşlar[1,*]

[1]Institute of Nuclear Sciences, Ankara University, 06100, Ankara, TURKEY
https://orcid.org/0000-0002-1414-0317
*corresponding author: easlar@ankara.edu.tr

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Abstract: Photo-transferred thermoluminescence (PTTL) is defined as the transfer of electrons from deep traps into shallow traps via optical stimulation. The importance of PTTL is that it allows for a second measurement of dose assessments for accuracy in cases such as an erroneous dose evaluation. In this study, the PTTL signal of TLD-100 was investigated in detail for a wide dose range from mGy to Gy. The investigation of PTTL signals in the order of Gy is the main innovation of this study. Based on the results of the low dose measurement (mGy), the PTTL dose-response curve has a significant sublinear characteristic in the order of mGy for the total area condition. Additionally, PTTL signals could not be distinguished from the background signal up to 5mGy. Therefore, the PTTL method can be used by taking into account the sublinear function obtained after 5mGy for the total area. On the other hand, it can be applied to TLD-100 between 0.5mGy and 50mGy using ROI. Based on the high dose measurement results (Gy), the PTTL method can be applied up to 10Gy regardless of the total area and ROI. Therefore, the dose reassessment can be performed with PTTL signal in high dose measurements (Gy) such as in the radiotherapy field. Furthermore, in future studies, heating the dosimeters during UV exposure, predose effect, or subjecting the dosimeters to fast cooling following the annealing process may provide important outputs to obtaining higher PTTL intensity, thus, it may allow measuring lower radiation doses.

Key words: Photo-transfer, PTTL, TLD-100, LiF:Mg,Ti

1. Introduction

The photo-transferred thermoluminescence (PTTL) phenomenon is described as the transfer of electrons by light from deep electron traps to shallower electron traps already depleted. The glow curve obtained by heating the material to a certain temperature, followed by exposure to light of a certain wavelength for a period of time, causes the regeneration of the TL glow curve [1-4]. Although the thermoluminescence (TL) phenomenon is known to be irreversible, it is possible to reassess doses thanks to the PTTL method, since not all traps in the material are emptied [5]. The TL peaks obtained depend on the power of the light source, wavelength, and illumination duration [6]. PTTL has been seen in both natural and artificial materials, this makes the PTTL a useful tool for dosimetry and dating applications [7]. Especially in personal dosimetry, it may be necessary to re-evaluate the dose and control the accuracy of the measurement. In this case, the use of the PTTL method is of critical importance [8,9].

TLD-100 (LiF:Mg,Ti) has important features in radiation dosimetry such as tissue equivalent, low energy response, and linear dose-response over a wide dose range [10].

The PTTL behavior of TLD-100 has been investigated by various researchers for a long time [5,8,9,11-20]. Initial studies performed with TLD-100 have shown that dose reassessment with PTTL is possible for doses higher than 10mGy [11]. Mukherjee and Duftschmid [12] showed that doses of up to 2mGy can be recalculated using a 30W UV lamp with TLD card dosimeters. Apart from these studies, Delgado et al. [5], by designing a simple and effective UV irradiator, it was determined that doses in the range of 0.2mGy could be determined by PTTL. It has been reported that the method can be routinely applied for re-assessment of the doses. According to the study carried out by Budzanowski et al. [9], the PTTL behavior of the TLD-100 was investigated throughout the dose range between 5 and 50mGy. The PTTL properties of TLD-100 were also investigated by Ben-Shachar [14]. According to this study, the doses can be re-evaluated with dosimeters between 5 and 100mGy for TLD-100. In addition, it has been reported that the PTTL signal intensity can be increased by heating the samples during UV exposure and by pre-dose sensitized dosimeters [5,15]. A similar study has been performed in recent years by Wrzesień et al. [16]. In this study, PTTL properties of TLD-100 were investigated between 100 and 1000mGy.

PTTL studies of TLD-100 have been performed mostly in the personnel dosimetry dose range (order of mGy) in the literature. It was seen that studies on the behavior of the PTTL signal at high dose values (Gy) were inadequate when the literature was examined. In the present study, PTTL signals were investigated both in the order of mGy and Gy. In this context, the investigation of PTTL signals in the order of Gy is the main innovation of this study. The results obtained in the order of Gy may provide important contributions and new perspectives to high-dose dosimetry area for dose evaluation with PTTL signal, especially in the field of radiotherapy. Secondly, when the literature is examined, the dose values used in the order of mGy are in a very limited range, but in the present study, the dose values are selected over a wide range.

The purpose of this study is to investigate the PTTL signal behavior of TLD-100 in a wide range of doses, starting from the lowest possible dose (0.1mGy) up to 100 Gy. PTTL behavior, especially at high doses, is one of the main aims of this study. Both TL and PTTL dose-response curves were established for TLD-100. In addition, the UV sensitivity of TLD-100 was studied at different UV exposure durations.

2. Material and Method

2.1. Material

The LiF:Mg,Ti (TLD-100) chip dosimeters with dimensions of 3.2×3.2×0.9 mm^3 were used in the study. The $^{90}Sr/^{90}Y$ beta source was used as irradiation source. The Harshaw TLD Model 2210 Chip Irradiator a dose rate of 0.92μGy/s was used for low dose (mGy) measurement. For high dose (Gy) measurement, the internal $^{90}Sr/^{90}Y$ beta source in the Risø TL/OSL reader with a dose rate of 0.11 Gy/s was used. TL measurements were performed with Harshaw TLD-3500 equipped with a normal glass filter. A programmable Thermo Theldo furnace was used for the preheat and annealing of the dosimeters. For UV exposure, a 15 Watt UVC TUV/G15 T8 model Philips brand UV lamp with a wavelength of 254nm and a power of 0.15 W×m^2 at 7 cm was used.

2.2. Method

The dosimeters were calibrated according to both dose values (mGy and Gy). For this purpose, the irradiations were performed at 10mGy in low-dose measurements and 1Gy in high-dose measurements. Element correction coefficients (ECC) were assigned to the dosimeters separately for each type of measurement in the order of mGy and Gy. Forty dosimeters were used throughout the study, having a standard deviation of around %5. The final TL intensity was obtained by multiplying the intensity values obtained from the TL reader by the predetermined ECC factors.

The measurement protocol for PTTL measurements was given in Table 1. RT refers to the room temperature in Table 1. This protocol was the same given in the study by Budzanowski et al. [9]. The dosimeters were placed in the center at a distance of 7 cm from the UV lamp. All measurements were performed using three dosimeters. The error bars in the figures describe the standard deviation over the three dosimeters.

The total area value was determined as the area under the glow curve, while the Region of Interest (ROI) was obtained over three peaks in the dosimetric peak region (Channels: between 110 and 160). The total area value was generally used in the order of Gy measurements. The parts where the ROI was used were indicated in the text.

Table 1. PTTL measurement protocol

Steps	Measurements	Process
1	Annealing of the dosimeters	1 hour at 400°C followed 2 hour at 100°C
2	Irradiation of the dosimeters	mGy to Gy
3	Preheat of the dosimeters	10 min at 100°C
4	TL measurement	RT to 300°C (Heating rate=5°C/s)
5	UV exposure	15 min at room temperature
6	Preheat of the dosimeters	10 min at 100°C
7	PTTL measurement	RT to 300°C (Heating rate=5°C/s)

Two different dose range was studied for dose-response: First, dosimeters were irradiated in the order of mGy at 0.1, 0.5, 1, 5, 10, 15, 20, 30, 40 and 50mGy. Secondly, irradiation doses were chosen as 0.10, 0.25, 0.50, 0.75, 1, 10 and 100Gy in the order of Gy. A pinhole was used in the first TL measurement (Step 4 in Table 1) for 100Gy in front of the glass filter in the TLD reader to prevent the possible saturation of the photomultiplier tube, decreasing the TL intensity by about 80%.

3. Results

3.1. Optimum UV exposure duration

Figure 1 shows the variation of PTTL signal intensity obtained according to different UV exposure durations. The figure was constructed using both total area and ROI. In both cases, the PTTL signal intensity showed the same behavior according to the UV exposure duration. The PTTL signal intensity increased from 5 to 15 min with UV exposure, then started to decrease, and finally, it showed an almost stable behavior after 120 min. The highest PTTL signal intensity was obtained after 15 min of UV exposure. Therefore, 15 min of UV exposure was adopted throughout the study to build the PTTL signal.

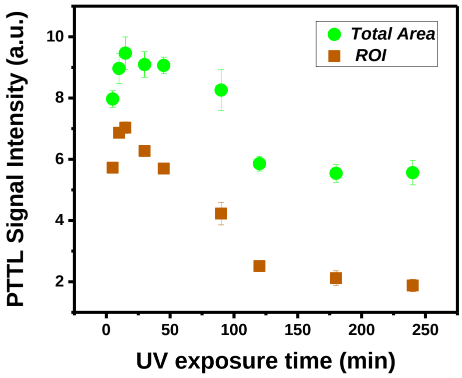

Figure 1. PTTL signal intensity obtained versus different UV exposure durations

The behavior of PTTL intensity with UV exposure time obtained in this study showed a similar pattern with the Alzahrani et al. [6] and Budzanowski et al. [9] although the optimum UV exposure time obtained in these studies differs due to reasons such as different power of the lamp and difference in distance of sample and lamp.

3.2. Glow curves (TL and PTTL)

Figures 2a and b show the TL and PTTL glow curves in the same figures obtained for 20mGy and 1Gy, respectively. According to Figure 2a, the TL intensity was almost eight times bigger than the PTTL intensity when taking into consideration peak maximum intensity (known as peak 5). The maximum temperature difference of the main peak in the TL and PTTL glow curves was ~6°C. Similar difference was also seen in Budzanowski et al. [9]. This temperature difference can be originated from factors such as the temperature changes in the heated dosimeter and the planchet material cannot be fully distinguished, and the differences in the temperature sensitivity in the thermocouple system. Therefore, it can be accepted that TL and PTTL peaks appear at the same temperatures. As for the 1Gy, again TL intensity was eight times bigger than the PTTL intensity according to peak maximum intensity (Figure 2b). The temperature difference of the main peak between TL and PTTL was the same as ~6°C.

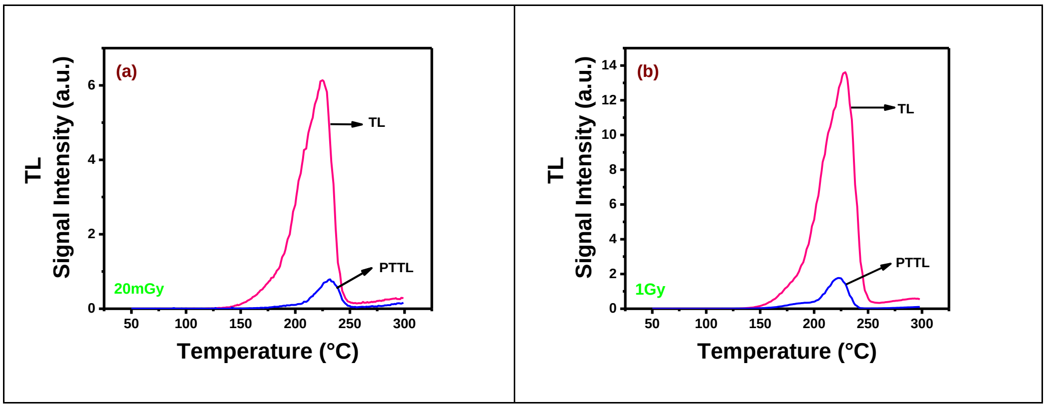

Figure 2. TL and PTTL glow curves obtained according to different radiation doses: a) 20mGy; b) 1Gy

The ratio of PTTL intensity to TL intensity varied between (10-12)% according to both ROI and total area for the doses between 10 and 50mGy. On the other hand, this ratio varied between (15-45)% for ROI and (20 – 85)% for the total area at doses between 0.5 and 5mGy. The PTTL intensity obtained at 0.1mGy was greater than the TL intensity contrary to expectations, both in terms of ROI and total area. Therefore, reassessment of doses with the PTTL method for 0.1mGy was not possible under these conditions. Furthermore, TL peaks were not evident in the PTTL glow curves at doses between 0.1

and 1mGy considering the total area. However, the PTTL peaks became distinguishable for these dose ranges in the case of ROI. The ratio of PTTL intensity to TL intensity in the order of Gy varied as (10-12)% for all doses between 0.1 and 100Gy. This ratio did not change according to ROI either. Budzanowski et al. [9] reported that the ratio of PTTL intensity to TL intensity reached 17% in their study. Similarly, Wrzesień et al. [16] obtained this ratio as 19%. These results are almost compatible with our study. The slightly higher value seen in both Budzanowski et al. [9] and Wrzesień et al. [16] is due to the increased PTTL efficiency as a result of heating the dosimeters at the same time during UV exposure.

3.3. UV sensitivity

Figure 3 shows the TL signal intensity obtained from UV exposed dosimeters ranging from 5 to 120 minutes for annealed dosimeters. Dashed lines show the mean value of all data. In order to understand the UV sensitivity of TLD-100, both the area values under the glow curve and the formation of the TL glow curve were investigated. The area values obtained after direct UV exposure for annealed dosimeters showed different behavior during the 5 to 15 min UV exposure according to ROI and the total area. In the case of ROI, the UV sensitivity obtained from the TLD-100 in general was quite low even though the intensity at low UV exposures showed an increasing trend. However, a significant peak structure could not be seen in the glow curve. The maximum deviation from the mean was around 13% in the case of total area, while it was around 33% for the ROI. The high deviation in the ROI situation was due to an increase seen in the first three UV durations. No regular increase or decrease in intensity was observed for the total area. Similar to ROI condition, no notable TL glow curve was observed in the total area condition. As a result, TLD-100 did not show UV sensitivity with respect to both ROI and total area.

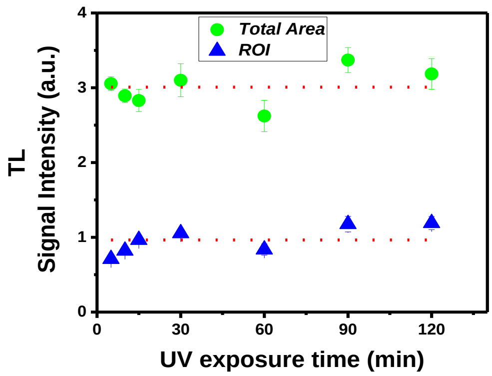

Figure 3. TL signal intensity obtained following different UV exposure durations

According to a study performed by Mason et al. [21], the UV sensitivity of TLD-100, TLD-200 and TLD-300 has been reported as low. The UV sensitivity of the dosimeters was compatible with those obtained by both Ben-Shachar et al. [14] and Mason et al. [21].

3.4. Dose-response curve (TL and PTTL)

Figures 4a and b show the TL and PTTL signal intensity obtained doses between 0.1mGy and 50mGy, respectively in the log-log scale. Figure 4a was constructed according to the total area, while Figure 4b was constructed according to both total area and ROI. Dose-response curves were fitted to the function of y=a×D^b where the D is applied dose, a is the constant and b is the linearity coefficient. In this equation, if b equals 1, a curve is linear, if b<1 or b>1, the curve shows sublinear and supralinear behavior, respectively [22,23]. According to Figure 4a, the TL signal intensity showed sublinear behavior with *b* equal to 0.92±0.02. However, this value can be considered linear as *b* is close to 1.00. On the other hand, Figure 4b shows different dose-response characteristics depending on the total area and ROI. PTTL signal intensity has prominently sublinear characteristics by *b* equal to 0.41±0.08 for the total area condition. As for the ROI, it showed a slightly sublinear behavior similar to Figure 4a by *b* equal to 0.84 ±0.02. It can be said that the use of ROI increases its linearity.

According to studies conducted by [11-14], PTTL dose-response curves in the mGy order have been reported to show linear behavior. However, the linearity of the dose-response curves was not investigated with any fit function, it was interpreted only visually. In the present study, the PTTL signal generally increases as the dose increases for both mGy and Gy order. In this sense, the data obtained are compatible with the literature [11-14]. When the linearity of the curves was examined comprehensively, a serious sublinearity appeared in the case of the total area case in the order of mGy. Therefore, attention should be paid to the sublinearity of the dose-response function when determining the dose with the PTTL signal in the mGy order according to the total area. As a result, the PTTL signal obtained at between 0.1 and 1mGy cannot be used since the peaks cannot be distinguished from the background signal for the total area. Therefore, dose evaluation with PTTL can be used after 5mGy. On the other hand, in the case of ROI, it is possible to re-evaluate doses with the PTTL signal at dose values between 0.5 and 50 mGy.

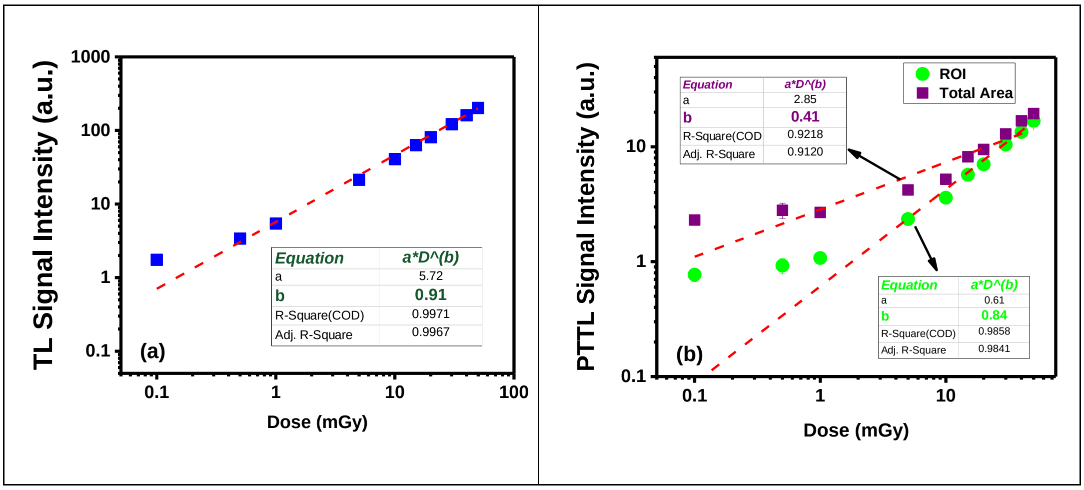

Figure 4. Dose-response curves obtained for the order of mGy: a) TL signal intensity, b) PTTL signal intensity

Figures 5a and b show the TL and PTTL intensity obtained between 0.1 and 100 Gy in the log-log scale. The correction was applied to the last data (100Gy) due to the pinhole reducing the intensity. Both TL and PTTL intensities increased with increasing dose values.

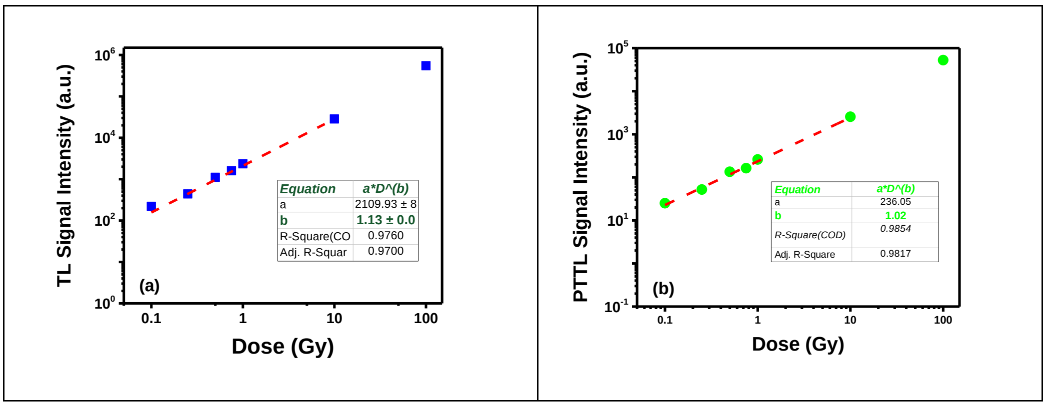

Figure 5. Dose-response curves obtained for order of Gy: a) TL signal intensity, b) PTTL signal intensity

According to Figure 5a, the TL signal intensity showed slight supralinear behaviour by *b* equal to 1.13 ±0.03 in the dose ranges between 0.1 and 10Gy. After 10Gy, the supralinearity increases further. In Figure 5b, the PTTL signal showed a linear response with *b* equal to 1.02 ±0.02 and started to deviate from linearity after 10 Gy. Based on the results for the order of Gy, the PTTL method allows re-assessment of doses up to 10Gy.

4. Conclusion

In this study, PTTL signals were investigated in detail both in the order of mGy and Gy. The investigation of PTTL signals in the order of Gy is the main innovation of this study. Based on the results of the low dose measurement (mGy), the PTTL dose-response curve has a significant sublinear characteristic in the order of mGy for the total area. Additionally, PTTL signals could not be distinguished from the background signal up to 5mGy. Therefore, the PTTL method can be used by taking into account the sublinear function after 5mGy for the total area. On the other hand, it can be applied to TLD-100 between 0.5 and 50mGy using ROI. Based on the high dose measurement results (Gy), the PTTL signal can be evaluated up to 10Gy regardless of the total area and ROI. Therefore, the dose reassessment can be performed with PTTL signal in high dose measurements (Gy) such as in the radiotherapy field. With this study, it has been shown that dose reassessment is possible with a PTTL signal in the order of Gy. Furthermore, in future studies, heating the dosimeters during UV exposure, predose effect, or subjecting the dosimeters to fast cooling following the annealing process may provide important outputs to obtaining higher PTTL intensity, thus, it may allow measuring lower radiation doses.

Authorship contribution statement

Engin Aşlar: Conceptualization, Methodology, Investigation, Review and Editing, Original Draft Writing, Visualization

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.

Ethics Committee Approval and/or Informed Consent Information

As the authors of this study, we declare that we do not have any ethics committee approval and/or informed consent statement.

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