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EVALUATION OF TLD-200 SENSITIVITY AND COMPARISON WITH TLD-100 AND STATISTICAL ANALYSIS

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Abstract. *This study aims to evaluate the dosimetric performance of TLD-200 thermoluminescent dosimeters and compare them with TLD-100, evaluating their suitability for radiation monitoring applications. The research relies on key dosimetric features, including linearity, temperature sensitivity, fading, and reproducibility. All experiments were conducted under controlled environmental conditions, adhering to the ambient temperature and relative humidity specifications provided by the manufacturer. Our work began with the calibration and validation of the Harshaw 6600 TLD reader to ensure accurate dose measurements. A total of 200 dosimeters were used to obtain statistically significant results. Linearity was evaluated for various dose levels provided by the internal Sr-90 beta irradiator, while fading effects were investigated to determine signal attenuation over time. Additionally, temperature sensitivity tests were performed to evaluate the impact of thermal variations on dosimetric response. Advanced statistical techniques were employed to assess measurement repeatability, reproducibility homogeneity etc. The results demonstrate that both TLD-100 and TLD-200 display reliable performance, with notable variations in sensitivity and stability under different dose ranges and environmental conditions. These outcomes confirm the suitability of the TLD-200 dosimeters for accurate dose measurement for research study and other monitoring measurements, but we can't use those TLDs in the long term as bimonthly individual monitoring.*

Keywords: *thermoluminescient dosimeter, fading, trumped curve, reproducibility, repeatability, homogeneity*

1. Introduction

The dosimetry laboratory as part of the Institute of Applied Nuclear Physics, has a crucial role in radiation protection in Albania. Using thermoluminescence method, this laboratory provides service for all companies and hospitals that operate and works with ionizing radiation. Workers from these institutions are equipped with dosemeters that are measured at our Institute every two months to assess Hp(10) and Hp(0.07) occupational doses (in mSv), following IAEA recommendations and ISO standards [1-4].

The measurements Hp(10) and Hp(0.07) correspond to elements ii and iii of the dosemeter respectively which are located inside the dosemeter holder composed of two filters for filtering or attenuating radiation as we can understand from Figure 2. Ensuring accurate Understanding its statistical behaviour enables improved calibration protocols and better estimation of uncertainty in radiation dose estimates [5]. To estimate the uncertainty of our measurement system we must take into consideration all influencing measurements as uncertainty which comes from element correction coefficient ECC distribution [6-9]. Advanced statistical analysis is done with MATLAB and other programs (such as SPSS, R, EASYFIT) to conclude in the distribution of values and to inform detail parts of statistics.

2. Literature Review

Thermoluminescent dosimeters (TLDs) such as TLD-100 (LiF:Mg,Ti) and TLD-200 (CaF_2:Dy) have been widely employed for radiation protection, medical dosimetry, and environmental monitoring applications. Their performance characteristics, including linearity, homogeneity, environmental sensitivity, and signal stability, are critical for reliable dose assessment.

The linearity of the dose-response relationship is a fundamental parameter in dosimetry. Studies have shown that TLD-100 exhibits a linear response over a dose range of 50 μGy to approximately 5 Gy, maintaining proportionality between the absorbed dose and the emitted thermoluminescent signal [10]. In contrast, TLD-200 maintains linearity up to doses of about 10 Gy, although with increased deviation at higher doses due to saturation effects [11].

Homogeneity among a batch of dosimeters is essential to ensure consistent measurements across multiple devices. TLD-100 dosimeters, especially after appropriate annealing and UV treatment protocols, have demonstrated improved reproducibility, with standard deviations of the main dosimetric peak reduced below 10% over repeated irradiations. TLD-200, on the other hand, generally exhibits slightly larger variability, attributed to intrinsic material properties and the complexity of its glow curve structure

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[11, 12]. According to Alanazi et al. [12], the expected uniformity across batches must satisfy the acceptance criterion: (Emax - Emin)/Emin < 0.3, a requirement that both TLD-100 and TLD-200 typically meet under controlled conditions.

Environmental factors, particularly ambient temperature, significantly affect the stability of the stored signal. For TLD-100, studies have reported moderate fading, with signal losses of approximately 7–8% after 90 days of storage at 25°C, increasing to about 20% at elevated temperatures of 50°C. TLD-200, however, is more sensitive to environmental temperatures; at 25°C, it shows a fading of about 14% over the same period, and up to 32% at 50°C (Abul-Hail and Abdallah, 2018). These findings emphasize the need for strict environmental control during storage and transport, particularly for TLD-200, to maintain measurement accuracy [13].

Temperature sensitivity during field use is another critical aspect. The thermally stimulated luminescence process inherently renders TLD materials vulnerable to thermal fluctuations. Experimental data indicate that exposure of TLD-100 to 60°C for extended periods (1–3 hours) can reduce the recorded dose by 10–24%, while TLD-200 shows reductions between 14–27% under identical conditions (Current study; Sadeghi et al., 2015). These temperature effects are primarily due to the premature release of charge carriers from shallow traps, leading to a loss of signal before readout [14].

In summary, TLD-100 offers superior performance in terms of reproducibility, stability under varying environmental conditions, and linearity within clinically relevant dose ranges. TLD-200, with its higher sensitivity, remains valuable in specific high-dose or low-dose detection applications, provided that environmental influences are carefully managed.

3. Materials and Methods

The Harshaw 6600 PLUS reader (Figure 1) was installed in Albania in 2022 as part of the ALB9011 project in cooperation with the IAEA, ensuring compliance with all specified conditions. This system complements the existing Harshaw 4500 reader, increasing the capabilities of the dosimetry laboratory. All dosemeters in our study are TLD-100, TLD-100H, tld-200, [11] manufactured by ThermoFisher and by Radcard s.c (Figure 2).

To calibrate the reader, the best performing dosimeters, known as calibration or "Golden" dosemeters [15], were selected (1-2% of all dosemeters). These dosimeters were sent for irradiation in Ruder Boskovic Institute (SSDL) and then measured using the Harshaw 6600PLUS reader, where the Reader Calibration Factor (RCF) was determined [16]. The RCF was generated for some time-temperature profiles (TTP) corresponding to some types of dosimeters in use. For example, for the TLD-100 dosimeters manufactured by Radcard, the recommended time-temperature profile is: preheat for 5 seconds at 170 °C, acquire with a temp rate of 25 °C/s, for 13 seconds up to 300 °C, and anneal for 5 seconds at 300 °C as seen in Figure 1 (red line). The gray part in Figure 1 and the blue part in Figure 2 represent the radiance curve which gives the intensity of the photons emitted by the dosimeter crystal. Integration of the entire closed surface gives the measured dose accumulated in the dosimeter which is automatically calculated by the WinRems software [17].

Figure 1. Harshaw 6600 Plus reader

The same calibration procedure was applied to determine the TTP settings for the TLD-200 and TLD-100H dosimeters, ensuring accurate dose measurements and consistency across different types of dosimeters [18]. Quality Control and determination of Annealing conditions for which a stable signal is obtained have been performed.

For every dosemeter we should calculate one correction coefficient which is easier to find by means of the internal source of Harshaw 6600 which is Sr-90 beta irradiator. The ecc(ii) value is determined according to the formula for each dosemeter and for each element

$$Hp_{ij} = \frac{ECC_{ij} \times Q}{RCF_j} - \text{bg} \qquad (1)$$

where RCF(ii)=0.0295 (RCF(iii)=0.0298) is determined by Golden Cards (Element correction coefficient is between 0.9 to 1.1 for golden dosimeter). RCF(TLD-200)=1.01, RCF(TLD-100)=0.03.

Figure 2. Dosemeter card and holders

4. Results

The dosimeters were irradiated with 200 gU which is defined as 1210µSv and were measured after 24 hours. The WinREMS software enables direct calculation and determination of ECC coefficients for the crystal in position ii and iii. Initially, we considered all the ECC for dosimeters in routine use known as Field Dosemeter and studied their statistics. The distribution of values is given in Figure 3, where the red line represents the Generalized Extreme Value distribution, the blue line represents the normal distribution, and the brown line represents the loglogistic distribution which is adapted to the specific case [19, 20].

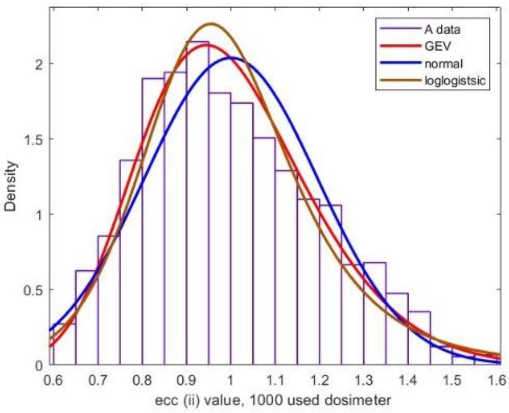

Figure 3. Statistical distribution of ECCs

4.1. Linearity and comparison between tld-200 and tld-100

Ten groups of dosimeters were irradiated (with internal source of Harshaw 6600), with 10 dosimeters for different doses for both dosimeter models (Hp(10)=0.325, 0.65, 1.3, 1.95, 2.6, 3.25, 3.9, 4.55, 5.2, 13 mSv). The measurements were performed with Harshaw 6600plus and analyzed with Matlab to see if they are within the limits or not. Referring to the formula below, consider the recommendations [15]:

$$R = \frac{H_s}{H_c} \quad (2)$$

$$\frac{1}{F}\left(1 - \frac{2H_0}{H_0 - H_c}\right) \le R \le F\left(1 + \frac{H_0}{2H_0 + H_c}\right) \quad (3)$$

The value of H_0 is taken as the lowest level recorded in monthly measurements 0.17 according to ICRP 35/60 or not less than 0.085 according to ICRP 60/75, [2, 8, 21].

From Figure 4 (Trumped Curve), it is observed that the measured values are within the recommended limits, an overestimation (not significant) is observed for tld-200 at low doses.

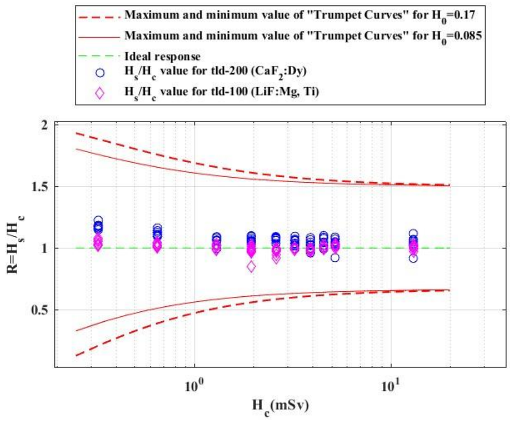

Figure 4. Trumped Curve

4.2. The influence of the storage temperature and the fading phenomenon

Thermoluminescence is the phenomenon of luminescence simulated by increasing the temperature of the luminescent material. It is expected that the system will be sensitive to temperature; therefore, it is advisable to store the dosimeter at ambient temperature. Storing the dosimeter at high temperatures may affect the accurate dose estimation due to the release of photons from shallow trapped energy levels [10]. We have conducted many experiments, and it turns out that keeping the dosimeters at a temperature of 60 degrees Celsius for one hour, 2 hours and 3 hours can reduce the dose and have information loss of 10.3% for one hour, 18.7% and 24.6% for 2 and 3 hours for TLD-100 and 14.8%, 16.3% and 27.38% for 1, 2 and 3 hours for TLD-200. The measurements performed are found in the two tables below (Table 1, Table 2), but clearer results can be obtained from the graph below where the measurements for TLD-200 are in blue and those for TLD-100 are in red and the linear regression of each case (Figure 5).

Table 1. Responses of Tld-100 after heating 60 °C

Time (hour)	H_1 (mSv)	H_2 (mSv)	H_3 (mSv)	H_4 (mSv)	H_5 (mSv)	Mean (mSv)	ε (%)
0 (Expected dose)	1.297	1.297	1.297	1.297	1.297	1.297	0
1	1.147	1.198	1.186	1.145	1.201	1.1754	10.3
2	1.109	1.091	1.103	1.088	1.069	1.092	18.7
3	1.056	1.024	1.044	1.031	1.046	1.0402	24.6

Table 2 Responses of Tld-200 after heating in 60 °C

Time (hour)	H_1 (mSv)	H_2 (mSv)	H_3 (mSv)	H_4 (mSv)	H_5 (mSv)	Mean (mSv)	ε (%)
0 (Expected dose)	1.297	1.297	1.297	1.297	1.297	1.297	0
1	1.056	1.224	1.08	1.143	1.143	1.1292	14.8
2	1.117	1.13	1.072	1.173	1.092	1.1168	16.13
3	1.026	1.07	0.981	1.061	0.953	1.0182	27.38

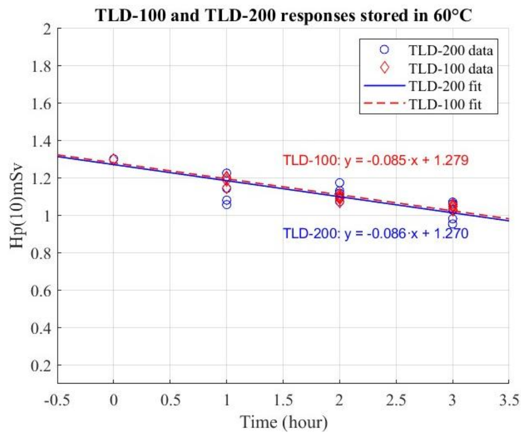

Figure 5. The dependence of the dosimeter response on the time of exposure to temperatures slightly above normal

However, it is expected that the dosimeter will fade even at room temperature for long periods. This affects the inaccurate dose assessment, so we recommend that the dosimeters be measured frequently, once every one or two months. Our case examines the loss in 2 weeks, where 70 dosimeters of one type and 70 of another type were irradiated and were measured approximately every 2 days and we studied the loss or fading that they suffered for approximately 2 weeks (Figure 6).

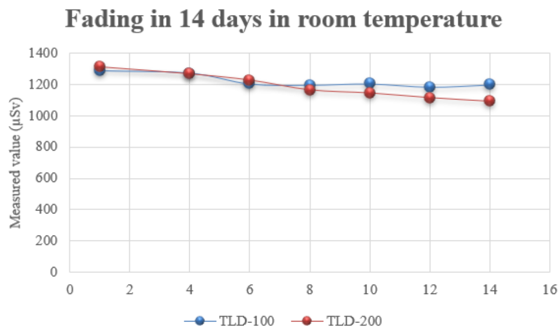

Figure 6. Fading in room temperature for TLD-100 and TLD-200

It is noted that the TLD-200 dosimeter has a higher attenuation for 2 weeks. It remains to be examined the loss for longer periods, but referring to the manufacturer, and other studies, the TLD-200 dosimeters have greater loss, which has prompted us to continue further studies and not to use them for long periods of time such as for periodic individual assessment (2 months).

4.3. The homogeneity of TLD-200 and TLD-100

For this case, 60 TLD-100 dosimeters and 60 TLD-200 dosimeters were taken into consideration randomly from a group of 300 TLD-100 dosimeters and 300 TLD-200 dosimeters. They were irradiated by the internal source and measured after 24 hours.

The homogeneity must be within 30% and will be calculated according to the following formula [12]:

$$\frac{E_{max}-E_{min}}{E_{min}} < 0.3 \qquad (4)$$

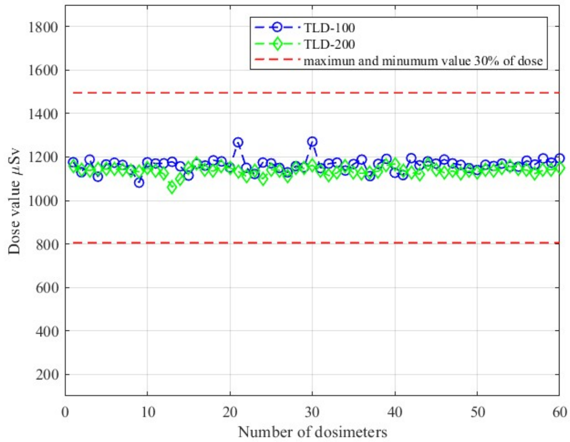

Figure 7. Homogeneity of measurements for 60 dosimeters

Table 3. Homogeneity limits and calculations

	Tld-100	Tld-200
E_{max}	1270.54	1170.60
E_{min}	1081.90	1060.74
E_{mean}	1163.51	1137.23
dev	107.026	76.488
dev%	9.19	6.72
stdev	30.67	17.94
$\frac{E_{max}-E_{min}}{E_{min}}$	0.174	0.103

From Table 3 and Figure 7, we understand that the dosimeters maintain homogeneity in measurement with a deviation of approximately 9% and 6% and within the limits of 0.3 referring to the above formula (0.174 and 0.103).

4.4. Reproducibility and repeatability

For reproducibility and repeatability, 10 dosimeters of the same type (TLD-100 and TLD-200) were taken, irradiated ten times with the same dose and measured ten times each. These tests helped to assess the stability of the measurements under real working conditions [22].

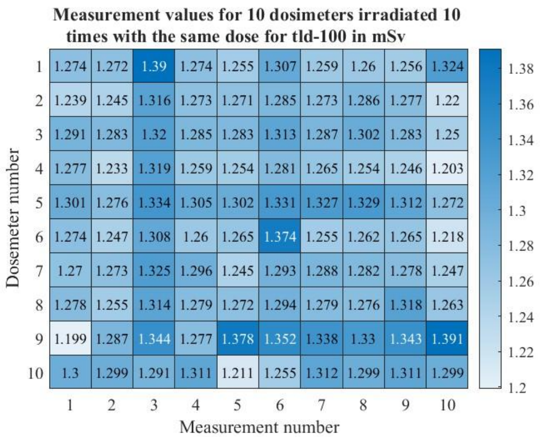

Figure 8. Measurement for 10 irradiations of 10 TLD-100

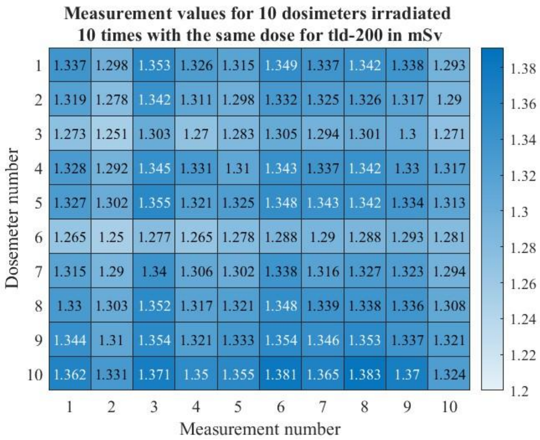

Figure 9. Measurement for 10 irradiations of 10 TLD-200

Figures 8 and 9 show the values measured after irradiation for 10 dosimeters, irradiated 10 times, where the order according to the respective code has been maintained for each dosimeter. From the data, both tests and tests of repeatability and reproducibility of the values have been performed. Repeatability provides the preservation, or homogeneity of the values for different measurements, while reproducibility provides the same assessment for different dosimeters. The reproducibility of measurements for TLD-100 and TLD-200 demonstrated good stability in the results. The coefficient of variation (CV%) for TLD-100 ranged from 1.2% to 4.7% with an average of about 2.4%, while for TLD-200 it ranged from 1.4% to 2.3%, with a lower average of about 1.9%, indicating that TLD-200 offers slightly higher stability for repeated measurements with the same dosimeters (Table 4 and Figure 8).

The repeatability of the measurements was assessed using ten different dosimeters, which were irradiated under identical conditions but at different times. The CV% for TLD-100 ranged from 1.5% to 4.2%, while for TLD-200 it was significantly lower, ranging between 1.07% and 1.55%. This indicates a better repeatability for TLD-200, especially under standardized conditions (Figure 10 and 11).

Table 4. Measurements for different dosimeters, average and coefficient of variation for TLD-100 and TLD-200 for reproducibility

Measurements nr	Average (mSv)	CV%	Average (mSv)	CV%
	TLD-100		TLD-200	
1	1.27	2.4	1.32	2.3
2	1.27	1.5	1.29	2.0
3	1.33	1.9	1.34	2.1
4	1.28	1.2	1.31	2.0
5	1.27	3.2	1.31	1.8
6	1.31	2.4	1.34	1.9
7	1.29	2.3	1.33	1.8
8	1.29	2.2	1.33	2.0
9	1.29	2.5	1.33	1.6
10	1.27	4.7	1.30	1.4

Table 5. Measurements for different irradiation, average and coefficient of variation for TLD-100 and TLD-200 for repeatability

TLD nr	TLD 100		TLD 200	
	Average	CV%	Average	CV%
1	1.29	3.32	1.33	1.550
2	1.27	2.16	1.31	1.510
3	1.29	1.50	1.29	1.423
4	1.26	2.44	1.33	1.266
5	1.31	1.69	1.33	1.241
6	1.27	3.30	1.28	1.075
7	1.28	1.84	1.32	1.312
8	1.28	1.58	1.33	1.240
9	1.32	4.24	1.34	1.174
10	1.29	2.48	1.36	1.446

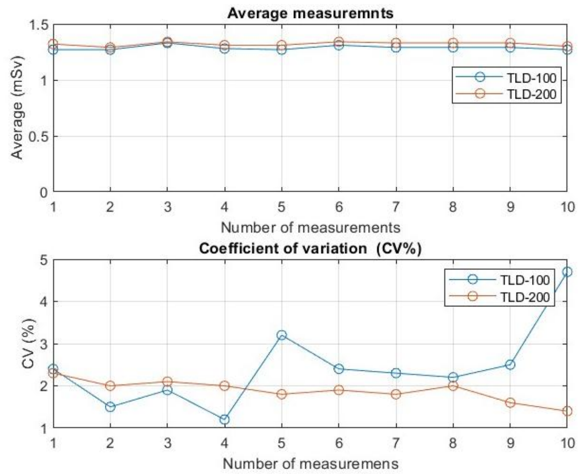

Figure 10. Dose measurements for reproducibility for 10 different dosemeter irradiated and measured 10 times

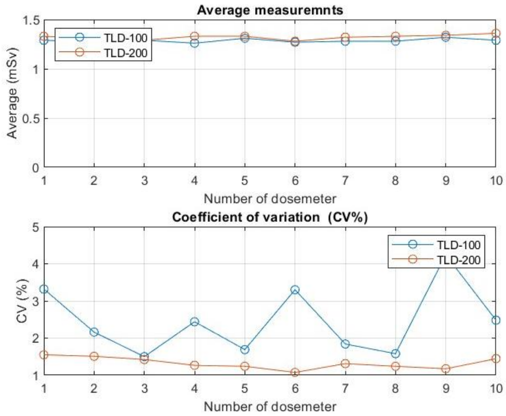

Figure 11. Dose measurements for repeatability for 10 different irradiations and measured for 10 dosimeters

5. Conclusion

This study comprehensively evaluated and compared the dosimetric performance of TLD-200 (CaF_2:Dy) and TLD-100 (LiF:Mg,Ti) thermoluminescent dosimeters through a series of controlled experiments focusing on key parameters including linearity, sensitivity, reproducibility, repeatability, thermal fading, and batch homogeneity. The experiments were conducted using the Harshaw 6600 PLUS reader system, following standard calibration protocols and employing internal β-source irradiation for consistent dose delivery.

The findings confirm that both TLD types demonstrate satisfactory linearity within their respective operating dose ranges. TLD-100 displayed a consistent linear response up to approximately 5 Gy, making it well-suited for low to moderate dose measurements. Conversely, TLD-200 maintained linearity up to 10 Gy, suggesting enhanced sensitivity particularly advantageous in high-dose environments. However, at lower doses (e.g., below 1 mSv), a slight over-response was observed for TLD-200, which may lead to overestimation of dose if not properly corrected.

In terms of reproducibility, TLD-200 demonstrated slightly superior stability, with coefficient of variation (CV%) values ranging from 1.4% to 2.3%, compared to 1.2% to 4.7% for TLD-100. Similarly, in repeatability tests—where 10 different dosimeters were irradiated under identical conditions—TLD-200 showed CV% values as low as 1.07% to 1.55%, significantly better than TLD-100 (1.5% to 4.2%). These results indicate that TLD-200 offers higher precision for repeated short-term measurements under standardized conditions.

However, a critical limitation of TLD-200 was observed in its thermal stability and fading behavior. When stored at 60 °C for 3 hours, TLD-200 exhibited a signal loss of 27.38%, compared to 24.6% for TLD-100. More importantly, under ambient room temperature conditions (approximately 25 °C), the fading of TLD-200 over a two-week period was considerably higher than that of TLD-100. This degradation, attributed to the early release of charge carriers from shallow traps, raises concerns for long-term storage and delayed readout, rendering TLD-200 unsuitable for extended monitoring intervals such as the standard two-month personal dosimetry cycle.

The batch homogeneity for both dosimeter types was within acceptable limits. For TLD-100, the (Emax – Emin)/Emin ratio was calculated at 0.174, while for TLD-200 it was 0.103—both well below the maximum allowed threshold of 0.3, confirming good uniformity among dosimeters of the same type.

Considering all the results, TLD-200 shows potential as a sensitive and statistically reliable dosimeter for controlled laboratory studies and short-duration monitoring scenarios where immediate readout is possible and environmental factors are tightly managed. In contrast, TLD-100, despite exhibiting slightly lower sensitivity, remains the dosimeter of choice for routine personal monitoring and operational dosimetry in field conditions due to its greater thermal robustness, lower fading rate, and reliable long-term performance.

Therefore, the use of TLD-200 is not recommended for bimonthly individual dose monitoring, whereas TLD-100 complies fully with the criteria established by IAEA, ISO 14146, and IEC 61066 standards for reliable and traceable personal and environmental dosimetry. Future research may focus on optimizing the thermal stability of TLD-200 or developing calibration algorithms to compensate for fading effects to further expand its applicability.

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