EVALUATION OF RESIDUE DOSE, FADING, AND REPRODUCIBILITY OF TLD SYSTEM

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Abstract

Thermoluminescence dosimetry (TLD) system has been used to estimate the personal dose for external occupationally exposed workers. The reliability and precision of dose measurements and the accuracy of dose evaluation are important factors for the improvement and achievement of individual monitoring objectives. In this piece of work, selected properties of TLD system, which are of relevance for personnel dosimetry, were evaluated on the basis of their usage in Centre for Energy Research and Training (CERT) ABU Zaria. The cards, produced by Vinten Instrument Limited were evaluated on the Solaro reader Model 680 and irradiated using Sr/Yr-90 source. The cards were equipped with 2 high sensitive (LiF) detectors in batch 55101 and $CaSO_4$ *detectors in batches 6400 and 57100 respectively. Evaluation of residue dose, fading, and re-usability over 10 cycles of reading of TLD system was investigated. The results of the investigated properties were compared for various batches of tlds and with the limits defined by IEC standard. These results are discussed in order to demonstrate the degree of accuracy achieved and the need for its improvement where necessary.*

Keywords: *Ionizing radiation, residual dose, isothermal decay constant, test dose.*

INTRODUCTION

Dosimetry is the quantitative assessment of ionizing radiation absorbed in matter and tissue. To assess this radiation dose accurately, the characteristic of the tld system among which are the residue dose, its re-usability, and stability of its element after along period of time that is fading. There are several techniques for detecting and measurement of dose and dose rate to an individual. (Herman, 1992).Among these techniques, thermoluminescent dosimetry (TLD) system re often used within a facility because of their ease of deployment and the minimal maintenance required. There are characteristics unique about these passive detectors that make them suitable for use and re-use even after a long period of time. Despite the suitability of these TL detectors, different difficulties may be associated with its application (Karikmae, 2004). It may be possible that some of the chips are not as sensitive as the others, changes in the properties of the chips due to its heating in the readout phase, and there could be gradual fading due to the relative long time they have been acquired.

The aim of this work is to check the level of performance of TL detectors based on its reproducibility, thermal fading, and residue dose in order to compare results from different batches and with limits provided by IEC so as to obtain results that could be used for better service delivery for dosimetry. It is important to have data on the characteristics of TL detectors to reduce the possibility of variation in dosimeter characteristics during usage. This goes a long way to ensure proper assessment of the dose it has accumulated, thus enhancing the safety of the patient, personnel, the environment and the populace at large. Comparison of the data obtained with those of similar institution in the country will indicate best practice and compliance with safety standards. The theoretical explanation of thermoluminescence is based on the electron band theory. When TL materials are exposed to ionizing radiation at room or at low temperature, electrons are released from the valence band to the conduction band. This leaves a hole in the valence band. Both types of carriers become mobile in their respective bands until they recombine or until they are trapped in lattice imperfections in the crystalline solids (Ogundare *et al.*, 2006) (Shallow and deep traps). The trapped electrons may remain for a long period when the crystals are stored at room temperature. They are released if sufficient energy is given to the electron when the crystal is heated (Haug, 1972). All steps of the measurement cycle, such as annealing, packaging and storage, irradiation, readout and mathematical evaluation, influence the characteristics and uncertainties of the dosimeter system (Furetta & Weng, 1998).

A mathematical evaluation enables the determination of the evaluated dose value D_e from the TL readout value (TL response, M) using the evaluation factor

$$D_e = F_e \times M \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

The TL response can be represented either by the maximum intensity (height of the peak) or by the area under the TL curve. The peak area method is more frequently used (Furetta & Weng, 1998). F_e involves the calibration factor, F_c which is given as:

$$F_c = \frac{D_c}{\overline{M} - \overline{M}_0} \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

$\overline{M}$ is the mean TL signal of TLDs irradiated by a calibration dose, D_c, and $\overline{M}_0$ is the mean TL signal of unirradiated control detectors. F_e contains the algorithm for the calculation in terms of the dose of interest and the combination of results obtained for more than one detector. F_e also enables corrections to be made that become necessary due to background, individual sensitivity of the detectors, fading, non-linearity and energy dependence (Ranogajec-Komor, 2003).

MATERIALS AND METHOD

Four Detector Cards

All the TLDs used in this work were obtained from Centre for Energy Research and Trainig (CERT), Ahmadu Bello University, Zaria. Several examples of the cards are presented in Fig. 1. Up to four TLD detectors, in form of discs with typical disc size 0.4mm in thickness and 12.7 mm in diameter can be placed in the card. All investigations were performed with 3 batches of TLD cards consisting of 10 TLD cards each. Group one (55101 series) contains LiF detectors in position 2 and 4, group two (6400 series) and group three (57100 series) contains CaSO4 in position 2 and 4, respectively.

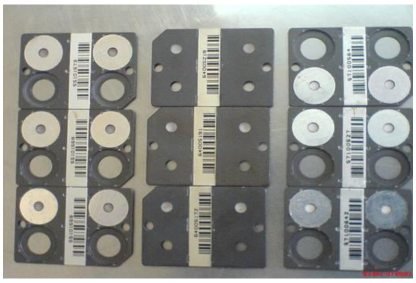

Fig. 1: TLD cards with detectors in positions 2 and 4

TLD reader

All cards were evaluated on Solaro Dual-Channel TLD reader model 680 produced by Vinten Instrument Limited. (Fig. 2). For readouts no nitrogen gas was applied. The following Time Temperature Profile (TTP) was applied for readout of the TLDs:

55101 Series (Table 4)

- Preheating: 160ºC, 10 s
- Heating (linear): 25ºC/s up to 260ºC
- Acquisition time: 16 s
- Annealing: 300ºC, 16 s

6400 and 57100 Series (Table 10)

- Preheating: 180ºC, 12 s
- Heating (linear): 25ºC/s - 300º
- Acquisition time: 10 s
- Annealing: 300ºC, 20 s

Standard voltage applied during the readout was 250V for all two photomultipliers. Sets of 30 TLD cards were stored in a plastic container and were kept at room temperature in a dark area when not in use.

Fig. 2: Solaro dual channel reader

Irradiation facility

The exposure was performed with the calibrated internal $^{90}Sr/^{90}Yr$ irradiator type 623 used in CERT, with source activity of 27.35 MBq on 19/09/2007, Fig. 3. This covers a dose range of approximately 0.011 mGy/s to 20 mGy/h. Up to 10 TL cards can be placed on the turn table 1cm between the upper and lower source location to attain electron equilibrium during irradiation.

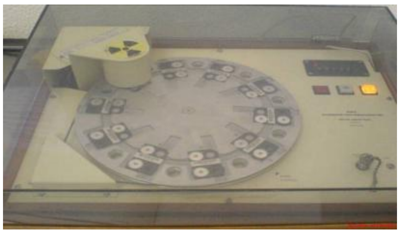

Fig. 3: Type 623 Dosimeter Irradiator with Sr/Yr-90 source

To test for the reproducibility of the system, all the cards were annealed, irradiated with a test dose (2 mGy) and read. The same procedure was repeated 10 times with the standard deviation σ_r, and their respective percentage coefficient of variation, %CV_r in each cycle determined. Also the standard deviation σ_c and percentage coefficient of variation, %CV_c of each detector in all the cycle was determined. The stability of the system over 10 cycles of readings was determined by calculating the detector variability index, DVI using the formula (Furreta & Weng, 1998).

$DVI = \sqrt{(SVI)^2 - (RVI)^2}$ ……1.0…. 4

$SVI = \frac{\sigma_c}{\%CV_c} \times 100$ is the system variability index

$RVI = \frac{\sigma_r}{\%CV_r} \times 100$ is the reader variability index

To test for residual signal, 10 TLD cards were exposed to doses between 0.25 to 2.5mGy with an increment of 0.25mSv for each card and read out with the standard TTP. Immediately afterwards all cards were re-read five times without irradiation to measure the residual signal left in the TL detectors.

For thermal fading, nine TLDs from a batch were divided into three sub-groups (A, B, and C) of 3 TLDs each and annealed. Group A was irradiated with a test dose of 2 mGy and stored inside a lead container together with annealed ones (groups B and C) but not irradiated. At the end of the storage period, t_a (2 weeks) group B was irradiated with the same test dose as group A and all the three groups were read. The isothermal decay constant, λ was evaluated using equation 2.0 (Furreta & Weng, 1998).

$\lambda = \frac{1}{t_a} \ln \frac{\overline{M}_B - \overline{M}_C}{\overline{M}_A - \overline{M}_C}$ (h^{-1}) ……2.0 ….. 5

$\overline{M}_A, \overline{M}_B, \overline{M}_C$ are the TL response corrected by background and sensitivity factor for the three groups. The time effect of fading was studied by annealing and irradiating the TLDs with a test dose of 3 mGy, each card was stored in a lead container at room temperature. At the end of every 24hr, three cards from each batch were read out and the process continued until all the cards were read with an increasing level of time. A graph of the TL intensity versus the time elapsed was then plotted to show the possible decrease of TL response.

RESULTS AND DISCUSSION

Reproducibility Test

Table 1 shows variation of the whole TL system for evaluated TL responses over 10 cycles of readings corrected for background and sensitivity factors. For each detector repeatedly irradiated 10 times with a test dose of 2mGy, the standard deviation and the percentage coefficient of variation is determined and also the standard deviation and the %CV of the mean response of all the detectors used in each cycle of reading.

Table 1: System, reader, and detector variability index of TL readings over repeated re-uses

Batch	SVI	RVI	DVI
55101	12.01	10.48	7.72
[illegible]	[illegible]	[illegible]	10.85
57100	28.16	26.56	9.35

From the readings, the highest amount of variation is generally from the whole system which is due to combination of instability of the reader, the detector and fluctuations of background readings from the environment and the reader. The variation of the response from 55101 series is the least as seen from individual percentage coefficient of variation and from the collective coefficient of variation of the batch as compared to 6400 and 5700 series, this may be because of the close sensitivity of this detectors and also the uniformity of the batch as obtained in their homogeneity test. It can also be seen that as the readings are generated, there are more fluctuations in the system. The variation in the reader may be partly due to accumulated background signals (photomultipliers noise) as readings are been generated, the internal reference light source stability, which have a major influence on the accuracy and stability of the system and also due to lack of Nitrogen purge to minimize thermoluminescence background signal.

Fig. 4 shows the average responses in each cycle against the cycle number. The only observed decrease of the response is an abrupt change which occurred in 57100 series at cycle no 4. This seems to be a reader effect as can be seen from the calculated RVI, because after this cycle the response is quite stable.

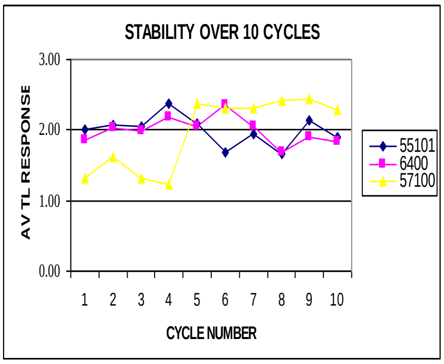

Fig. 4: Response of TLD cards over repeated re-uses, with respect to the first measurement.

Effect of Residual Signal

Residual signal is a signal remaining in the TL detector after the readout. If the level of stored energy from previous irradiations is significant with respect to succeeding doses, the residual energy must be reduced further before the detector can be re-used; this restores the sensitivity of the detectors (Bilski & Budzanowski, 2005). The value of the residual signal is determined by the subsequent read outs of the detector without prior irradiation. Figure 5.1-5.3 shows the plot of residual signal for various doses measured within five consecutive re-reads following initial readout of exposed detectors.

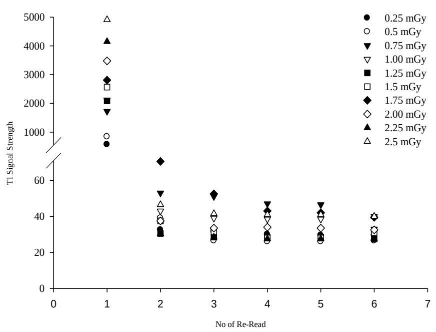

Fig. 5.1: Residual signal curve for 55101 series TLD Cards

The residual signal after the first readout is at the level of 5 % to 8 % of the initial signal. The next readouts, which can be treated as a simplified annealing, slightly reduces the signal below the first readout and become constant after the second readout as observed in 55101 and 6400 series. This is usually performed if the signal exceeds a set limit. In 57100 series; most of the TL responses were constant after the second and third readout with a slight increase and decrease in response of some detectors. For low dose irradiation, background.

Fig. 5.1 shows the TL signal strength of 55101 TLD cards as the cards are repeatedly re-read when exposed to different level of dose. For each given dose, the signal tends to be stable after the second read out and remains almost constant after the third readout with an overlap of the responses as the number of re-reads increases. There also seems to be a decrease in TL signal as the dose increases.

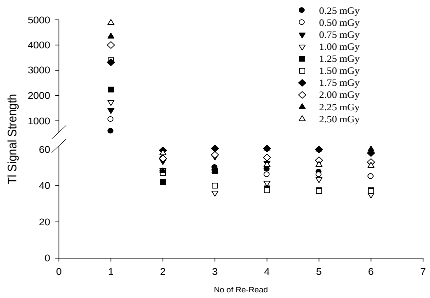

Fig. 5.2: Residual signal curve for 6400 series TLD Cards

The signals observed in 6400 series are reduced to about 8% of the initial signal in the second readout and remains almost constant after these. Although, there are slight increases in response with the number of re-reads, this may be due to increase of background signal in the reader.

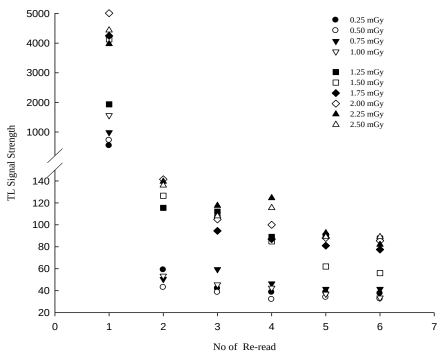

Fig. 5.3: Residual signal curve for 57100 series TLD Cards

In 57100 series, the response of the cards decreases to about 5% of the original signal in the second read out. The residual signal is almost constant after the second read out with a gradual decrease of TL signal as the number of re-read increase.

Time effect of fading

One of the important dosimetric characteristics of a TL material is fading, that is the loss of signal during storage or the stability of dosimeters under various climatic conditions as a function of time. Fading is an intrinsic effect of a TL material and encapsulation of TL elements into a dosimetric card has no influence (Bilski & Budzanowski, 2005).

Fading was tested over a period of 288 h. Fig. 6 shows the response of TLD cards over a period of 288 h for each batch. At each point is an average of 3 readings corrected for individual background and sensitivity factor. The relative TL response of the detectors, irradiated with β-rays (3 mSv) versus time elapsed from irradiation is shown below.

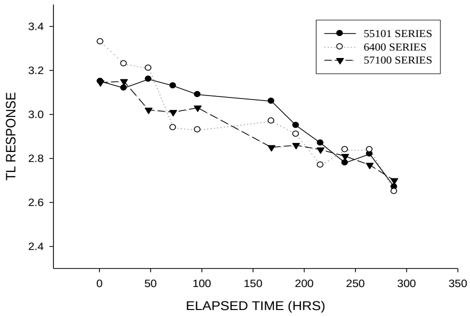

Fig. 6: Time effect of fading

Though there are fluctuations in the reading which could be due to influence of other factors such as instability of the reader and influence of natural background radiation, the most important conclusion from this study is that the main response did not vary by more than a few percent. Time period of all these investigations was limited to 288 h; although the time could be extended to periods of 1-3 months. It has been observed that even if TLDs are stored for longer time at room temperature, effects of fading will be negligible (Bilski & Budzanowski, 2005).

Table 2: Isothermal decay constant of cards stored for 2 weeks.

	TL SIGNAL (55101)	TL SIGNAL (6400)	TL SIGNAL (57100)
GROUP A	2.197	2.120	1.967
GROUP B	2.278	3.120	2.194
GROUP C	0.035	0.027	0.007
λ	0.0001	0.0012	0.0003

From the isothermal decay constant calculated using equation 2.0, the effect of fading is negligible for the period which these detectors where stored. Table 2 shows these constants calculated for each batch. The rate at which 55101 detectors decay is less than those of 6400 and 57100 series, this is further confirming the stability of these detectors as seen from previous tests. Within the time frame of the investigation, detectors from 55101 batch fades by 0.01 %, from 6400 series, 0.12 %, and from 57100 series, 0.03 %.

CONCLUSION

The residue dose was found to be about 3 % to 8 % of the original signal after the first read out and decreases to a constant level of about 1.36 %, 1.83 % and 2.76 % of the initial signal after the second read out in 55101, 6400, and 57100 series respectively. At lower doses, it is noted that the residual signal is high due to the effect of reader background noise and natural background radiation. It is recommended that the residual dose should be about 1 % and 2 % of the original signal in the second readout value and about 0.5 % of the initial signal during the third readout. The fading was found to be negligible over a period of 288 hours. The isothermal decay constant which indicates the rate of fading was found to be 0.01 %, 0.12 %, and 0.03 % for 55101, 6400, and 57100 series respectively when stored at room temperature for two weeks. According to the IEC Standard the fading should be within 5 % and 10 % for 30 and 90 days, respectively under standard test conditions.

Stability: after 10 readouts, the change of TL signal fluctuates for all the series with the least variation observed in 55101 series. None of the detectors satisfies the IEC recommendation which requires that the percentage coefficient of variation for each detector separately and n detector collectively should not be greater than 7.5 %. Part of this effect could be attributed to the TLD reader instability and due to non-availability of Nitrogen gas in the system. The investigations of TLD dosimetric cards with LiF detectors proved their superior properties for personnel dosimetry compared to $CaSO_4$ detectors. This has been attributed to the tissue-equivalence of these detectors. LiF detectors have higher stability and sensitivity to TL response, higher linear dose response, and lower percentage coefficient of variation. Although variations in 55101 series detectors are the least, there were observed variations in the whole system during several re-uses.

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