Performance Characteristics of a New Automatic Chip TLD Reader

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ABSTRACT

The TR5500 Thermoluminescent Dosimeter (TLD) reader was specifically designed and developed for the automated and efficient readout of Thermoluminescent (TL) chips and pellets in Iran. In accordance with International Atomic Energy Agency (IAEA) requirements for dosimetry laboratories, implementing a comprehensive Quality Management System (QMS) is essential to ensure adherence to standard criteria. This study aimed to evaluate key characteristics of the reader, including response non-linearity, Coefficients of Variation (COV), readout stability over time, and the reproducibility of TLD measurements. LiF: Mg, Cu, P TLDs were exposed to a standard photon radiation field and subsequently read using the TR5500 reader. The characteristics were then calculated and compared against the relevant criteria outlined in International Electrotechnical Commission (IEC) and American Society for Testing and Materials (ASTM) standards, such as ASTM E668-10 and IEC 62387. The reader met the key international standard requirements and, in certain aspects, even surpassed them. The device exhibited excellent stability and reproducibility in readouts, confirming its robust reliability and long-term suitability for routine use in various accredited dosimetry laboratories.

Keywords

TLD; Dosimetry; Reader; Radiation Monitoring; Equipment Design; Thermoluminescent; Health Care

Introduction

A key advantage of chip/pellet-based readers is their flexibility in selecting, replacing, preheating, and oven-annealing Thermoluminescent Dosimeters (TLDs) in any desired configuration, regardless of the dosimetry system's intended application. However, fully automated readers, capable of sequentially and continuously reading multiple dosimeter chips/pellets, have only been developed and commercialized to a limited extent.

A Quality Management System (QMS) is mandated for dosimetry laboratories under the requirements of the International Atomic Energy Agency (IAEA) to ensure adherence to standard criteria [1].

Consequently, several studies, such as type-testing programs, have been conducted by researchers on various TLD reader models [2-8].

This study aimed to evaluate key characteristics of the reader, including response non-linearity, Coefficients of Variation (COV), readout stability over time, and the reproducibility of TLD measurements.

Material and Methods

The experimental study was conducted using a TR-5500 TLD reader

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(Radonik, Iran) (Figure 1-a). In this system, 27 TLD chips/pellets are linearly arranged in a numbered magazine. During operation, the magazine moves step by step so that each TLD chip/pellet is brought directly under the Photomultiplier Tube (PMT) for measurement. A user-defined Time-Temperature Profile (TTP) is applied using hot dry air, while cooling air is simultaneously directed onto adjacent dosimeters to prevent thermal interference with subsequent readings.

The reader incorporates a stable Light-Emitting Diode (LED) Reference Light (RL) source to monitor system response stability during each readout cycle. A dedicated software interface, connected via Local Area Network (LAN), records numerical data and glow curves in Excel format.

Dosimeters and Annealing

LiF: Mg, Cu, P (GR-200, China) dosimeters were used. Annealing was performed at 240 °C for 10 minutes, followed by preheating at 100 °C for 10 seconds. The readout parameters included: maximum temperature (240 °C), readout time (40 seconds), and heating rate (10 °C/s).

All dosimeters were irradiated using a cobalt-60 (^{60}Co) source at the Secondary Standard Dosimetry Laboratory (SSDL) of Iran. Testing was conducted under reference laboratory conditions with temperature (23 °C) and ambient light intensity (150 lux).

Non-Linearity and COV calculation (IEC 62387 Standard)

To assess the non-linearity of the reader, ten

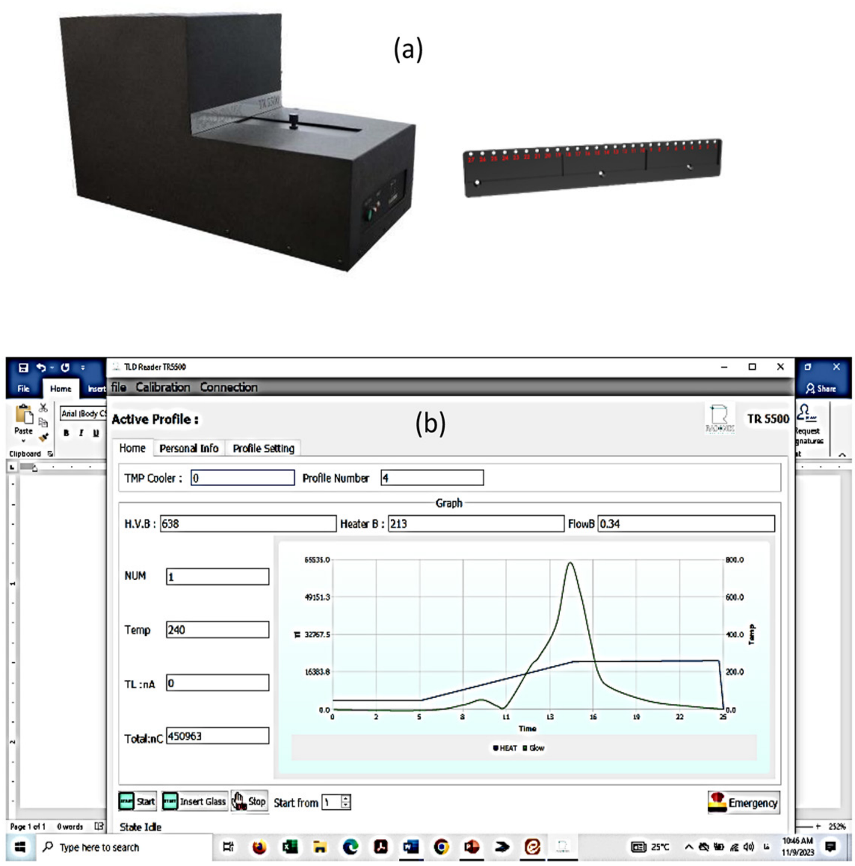

Figure 1: (**a**) The TR-5500 automatic chip Thermoluminescent Dosimeter (TLD) reader system, equipped with a dosimeter loading cartridge, (**b**) A representative Thermoluminescent (TL) glow curve of Gr-200.

sets of dosimeters were exposed to reference doses of ^{60}Co ranging from 0.1 to 1000 mSv. Repeated measurements, four at each of the seven dose levels, were performed [10]. Moreover, the Coefficient of Variations (COV), which is defined as the ratio of the Standard Deviation (SD) to the mean value of repeated measurements, is expressed as a percentage.

Reproducibility Testing (ASTM Standard)

In accordance with American Society for Testing and Materials (ASTM) standards, the reproducibility of reusable dosimeters was assessed using the following criteria: irradiating and reading a single TLD 30 times; and calculating the mean value and standard deviation of the measurements [9].

PMT Reference Light Stability

Variations in the PMT reference light values were recorded at specified time intervals to monitor system stability.

Results

Glow curve analysis and linearity response

Figure 1-b displays the glow curve of a GR-200 TLD pellet obtained using the reader's dedicated software. The curve exhibits all characteristic peaks, low-temperature, dosimetric, and high-temperature, consistent with those observed in commercial TLD readers. This similarity confirms the system's capability to properly resolve the thermoluminescent signal.

The calibration curve for Hp (10) doses ranging from 0.1 mSv to 100 mSv is presented in Figure 2. The reader demonstrates excellent linear response across this dose range, with a correlation coefficient (R^2) of 0.99955. The results indicate that this reader provides a perfectly linear response across the mentioned dose range.

Non-Linearity of response and COV

Table 1 presents the comprehensive results for response non-linearity and its associated coefficient of variation (COV). The values computed for the inequality are as follows:

$$0.91 - U_{C,com} \leq \left(\frac{\overline{G_i}}{G_{r,0}} \pm U_{com} \right) \cdot \frac{C_{r,0}}{C_r} \leq 1.11 + U_{C,com} \quad (1)$$

The variable C_r represents the conventional true value of the (delivered) dose equivalent under reference conditions, while $C_{r,0}$ indicates the same for C_r but only as the reference dose equivalent. U_{com} denotes the expanded uncertainty of a combined quantity, and $U_{C,com}$ refers to the expanded uncertainty for a combined quantity of conventional true values. These definitions apply to all ten dose values, confirming that the non-linearity of response aligns with the IEC criteria.

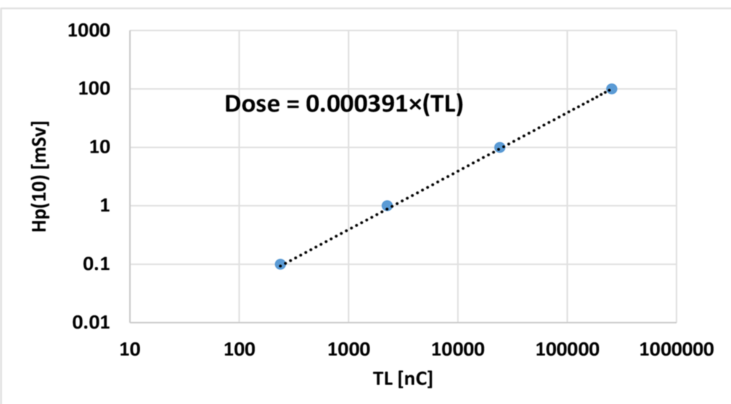

Figure 2: Primary calibration curve using Thermoluminescent Dosimeter (TLD) reader of model TR5500

As stated in the IEC 62387 standard [8], the COVs for doses must meet specific requirements: for doses under H<0.1, 0.1≤H<1.1, and H≥1.1 mSv, and the COVs should be below 15%, (16–H/0.1mSv) %, and 5%, respectively. The observed values below the criteria are outlined in Table 1 of the IEC 62387 standard [8].

Stability of PMT

As presented in Figure 3, the RL outputs of the photomultiplier tubes were monitored at two-month intervals. Although specific limits for PMT readings are not provided, deviations up to ±3.6% are considered permissible and in agreement with other commercially available TLD reader models [10].

Table 1: The results of non-linearity of response and Coefficient of Variation (COV) for the TR5500 Thermoluminescent Dosimeter (TLD) reader model in a dosimetry system.

Dose Value (mSv)	U_{com}	$U_{C,com}$	Test result for $0.91-U_{C,com} \le \left(\frac{\overline{G_i}}{G_{r,0}} \pm U_{com}\right).\frac{C_{r,0}}{C_r} \le 1.11+U_{C,com}$	Test result for $\frac{S_i}{G}(\%)$	IEC Criteria for COV (c_1×#)	IEC Criteria for COV (c_2×#)
0.1	0.003		0.85≤0.91 _ 1.10≤1.17	7.50	<18.23	
0.3	0.012		0.85≤0.85 _ 1.08≤1.17	11.30	<15.80	
0.7	0.012		0.85 ≤ 0.86 _ 1.07 ≤ 1.17	6.09	<10.94	-
1.0	0.029		0.85≤1.00 _ 1.03≤1.17	6.09	<7.29	
3.0	0.028		0.85≤0.85 _ 1.02≤1.17	3.88	<6.08	
10.	0.108	0.06	0.85≤0.89 _ 1.11≤1.17	5.75	<6.08	
30.	0.385		0.85≤0.93 _ 1.16≤1.17	7.93	-	<8.86
100.	1.096		0.85≤1.01 _ 1.17≤117	3.46	<6.08	-
300.	2.996		0.85≤0.92 _ 1.12≤1.17	3.38	<6.08	
1000.	11.124		0.85≤0.86 _ 1.08≤1.17	6.94	-	<8.86

IEC: International Electrotechnical Commission, COV: Coefficients of Variation

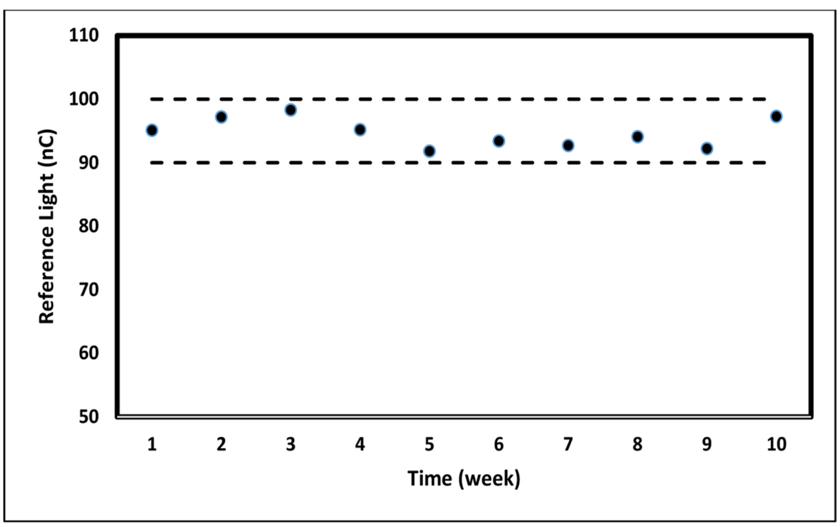

Figure 3: Stability of Photo Multiplier (PM) tubes Thermoluminescent Dosimeter (TLD) reader of model TR5500

Reproducibility

To assess reproducibility, the response-versus-cycle data were analyzed using a least-squares fitting approach. The evaluation involved calculating the standard deviation of the data points from the fitted curve. As shown in Figure 4, the ratio of this standard deviation to the average response value was determined to be 1.8%, which complies with the ASTM Standard [9] requirement of remaining below 5.0%.

Discussion

The results obtained from the TR5500 TLD reader demonstrate that the device consistently provides accurate, stable, and reproducible dosimetric measurements. The highly linear response over a wide dose range (0.1 to 100 mSv) with a correlation coefficient of R^2=0.99955 indicates that the reader can reliably quantify radiation doses relevant for occupational monitoring. This level of linearity is comparable to, and in some cases superior to, that reported for commercial TLD readers, confirming the efficacy of the reader's design and calibration protocol. The non-linearity and COV values remained well within the acceptance criteria set by IEC 62387, underscoring the precision and reliability of the system. Such adherence to international standards is essential for dosimetry laboratories seeking accreditation and ensures confidence in routine dose assessments. Furthermore, the stability of the PMT, demonstrated by a maximum ±3.6% variation over bimonthly intervals, aligns closely with benchmarks established for commercial readers, suggesting that the device maintains consistent sensitivity over time. Reproducibility tests also yielded favorable results, with an average standard deviation ratio of 1.8%, significantly below the ASTM-recommended threshold of 5.0%. This confirms that the TR5500 reader can produce consistent readouts across repeated measurements, which is critical for minimizing uncertainty in dose estimations. Overall, these findings illustrate that the TR5500 TLD reader is a robust and reliable instrument suitable for implementation in accredited dosimetry laboratories, particularly in settings where a locally developed alternative to imported readers is desirable. While this study focused on photon radiation fields, further evaluation under mixed radiation types and extended long-term operational conditions would provide additional validation of the reader's capabilities. In this article, we have evaluated the most important parameters of a TLD reader device. In this

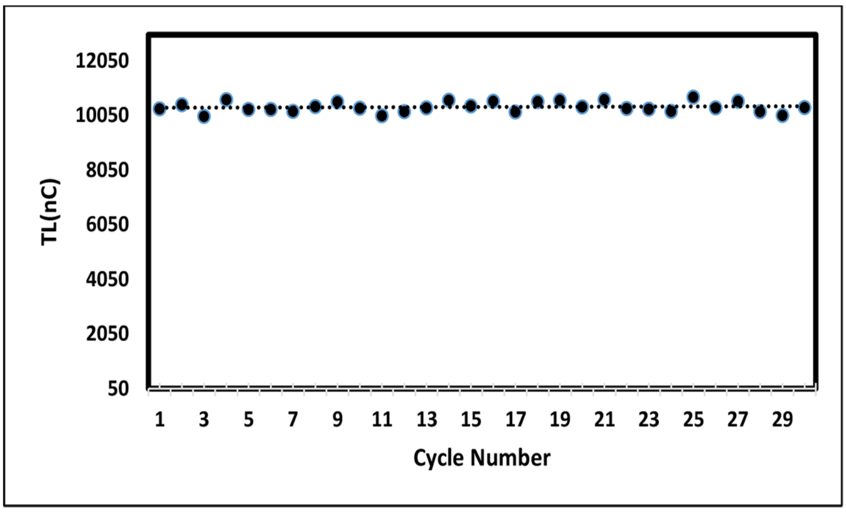

Figure 4: Reproducibility test of Thermoluminescent Dosimeter (TLD) reader of model TR5500 for 30 annealing-expose-readout cycles

regard, there are no limitations for this device.

A comprehensive evaluation of all parameters of a reader based on standard criteria requires additional tools and equipment and cannot be covered within the scope of a short article such as this one. However, it is under investigation, and the results will be published in another paper.

Conclusion

The performance criteria of a prototype TR-5500 homemade TLD reader were evaluated. The reader was found to meet key international standard requirements by significant margins. The device demonstrated excellent stability and reproducibility in readouts, confirming its suitability for reliable and efficient use in an accredited dosimetry laboratory.

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Authors' Contribution

S. Betyar was responsible for the writing of the original draft, Data collection, and editing. SM. Hosseini Pooya contributed through conceptualization, methodology, and data collection. M. Divsalar participated in supervision. All authors read, modified, and approved the final version of the manuscript.

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Conflict of Interest

None

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