

RESEARCH ON THE PARAMETERS OF A PASSIVE (INTEGRAL) DOSIMETRIC SYSTEM FOR NATURAL RADIATION BACKGROUND MEASUREMENT

Tsvetelin P. Tsrunchev, Daniela P. Draganova, Georgi E. Apostolov

National Centre of Radiobiology and Radiation Protection, Sofia, Bulgaria

Abstract

The TLD RADOS-2000-A dosimetric system is designed for measuring the ambient dose $H^*(10)$ related to environmental and workplace radiation. The system includes environmental thermoluminescent dosimeters and a thermoluminescent reader. Each dosimetric system must be calibrated before commissioning to establish the relationship between irradiation parameters and the measured controlled parameter. The relationship between the ambient dose $H^*(10)$ and the luminescence read by the thermoluminescent reader is applied for measurement. This dependency is influenced by the composition of the dosimeter tablets and the production conditions. Thus, batch homogeneity and dosimeter separation must be investigated. This article describes and documents the initial procedures in commissioning a dosimetric system—separation and calibration of the dosimeters. The methods applied are based on international standards and guidelines, as well as on the long-standing experience of NCRRP in using thermoluminescent dosimeters for measuring individual equivalent doses in personal dosimetric control. Various factors influence the readings of dosimetric calibration measurements. One significant factor is the angular dependence of the radiation incident on the dosimeters. At this stage, the effect was studied at incident angles of $\alpha = 0^\circ, \pm 60^\circ$, and $\pm 90^\circ$. The studies and calibrations were carried out using the G10 Gamma Beam Irradiator System, Hopewell Designs Inc., loaded with a ^{137}Cs source. The system includes a positioning system, a reference measurement system (electrometer and ionization chamber). Using this system ensures high calibration accuracy and traceability of dosimetric measurements.

Keywords: radiation, dosimetry, TLD, background, calibration, measurements

1. INTRODUCTION

Thermoluminescent dosimetric systems are widely used passive dosimeters applied both in individual dosimetric control and in radiation protection for measuring ambient dose $H^*(10)$ in the environment and workplaces. The principle of thermoluminescence involves heating a thermoluminescent material (TLM) that has been exposed to ionizing radiation (IR), releasing stored energy as photons. When exposed to IR (such as X-rays, gamma rays, beta radiation, and electrons), electrons in the material are excited and trapped in defect centers or impurities. Upon heating, the trapped electrons are released, emitting light proportional to the absorbed radiation dose, counted by a photomultiplier tube (PMT) [1]. According to international standards, international publication and national legislation, as well as good laboratory practice, all measurement systems must be calibrated to establish the relationship between the nominal and measured quantities and ensure measurement traceability [2, 3, 4, 5, 6, 7, 8]. Manufacturing thermoluminescent detectors often leads to varied responses, necessitating preliminary dosimeter separation. For high-quality measurements and uncertainty assessment, influencing factors such as energy and angular dependence, fading, measurement range, and calibration linearity must be studied. This article presents results from the initial commissioning of a TLD system for measuring environmental radiation parameters and investigates several influencing factors.

2. MATERIALS AND METHODS

2.1. Materials

For commissioning a TLD system for measuring ambient dose $H^*(10)$ in the environment, the standard equipment of the Secondary Standard Dosimetry Laboratory (SSDL) at NCRRP was used [4]. The laboratory is part of the WHO and IAEA international SSDL network.

Irradiation Equipment includes:

G10 Gamma Beam Irradiator System, Hopewell Designs Inc., loaded with a ^{137}Cs source (740 GBq), positioning system, and control systems ensuring radiation safety. Reference measurement equipment: PTW UNIDOS Weblin electrometer model T10022, and 1000 cm³ ionization chamber, model TW 32002. Calibrated at IAEA SSDL, Seibersdorf, Austria, ensuring international traceability. Meteorological station monitoring air temperature (°C), atmospheric pressure (hPa), and relative humidity (% rH). Chronometer integrated into the gamma system control. **Fig. 1** shows the gamma calibration setup used for determining the nominal $H^*(10)$ and irradiating the thermoluminescent dosimeters.

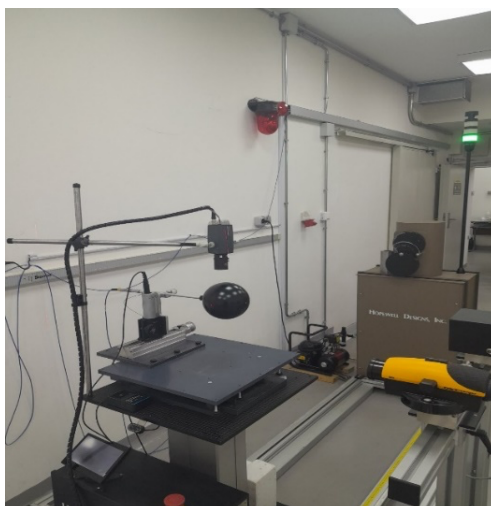


Fig. 1. Gamma – alibration setup

The thermoluminescent dosimetric system for ambient dose measurement includes: TLD system RADOS-2000-A, composed of: thermoluminescent Reader RE-2000-A with WinTLD Pro software installed on a PC, thermoluminescent dosimeters type MCP-N. The Thermoluminescent Reader RE-2000-A is shown in **Fig. 2**.



Fig. 2. Thermoluminescent Reader RE-2000-A

It consists of:

Photomultiplier Tube (PMT); Light guide from a reference light source; Nitrogen temperature sensor; Nitrogen input and output; Heater; Slider to push the dosimeter slide; Vacuum needle; Vacuum filter; Temperature control unit; Signal output; TLD Server Pro user interface **Fig. 3**.

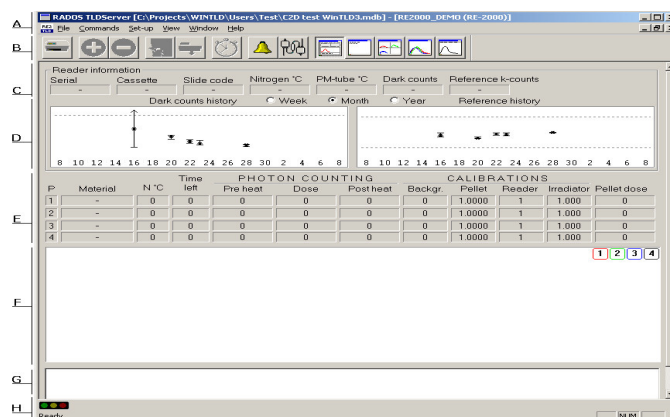


Fig. 3. TLD Server Pro user interface

Dosimeters consist of MCP-N thermoluminescent tablets (LiF:Mg,Cu,P) inserted into slides with corresponding barcodes. Each slide holds up to four tablets and is placed into a slide holder **Fig 4**.



Fig. 4. Slide holder

Each slide includes two positions shielded by a 0.5 mm aluminum (Al) filter. DORIS (Dosimeter for Indoor and Outdoor Surveys) is based on standard RADOS TLD cards with two or four detectors in a slide. The combination of dose measurements from all positions provides a dosimeter response that closely approximates the personal ambient dose equivalent $H^*(10)$, allowing measurements over a wide energy range (10 keV to 10 MeV). The external shell of a TLD dosimeter is shown in **Fig. 5**.



Fig. 5. External shell of a TLD dosimeter

The Glow Curve represents the intensity of emitted light as a function of temperature and time [9]. It often displays as light intensity over time for better interpretability, depending on the heating profile, which includes preheating, reading, and annealing periods. The glow curve may contain one or more peaks depending on the chosen measurement method. If the tablets have not been preheated before reading, a low-energy peak will appear. At this stage, the following were completed: separation of available dosimeters, calibration of the dosimetric system, investigation of one of the main influencing factors — angular dependence. Methods are based on international standards and long-term expertise in radiation metrology and personal dosimetric control.

2.2. Calibration Methods

Irradiation time for calibration dosimeters is determined using measuring equipment (UNIDOS Weblin dosimeter PTW FREIBURG, Germany, and corresponding ionization chamber). Irradiation of calibration dosimeters is performed at the gamma beam irradiator loaded with ^{137}Cs on the calibration setup [3, 4, 5, 6, 7, 8]. The dosimeters are placed freely standing on holders. The phantom is positioned so that its center coincides with the calibration point. Ten independent measurements of [Gy/h] are performed. The mean value is calculated using the following equation:

$$\bar{K}_a = \frac{\sum_{i=1}^{10} K_{ai}}{10}, [\text{Gy/h}] \quad (1)$$

Dosimeters are irradiated at ten dose levels: 0.1; 0.2; 0.5; 1.0; 2.0; 5.0; 20.0; 50.0; 100.0; 200.0 [mSv].

After irradiation: Dosimeters are measured with the RE-2000-A TLD Reader; mean TL signal and standard deviations are calculated; background dosimeters are measured separately; a calibration curve is built (individual equivalent dose vs. TL signal, and calibration factor N is determined by the formula:

$$N = f\left(\frac{Hp(10)_i}{\bar{A}_i - \bar{a}}\right) \quad [\text{mSv/TL signal}] \quad (2)$$

Where: $Hp(10)_i$ is the individual equivalent dose; $\bar{A}_i$ mean value of TL signal at the i -th dose level; $\bar{a}$ —mean background value. Additionally, the dosimeters were irradiated at seven low – dose levels – 0,05[mSv]; 0,1[mSv]; 0,25[mSv]; 0,5 [mSv]; 0,75 [mSv]; 0,9[mSv]; 1 [mSv].

2.2.1. Angular dependence

According to international standards [1], measurements were carried out at angles: $\alpha = 0^\circ, \pm 60^\circ, \pm 90^\circ$, and the relative response at these angles must meet standard requirements.

3. RESULTS

Separation of dosimeters

The batches of MCP-N tablets were non-homogeneous, requiring separation. After annealing and irradiation with $H^*(10) = 0.5$ mSv, the TL signal was measured. Fig. 6 shows a histogram of the responses. Based on $\pm\sigma$ range (standard deviation), 24 dosimeters were selected from 100 available, providing repeatable measurements for ambient dose monitoring.

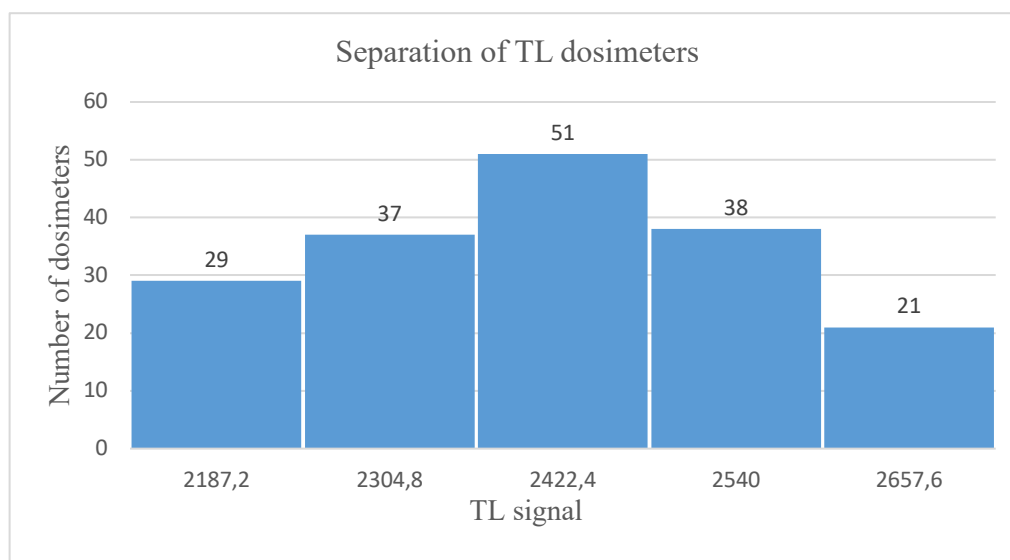


Fig. 6. Histogram Distribution of Dosimeter

Calibration of the dosimetric system

Using the separated dosimeters, a full calibration was performed. Applying the above-described method: Results are shown in **Table 1**. The calibration curve is presented in **Fig. 7**. The calibration coefficient determined was $N = 7.69 \times 10^{-4} [mSv/TL\ signal]$. The calculated coefficient of variation for each dose level indicates very good linearity of the calibration curve, according to international standards [4]. Brunzendorf, and Behrens have similar results presented in their paper [10].

Table 1. Calibration of the Thermoluminescent Dosimetric System for Measuring Ambient Dose $H^*(10)$

Referent value, $H^*(10)$ [mSv]	Indentification №	TL signal A_1	TL signal A_2	Average $\bar{A}$	Average without background $\bar{A} - \bar{a}$	STDV $\sigma(D)$	Variation coeff. $v(D)$ [%]
0.05	900026	1528	1656	1586	87,5	64	4
	900028	1536	1624				
0.10	900020	1704	1504	1641	143	90	5,5
	900021	1736	1560				
	900022	1688	1656				
0.25	900045	1764	1728	1800	314	49	2,75
	900046	1864	1792				
	900047	1840	1808				
0.50	900023	2192	1900	2164	665	176	8,16
	900024	2204	2052				
	900025	2428	2208				
0.75	900017	2260	2252	2431	932	246	10,13
	900018	2812	2672				
	900019	2268	2320				
0.90	900048	2624	2888	2680	1194	213	7,9
	900049	2620	2764				
	900051	2868	2312				
1.00	900011	2856	3592	3041	1543	309	10,16
	900012	2992	2952				
	900013	2700	3156				
Background	900008	1492	1448	1500		69	
	900015	1520	1436				
	900029	1416	1540				
	900030	1632	1504				

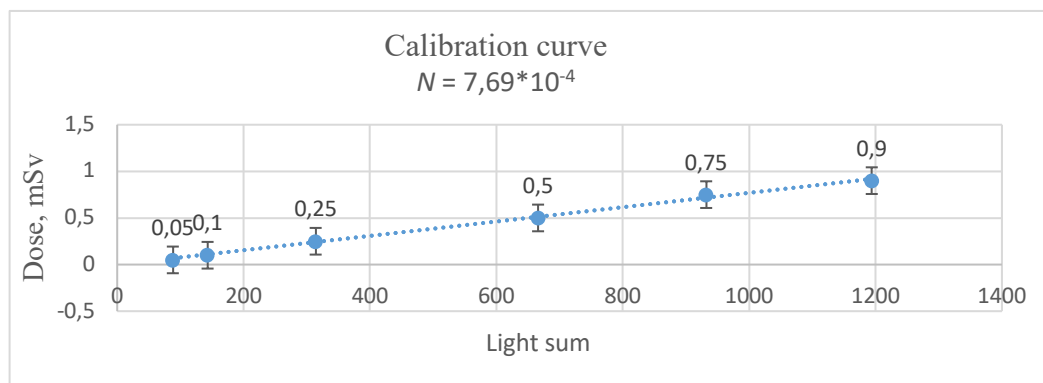


Fig. 7. Calibration curve

Angular Dependence

A significant influence on dosimeter readings is the angle of radiation incidence. Experiments were conducted at angles of $\alpha = 0^\circ, 60^\circ, 90^\circ$. Dosimeters were irradiated with $H^*(10) = 0.5$ mSv. For each angle, 3 dosimeters were used. Standard deviations and coefficients of variation were calculated. Measured doses were corrected using the calibration factor. The results meet the criteria of international standards shown in **Table 2**.

Table 2. Calibration of the Thermoluminescent Dosimetric System — Angular Dependence.

Referent value, $H^*(10)$ [mSv]	Identification №	TL signal A_1	TL signal A_2	Average $\bar{A}$	Average without background $\bar{A} - \bar{a}$	STDV $\sigma(D)$	Variation coeff. $\nu(D)$ [%]	Dose $H^*(10)$ [mSv]
0.50	900023	2192	1900	2164	665	176	8,16	0,46
	900024	2204	2052					
	900025	2428	2208					
0.5 $\alpha = 60^\circ$	900055	1920	1884	2056	571	186	9	0,42
	900056	2056	2344					
	900059	2212	1924					
0.5 $\alpha = 90^\circ$	900065	2336	2304	2150	664	134	6	0.47
	900066	2040	2040					
	900086	2088	2092					
Background	900088	1464	1452	1485		70	4	
	900089	1476	1396					
	900094	1600	1524					

4. CONCLUSION

Before using the TLD system RADOS-2000-A, the dosimeter separation must be performed because this will improve the repeatability of the results. Different calibration coefficients must be applied for different groups because this will improve the accuracy of the results. The evaluated factors that affect

the measurements during calibration show that: the relative response due to non-linearity is within standard requirements. The coefficient of variation for the studied range complies with standards. The angular dependence of the reference radiation incidence is within acceptable limits, but further studies are recommended, such as: Fading effects, Energy dependence, Environmental influence factors. Based on these studies, an overall measurement uncertainty for the dosimetric system must be determined.

ACKNOWLEDGMENTS

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