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Performance Evaluation of a Thermo-luminescent Dosimetry System for Occupational Monitoring in Federal Teaching Hospital Katsina, Nigeria

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Abstract

Thermo-luminescent dosimeters (TLDs) are widely used for occupational radiation monitoring due to their sensitivity, reusability, and tissue equivalence. This study evaluates the performance of a TLD system deployed at the Federal Teaching Hospital, Katsina, Nigeria. Key performance parameters assessed include batch homogeneity, reproducibility, and dose linearity in accordance with IEC 1066 standards. The homogeneity test yielded a percentage variation of 13.3%, well within the acceptable limit of 30%. Reproducibility analysis yielded a coefficient of variation of 7.71%, which is slightly above the IEC threshold of 7.5%. The dose linearity is in good agreement with irradiated dose values, with deviations ranging from 1.3% to 8.0% and a regression coefficient (R^2) of 0.9985, indicating excellent linearity. Overall, the system exhibits reliable performance for occupational monitoring, with minor deviations attributable to environmental and operational factors. Continuous quality assurance is recommended to ensure sustained compliance with international standards.

Keywords: Thermo-luminescence; Radiation protection; IEC 1066; Uniformity index; homogeneity test; annealing; dose linearity; LiF dosimeters.

I. Introduction

Radiation dosimetry plays a critical role in radiation protection by providing essential measurements of ionizing radiation doses absorbed by our biological tissues. Accurate dosimetric assessments are vital for safeguarding the health of both patients and healthcare workers in medical environments where ionizing radiation is routinely utilized. These include diagnostic radiology, nuclear medicine, and radiation therapy centers [1]. Thermo-luminescent dosimeters (TLDs) have emerged as one of the most widely adopted due to their precision, practicality, and capacity for accurate dose measurements [2-3].

TLDs function based on the principle of thermo-luminescence, in which certain materials, such as lithium fluoride (LiF), absorb energy from ionizing radiation, causing electrons to be trapped in the crystal lattice. Upon heating the material, these trapped electrons release their stored energy in the form of light [3]. The intensity of this emitted light is directly proportional to the amount of radiation absorbed. Thus, the absorbed radiation dose can be quantitatively determined. These features make TLDs highly suitable for both environmental and personal dosimetry in healthcare settings, particularly in radiotherapy, where precise dosimetric control is crucial for both therapeutic efficacy and patient safety [2].

Numerous studies have been conducted on the performance of TLDs globally. However, there is limited data on the operational performance of the TLD system in Nigerian healthcare facilities. The study conducted by [3] evaluated the performance of the thermo-luminescent dosimeters (TLDs) system used in the environmental monitoring program at the Bariloche Atomic Center, Argentina. The study found that the reproducibility of the TLDs gradually deteriorates over long-term use. Similarly, [4] conducted a study that evaluated the performance of thermo-luminescent dosimeters for personnel in vivo dosimetry. The results of their findings highlighted that the detectors responded linearly to dose, produced repeatable results, and showed only minimal fading during the storage process.

Despite the significant effects of radiation dosimetry in attaining radiation safety, a significant knowledge gap exists because environmental conditions, procedural practices, and equipment handling may differ from those reported internationally. Therefore, evaluating the TLD system at Federal Teaching Hospital, Katsina, will provide essential insight into its performance under local conditions. The study aims to assess the TLD system by evaluating linearity, homogeneity, and reproducibility. The findings will provide essential baseline data for quality assurance and enhance the effectiveness of occupational radiation monitoring programs within Nigerian healthcare settings.

II. Materials and Methods

A. Materials

In this study, lithium fluoride thermo-luminescent dosimeters (TLDs) doped with magnesium and titanium (LiF:Mg, Ti) were obtained from the Federal Teaching Hospital, Katsina, for the purpose of measuring and analyzing radiation exposure. The measurements were conducted using a TLD Reader. The system operates using two photomultiplier tubes (PMTs), which are housed within a sliding mechanism to enhance sensitivity and accuracy. It supports two modes of heating: planchet and hot gas. The TLD reader was integrated with the Windows Radiation Evaluation and Management System (WinREMS) software, enabling seamless data acquisition and processing. Irradiation of the TLDs was performed using a calibrated internal beta radiation source, a 90Sr/90Y irradiator (Type 2210). The irradiation setup included a turntable capable of accommodating up to eight TL cards. These cards were positioned with a 1 cm separation between the upper and lower source locations to establish electron equilibrium, ensuring uniform exposure across all TLDs. This systematic approach facilitated precise dose measurement, which is critical for evaluating the performance and reliability of TLD systems in radiation monitoring applications.

B. Methods

1) Assessment of TLDs Performance

Control experiments were carried out to evaluate the response of thermo-luminescent dosimeters (TLDs). These involved exposing the dosimeters to radiation doses within the range of 0.5 to 5 mSv.

2) Homogeneity Testing of TLDs

The 10 TLD cards used in this study were annealed based on the time-temperature profile (TTP) method. The samples were then irradiated with 5 mSv from a β source irradiator and readout to obtain the TL response, M_i. The samples were re-annealed and read out without irradiation to obtain the zero-dose reading, M_{i0}, from which the net TL response $M_{i\text{-}net}$ was obtained.

3) Uniformity index

The following equations were used to compute the uniformity index [5].

$$M_{i,net} = M_i - M_{i0} \tag{1}$$

$$i = 1, 2, \dots, N$$

Where, M_i is the final uniformity index and M_{i0} is the initial uniformity index.

To determine the homogeneity of a batch, the uniformity index, Δmax, was calculated using (2).

$$\Delta_{max} = \frac{(M-M_0)_{max} - (M-M_0)_{min}}{(M-M_0)_{min}} \times 100 \leq 30 \tag{2}$$

Where, $(M - M_0)_{max}$ is the maximum value of TL reading corrected for background, and $(M - M_0)_{min}$ is the minimum value of TL reading corrected for background.

Equation (2) represents the tolerance level above which the result is unacceptable.

4) Reproducibility Test

Ten (10) TLD cards were annealed, irradiated, and read with a test dose (2.0 mSv). The same procedure was repeated 10 times, and the standard deviation (SD) for the detectors in each cycle and their respective percentage coefficient of variation (%CVr) were determined. The stability of the detector over 10 cycles of readings was determined by calculating the detector variability index, DVI, using (3) - (5).

$$DVI = \sqrt{(SVI)^2 - (RVI)^2} \tag{3}$$

$$SVI = \frac{\sigma_c}{\%CV_c} \times 100 \tag{4}$$

Equation 4 is the system variability index

$$RVI = \frac{\sigma_r}{\%CV_r} \times 100 \tag{5}$$

Equation (5) is the reader variability index equation [6-7].

The average TL response in each cycle was plotted against the number of cycles to show the deviations in TL response over repeated re-uses with respect to their response in the first cycle.

5) Dose Linearity

For the linearity test, ten thermo-luminescent dosimeters were exposed to different exposure levels, with the doses progressively increasing. The readings from these dosimeters were compared to those of IEC to determine the percentage variation between them. The difference between the actual measured doses and the known irradiated doses was calculated using (2), allowing for an assessment of the dosimeters' response to different exposure levels. This test helped verify the accuracy and reliability of the TLDs across a range of doses, ensuring they provided consistent readings. In addition, linear regression analysis was used to determine the relationship between the irradiated dose, D_{irr}, and the measured dose, D_{meas}, using (6).

$$\%Deviation = \frac{D_{meas} - D_{irr}}{D_{irr}} \times 100 \quad (6)$$

III. Results and Discussion

The uniformity of response was assessed using the test methods outlined in the International Standard for Thermo-luminescent Dosimetry Systems for Personal Monitoring, as specified by the International Electrotechnical Commission (IEC) standard. The results are displayed in tables and evaluated according to the performance criteria, focusing on meeting the necessary accuracy and precision standards for this type of service.

A. Batch Homogeneity

The uniformity of TL responses in a given batch, which is obtained from their uniformity index (IEC technical recommendation), is shown in Table I. The table indicates the list of net values of TL response corrected for individual background readings. Applying (1) and (2) to calculate the uniformity index, Dmax of TLD cards' responses from the TLD cards satisfy the homogeneity test with 100% degree of acceptance.

The homogeneity assessment revealed that the detectors within this batch responded consistently under identical conditions, with a percentage variation of 13.3%. The mean and standard deviation of the measured doses were 5.6 and 0.22 mSv, respectively. Minor variations were attributed to environmental conditions during irradiation and operator handling, such as inconsistent placement or reading procedures, which may cause minor variability. These results are well below the IEC 1066 standard's recommendation. Demonstrating that the TLDs used in this study are suitable for reliable occupational monitoring. This aligns with the findings of [2-5], which reported a variation of 12% and 20%, respectively, both well within the acceptable reference range of < 30%.

Table I: Homogeneity Test for the TLD Cards

S/N	Mi (mSv)	Moi (mSv)	Mi – Moi (mSv)
1	5.35	0.03	5.32
2	5.37	0.01	5.36
3	5.43	0.02	5.41
4	5.45	0.04	5.41
5	5.51	0.02	5.49
6	5.60	0.03	5.57
7	5.68	0.02	5.66
8	5.80	0.05	5.75
9	5.96	0.15	5.81
10	6.14	0.11	6.03
AVG	5.63	0.05	5.58
σ	0.25	0.04	0.22

Mi: irradiated TLDs, Moi: Non-irradiated TLDs.

B. Reproducibility

Table II shows the variation of the whole TL system for evaluated TL responses over 10 cycles of readings. Each detector was irradiated repeatedly 10 times with a test dose of 2 mSv. The table reports the standard deviation, the percentage coefficient of variation (%CV), as well as the standard deviation and %CV of the mean response for all detectors used in each reading cycle.

Table II: TLD response over 10 cycles of reading.

SN	1	2	3	4	5	6	7	8	9	10	AVG (mSv)	SD	%CVr
1	2.07	2.14	2.22	2.20	2.01	1.69	1.92	1.85	1.99	1.87	2.00	0.17	8.47
2	1.96	2.21	1.52	2.44	1.69	1.58	1.95	1.69	2.09	2.72	1.98	0.39	19.59
3	1.95	2.10	2.14	2.33	2.11	1.77	1.97	1.71	2.11	1.75	1.99	0.20	10.14
4	2.05	2.07	2.08	2.53	2.19	1.52	1.90	1.73	2.07	1.74	1.99	0.28	14.09
5	2.13	2.04	2.12	2.38	2.16	1.63	2.01	1.75	2.14	1.54	1.99	0.27	13.35
6	2.08	2.18	2.01	2.27	2.20	1.77	1.99	1.63	2.11	1.70	1.99	0.22	11.15
7	1.86	2.04	2.19	2.31	2.13	1.57	1.67	1.47	2.13	2.49	1.99	0.33	16.81
8	1.89	2.01	1.91	2.50	2.25	1.78	1.99	1.56	2.25	1.79	1.99	0.28	13.93
9	2.06	2.00	2.13	2.42	2.08	1.72	1.99	1.70	2.15	1.70	1.99	0.23	11.61
10	2.03	1.87	2.15	2.35	2.10	1.74	1.98	1.67	2.22	1.83	1.99	0.22	11.00

SVI = 13.01, RVI = 10.48, and DVI = 7.71

RVI: Reader variability index, SVI: system variability index, DVI: detector variability index, %CVr: percentage coefficient of variation, SD: standard deviation

The reproducibility of the TLD system over repeated irradiation cycles is further illustrated in Fig. 1. The mean TL response remains nearly constant across all cycles, with moderate fluctuations around the nominal value of 2 mSv. The inclusion of error bars representing the standard deviation highlights the variability associated with each cycle. Despite a slight exceedance of the IEC recommended coefficient of variation, the overall stability of the response indicates that the system maintains consistent performance over repeated use. The observed variations may be attributed to environmental conditions, instrumentation factors, and positioning inconsistencies during irradiation and measurement.

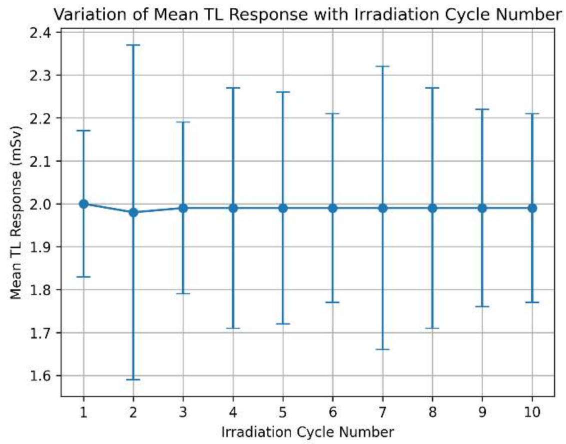

Fig. 1. Variation of mean thermo-luminescent (TL) response with irradiation cycle number for a test dose of 2 mSv, showing the reproducibility of the TLD system over repeated measurements.

The deviation in TL responses due to the whole system which comprises of the TLDs, the reader and the irradiation facility expressed as system variability index, SVI, the contribution of reader and its components to the deviations observed in TL response expressed as reader variability index, RVI and the deviation due to the detector alone expressed as detector variability index, DVI is calculated using (3) [8].

The percentage deviation is 7.71%, which slightly exceeds the IEC 1066 standard requirement of 7.5%. These results are slightly higher than those reported by [2-9], whose findings were 7.1% and 4.8%, respectively. The observed minor deviations may result from environmental influences during irradiation, such as temperature, and also differences in the positioning of the TLDs during irradiation. The following factors: environmental condition which include temperature, humidity, uncontrolled airflow, and light exposure, may considerably affect the TL dosimetry results. Instrumentation variability is also a factor that may affect the results due to the calibration offset, instrumentation wear, or worn-out TLD components. In addition, positioning error is another factor that affects the dosimetry results due to the parallax error, human error, handling error, as a result of contamination level or storage procedure [10-11].

C. Dose Linearity

Table III: The dose response performed for doses between 0.5 and 5.0 mSv.

S/N	Irradiated dose (mSv)	Measured dose for TLD (mSv)
1	0.5	0.54
2	1.0	1.03
3	1.5	1.60
4	2.0	2.12
5	2.5	2.64
6	3.0	3.04
7	3.5	3.75
8	4.0	4.27
9	4.5	4.85
10	5.0	5.36

The results in Table III indicate a direct proportional relationship between irradiated and measured doses, which is further confirmed by the linear regression analysis in Table IV. The regression yielded $y = (1.072 \pm 0.015)\, x + (0.008 \pm 0.045)$ with $R^2 = 0.9985$ ($n = 10$, $p < 0.001$), demonstrating excellent agreement between measured and applied doses. The near-zero intercept and high coefficient of determination (99.85%) confirm the accuracy and linearity of the dosimetric response across the investigated range. These results are consistent with previous studies [12–14].

Table IV: Linear regression parameters for irradiated dose and measured dose

Parameter	Value
Slope	1.072 ± 0.015
Intercept	0.008 ± 0.045
R^2	0.9985
N	10

The observed deviations are within acceptable limits, indicating that the system shows reliable performance for occupational radiation monitoring. IEC 1066 stipulates that the measured dose should not differ from the conventional true dose value, D, by more than ±10% [15–16]. In this study, the percentage deviation between the measured and irradiated doses ranged from 1.3% to 8.0%, which is well within the prescribed tolerance. The results confirm the compliance with the performance criteria IEC 1066 [5].

Table V provides a summary and comparative evaluation of the performance characteristics of TLD dosimeters.

Table V: Summary and comparison of results of TLD dosimeter characteristics performance evaluation.

Assessment	IEC 1066 Recommendation	Result obtained
Batch Homogeneity	The difference between the maximum and minimum evaluated values should not exceed 30%	13.3%
Reproducibility	The coefficient of variation should not exceed 7.5 for the dosimeters.	7.71%
Linearity	The dosimeter's response variation should not be more than 10% over the range of 0.1 – 10.0 mSv	8.0%

IV. Conclusion

The performance of the thermo-luminescent (TL) dosimetry system used at Federal Teaching Hospital Katsina was assessed under clinical conditions, with evaluations conducted according to the IEC 1066 standard for personal monitoring. Evaluations performed included homogeneity, reproducibility, and linearity. The results indicated that the TL dosimeters exhibited strong performance, meeting almost all test requirements except for a minor deviation in the reproducibility test. However, factors like environmental conditions, instrumentation variability, and handling or positioning errors may significantly alter the dosimetry results. Overall, the findings suggest that the TLDs dosimetry system remains highly effective and reliable for routine personal radiation monitoring in both radio-diagnostics and radiotherapy practices and requires continued evaluation to ensure compliance with international standards.

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References

[1] R. Gombrade and L. Londero, "The understanding of the Physics of Ionizing Radiation through Text Reading," Journal of Revista de Ensino de Ciências e Matemática, vol. 17, no. 1, pp. 1-25, 2026. https://doi.org/10.26843/rencima.v17n1a03.

[2] B. S. Yahaya, U. Ibrahim, S. D. Yusuf, A. A. Mundi, M. M. Idris, Habib Sa'ad, Anas Mohammed, and R. J. Soja, "Performance evaluation of thermo-luminescent dosimeters in personnel in-vivo dosimetry," Dutse Journal of Pure and Applied Sciences (DUJOPAS), vol. 5, no. 2a, 2019.

[3] V. Andrew, and G. Braden," Loss of TLD signal due to high-temperature environmental conditions," *Radiation Protection Dosimetry*, vol. 130, no.34, pp.1-4, 2019.

[4] C. Furetta and P. S. Weng, "Operational Thermo-luminescence Dosimetry," *World Scientific, Singapore*, vol. 3, no. 2, pp. 22-28, 1998.

[5] International Electrotechnical Commission (IEC), "Radiation protection instrumentation – Passive integrating dosimetry systems for personal and environmental monitoring of photon and beta radiation," *International Standard*, vol. 13, no. 18, 1990.

[6] F.A. Selim, "Advanced thermo-luminescence spectroscopy as a research tool for semiconductor and photonic materials: a review and perspective." J. *Physica Status Solidi (a)* 220, no. 10, pp. 220-236, 2023.

[7] M. E. Latorre, L. A. Gonzalez, and A. Hernandez, "Development and assessment of new TLD materials for personal dosimetry in medical environments". *Journal of Radiation Research and Applied Sciences,* vol. 14, no. 2, pp. 118-126, 2021. https://doi.org/10.1016/j.jrras.2020.11.003

[8] M. Daniel, C. S. Ailza, F. S. Elizaima, and M. H. Ernesto, "Characteristics of a Thermo-luminescence Dosimetry System based on LiF:Mg,Cu,P (GR-200) Detectors for Environmental Monitoring", Journal *of Radiation Protection* and *Dosimetry*, vol. 60, no. 2, pp. 147 – 153, 2000.

[9] P. Antonio, T. N. O. Pinto, and L. V. E. Caldas, "TL and OSL techniques for calibration of 90Sr+90Y clinical applicators", *Dosimetry Poster presentations*, vol. 4, no. 7, pp. 69 – 775, 2010.

[10] A. I. Stochiou, F. Scarlat, I. I. Georgescu, and F. Alexiu, "Method to Manufacture Thermo-luminescent Detector Chips using LiF Crystal", *Journal of Optoelectronics and Advanced Materials* vol. 6, no. 4, pp. 1357-1363, 2004.

[11] A. Sharma, S. Agarwal, and J. Kaur, "Thermo-luminescent Dosimetry for Radiation Protection in Healthcare Workers: A review. *Indian Journal of Radiology*, vol. 47, no. 3, pp. 322-331, 2021.

[12] J. Yang, X. Chen, and W. Lin, "Passive dosimeters for radiation dosimetry: Materials, mechanisms, and applications," Advanced Functional Materials, vol. 34, no.41, 2024. https://doi.org/10.1002/adfm.202406186.

[13] R. U. M. Erdemir, M. M. Abuzaid, B. Cavli, H. O. Tekin, and W. Elshami, "Assessment of extremity dose for medical staff involved in interventional radiology procedures," *Journal of Medicine*, vol. 102, no. 43, pp. 112-120, 2023.

[14] P. Andres, "Environmental dosimetry in northwest Patagonia using LiF:Mg,Cu,P: Analysis of reproducibility, sensitivity, and fading changes over time." *Radiation Protection and Environment,* vol. 47, no. 2, pp. 78-82, 2024.

[15] E. Peter, D. Joseph, T. Adejoh, M. Gloria, G. Kpaku, and M. Abubakar, "Assessment of Radiation Protection Measures in a Nigerian Tertiary Health Care Center," *Journal of Health, Medicine and Nursing* (an international peer-reviewed journal), vol. 31, no. 1, pp. 90-104, 2016.

[16] P. Vaz, "Radiation protection and dosimetry issues in the medical applications of ionizing radiation." J. *Radiation Physics and Chemistry,* 104, no. 2, pp. 23-30, 2014.

