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BRAZILIAN JOURNAL OF RADIATION SCIENCES

doi.org/10.15392/2319-0612.2024.2502
2024, 12(4A) | 01-14 | e2502
Submitted: 2024-06-06
Accepted: 2024-03-21

Calibration and evaluation of the MTS-N dosimeter for absorbed dose measurement in blood components

Fonseca[a,b*], L. S.; Calheiro[a,b] D. S.; Mesquita[b], A. Z.; Alonso[b], T. C.; Squair[b], P. L.

[a]Faculdade de Medicina, Universidade Federal de Minas Gerais, UFMG, 30130-100, Belo Horizonte, MG, Brazil.

[b]Centro de Desenvolvimento da Tecnologia Nuclear (CDTN/CNEN), 30161-970, Belo Horizonte, MG, Brazil.

*Correspondence: lorena15fonseca@outlook.com

Abstract: The use of ionizing radiation has significantly expanded, particularly in the healthcare sector, where the irradiation of blood components prevents transfusion-associated graft-versus-host disease (TA-GvHD). The ISO ASTM 51939:2017 standard establishes a minimum dose of 25 Gy for this procedure, requiring a precise and traceable dosimetric system. This study investigates the calibration of MTS-N thermoluminescent dosimeters at the Gamma Irradiation Laboratory (LIG) of CDTN, which currently uses radiochromic films for routine dosimetry. The dosimeters were calibrated using a RISØ TL/OSL DA-20 reader, and the results indicated that doses above 5 Gy caused reader saturation, distorting the TL emission curve. The introduction of attenuating filters maintained linearity up to 25 Gy, and the calibration coefficient was determined as 6.774×10^{-7} Gy/Count, confirming the system's suitability for dosimetry in blood irradiation at LIG/CDTN.

Keywords: Thermoluminescence, blood irradiation, dosimetry, calibration.

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Calibração e avaliação do dosímetro MTS-N para a medição da dose absorvida em componentes sanguíneos

Resumo: O uso de radiações ionizantes tem se expandido significativamente, especialmente na área da saúde, onde a irradiação de componentes sanguíneos previne a doença do enxerto contra o hospedeiro associada à transfusão (TA-GvHD). A norma ISO ASTM 51939:2017 estabelece uma dose mínima de 25 Gy para esse procedimento, exigindo um sistema dosimétrico preciso e rastreável. Este estudo investiga a calibração de dosímetros Termoluminescentes do tipo MTS-N no Laboratório de Irradiação Gama (LIG) do CDTN, que atualmente utiliza filmes radiocrômicos para dosimetria de rotina. Os dosímetros foram calibrados com um leitor RISØ TL/OSL DA-20, e os resultados indicaram que doses acima de 5 Gy causam saturação do leitor, distorcendo a curva de emissão TL. A introdução de filtros atenuantes manteve a linearidade até 25 Gy, e o coeficiente de calibração foi determinado como $6{,}774\times10^{-7}$ Gy/Cont, confirmando a adequação do sistema para dosimetria na irradiação sanguínea no LIG/CDTN.

Palavras-chave: Termoluminescência, irradiação sanguínea, dosimetria, calibração.

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1. INTRODUCTION

In recent years, there has been a notable increase in the use of ionizing radiation across various sectors, aiming to enhance the quality of life in society and promote technological advancements. Among these sectors, the industry utilizes ionizing radiation for processes such as sterilization of medical and pharmaceutical products, treatment of chemical materials, irradiation of food and gems, irradiation of blood components, and other applications [1]. It is extremely important to validate and supervise these procedures to ensure that processes using ionizing radiation are producing the desired results. Therefore, a precise and safe dosimetric system is necessary, traceable to national and international dosimetry standards.

Given the significant application of irradiation techniques in the healthcare field, the irradiation of blood components is particularly noteworthy. This technique is used before transfusion to prevent the proliferation of certain T lymphocytes, which, upon contact with the recipient's immune system, can trigger Transfusion-Associated Graft-versus-Host Disease (TA-GvHD) [2].

Gamma irradiation inactivates the proliferative and functional capacity of T lymphocytes due to their high radiosensitivity, while preserving the functionality of other blood components. Consequently, T lymphocytes present in platelets, red blood cells, and freshly collected plasma lose their ability to proliferate, preventing their multiplication in the recipient's organism [3].

According to the ISO ASTM 51939:2017 standard – Practice for blood irradiation dosimetry, all blood and components must receive a minimum dose of 25 Gy, with no part of the blood components receiving more than 50 Gy or less than 15 Gy [4]. To meet this requirement, routine dosimetry is performed in services that carry out this procedure.

The Gamma Irradiation Laboratory (LIG) at the Center for Nuclear Technology Development (CDTN) is one of the laboratories dedicated to performing blood dosimetry and ensuring compliance with established standards. The laboratory conducts routine dosimetry using radiochromic films, which change color in response to the absorbed dose [5]. These films consist of an extremely thin layer, with thicknesses ranging from 7 to 23 μm, initially colorless. Upon exposure to ionizing radiation, they undergo a polymerization process that results in the development of blue and green hues, enabling precise measurement of the radiation dose.

Additionally, another widely used radiation dosimetry technique is thermoluminescent dosimetry, which is employed in the quantification of radiation doses ranging from 1 to 100 mGy, both in occupational radiation protection and environmental monitoring contexts. Thermoluminescent dosimeters (TLDs), in use since the 1960s, have become standard in diagnostic radiology and radiotherapy. Among the main advantages of this technique are the small size of the dosimeter, which allows measurements in phantoms, tissue equivalence, which enables accurate assessment of the absorbed dose in biological tissues and organs, and high sensitivity in radiation detection [6].

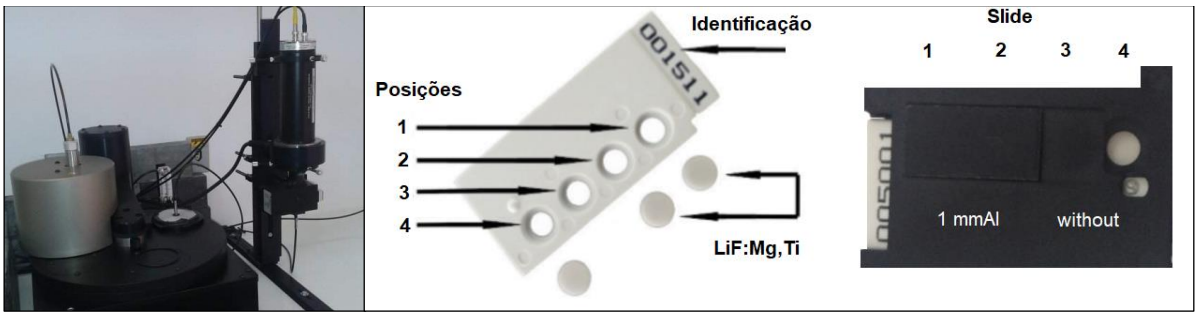
In this study, the calibration of MTS-N thermoluminescent dosimeters was carried out to evaluate the metrological capability for measuring the irradiation technique of blood derivatives.

2. MATERIALS AND METHODS

2.1 Evaluation Test of the Dosimetric System

The initial characterization tests of the MTS-N thermoluminescent dosimeter were performed using the RISØ TL/OSL DA-20 reader for application in the absorbed dose range used in the irradiation of blood components, which is between 15 and 50 Gy (Figure 1).

Figure 1: Reader TL RISØ TL/OSL DA-20 and TLD LiF:Mg, Ti (MTS-N)

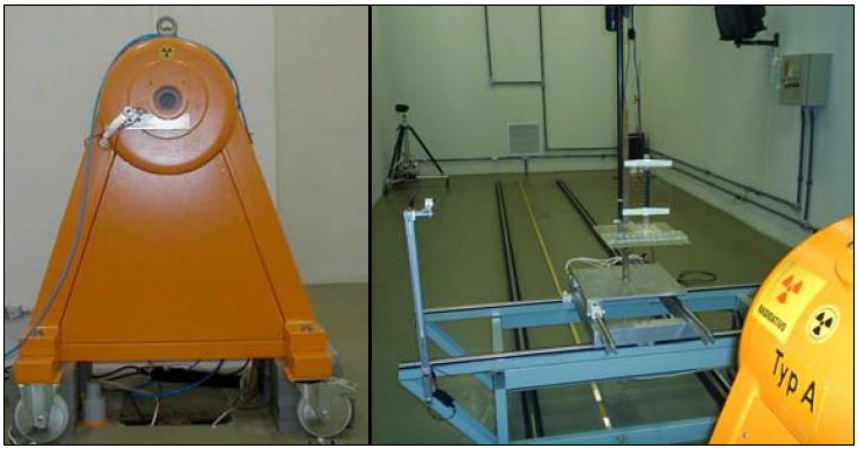


The first test was the assessment of the system's ability to obtain results, evaluating the linearity of the response for the range between 15 mGy and 50 Gy. The TL reading was performed immediately after irradiation, using a heating rate of 5°C per second.

2.2 Calibration of the Dosimetric System

The calibration of the dosimetric system was carried out for the following instrumentation: LiF : Mg,Ti thermoluminescent dosimeter (MTS-N), and RISØ TL/OSL DA-20 reader with the application of U340 and PMMA violet attenuator filters (filtering wavelengths in the range between 325 and 375 nm). For the system calibration, 10 dosimeters were irradiated at the Dosimeter Calibration Laboratory of CDTN (LCD), using a Cesium-137 source from the STS Steuerungstechnik & Strahlenschutz Gmbh OB85 irradiator model (Figure 2) with a value of 3 Gy.

Figure 2: STS Model OB85 Irradiator.



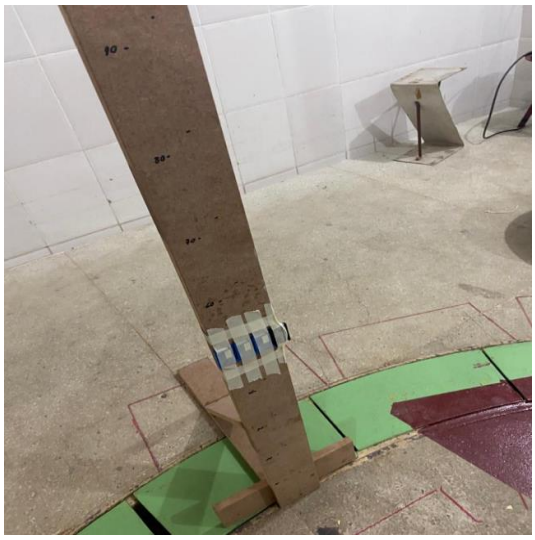
2.3. Dosimetry of Blood Products

The irradiation of blood derivatives at CDTN is carried out by the Gamma Irradiation Laboratory (LIG) using a Cobalt-60 source from Nordion (model: F127 GB 127, series: IR-214) with an activity of 59,298 Ci on 08/23/2023.

Two practical evaluations of the dosimetry of blood derivatives (blood) positioned in transport containers (Figure 03) and one in a dosimetry holder (Figure 04), suitable for maintaining the product's temperature range, were performed: one in a holder and two in blood transport boxes. The nominal values established for the absorbed dose for irradiation were 25 Gy at a distance of 1.0 m with a height of 0.5 m on a wooden stand on 09/13/2023 with an irradiation time of 3 min and 50 s. The absorbed dose values for blood irradiation were 25 Gy at a distance of 1.0 m in the transport boxes on 09/27/2023 and 11/14/2023, with irradiation times of 231 seconds and 235 seconds, respectively. The irradiation time varies each day due to the decay of the Cobalt-60 source.

Figure 3: Blood transport and irradiation boxes.

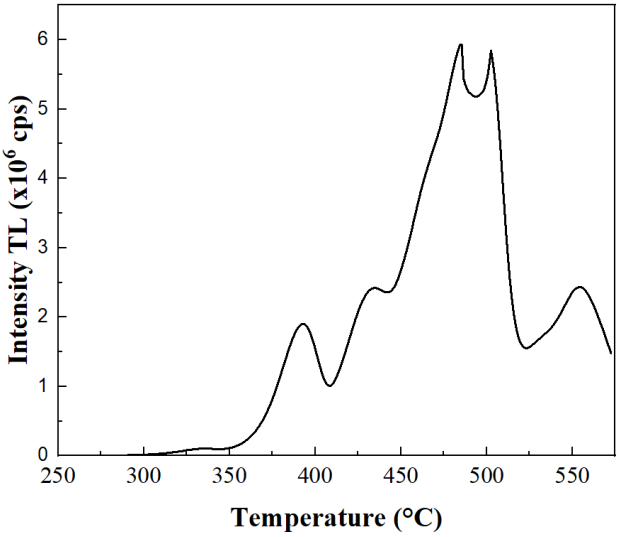
Figure 4: Dosimetry support.



3. RESULTS AND DISCUSSIONS

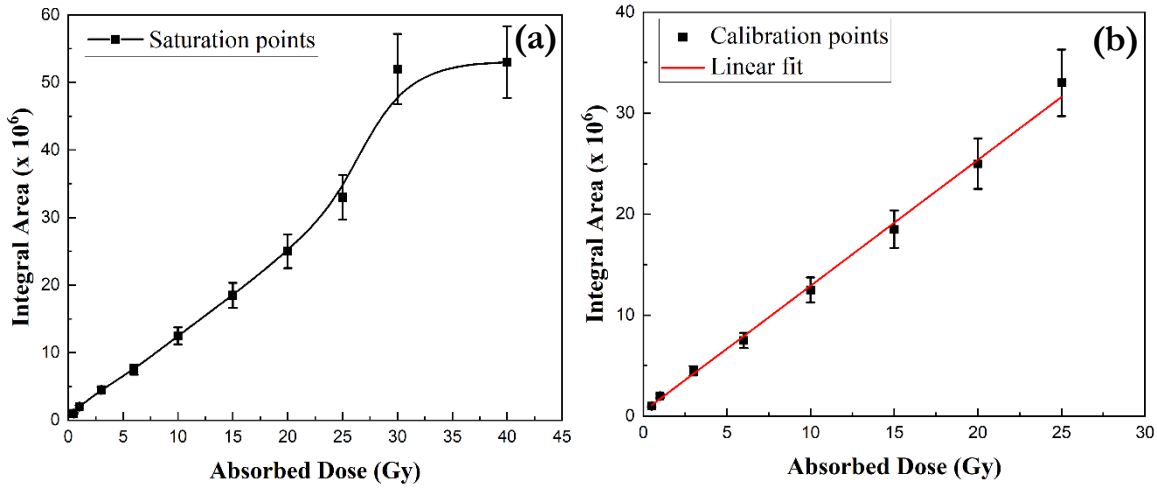
In the first evaluation test of the dosimetric system, it was observed that for values above 5 Gy, the RISØ TL/OSL DA-20 reader becomes saturated, distorting the TL emission curve (Glow Curve) at the central point (Fig. 5).

Figure 5: TL Emission Curve of MTS-N with saturation.



Considering the TL emission intensity after the dose value of 3 Gy, the insertion of attenuating filters between the TL crystal and the photomultiplier of the RISØ TL/OSL DA-20 reader was evaluated. The commercially used U340 and violet PMMA filters were employed for attenuation, with an overlap in the range between 325 and 375 nm, allowing an expansion of the operational range.

Figure 6: (a) Saturation points and (b) Calibration points.



By using attenuating filters, the TL emission curve remained linear between 10 mGy and 25 Gy. Beyond this value, there was a change in the curve's slope (supralinear) up to 30 Gy, and response saturation occurred after 30 Gy (Figure 6(a)). Given that saturation occurred for values above 25 Gy, a linear adjustment was performed, varying from 10 mGy to 25 Gy, as shown in Figure 6(b).

Simultaneously applying the attenuating filters, a linearity test was conducted to establish the operational limits of the dosimetric system and its capability to operate in the range of blood derivatives irradiation processes.

After the calibration of the dosimetric system, the result of the calibration coefficient Nk,Q was obtained as 6.774×10^{-7} Gy/Count, utilizing the UV340 and violet PMMA attenuation filters (Table 1).

Table 1: Calibration Irradiation Result.

Dosimeter	Calibration 3 Gy (LCD)
id	**Counts**
1	4,265E+06
2	4,112E+06
3	4,307E+06
4	4,554E+06
5	4,300E+06
6	4,772E+06
7	4,409E+06
8	4,933E+06
9	4,482E+06
10	4,155E+06
Mean	4,429E+06
s	2,635E+05
s (%)	5,95%
Kq (Gy/count)	6,774E-07

Table 1 presents the results of 10 gamma radiation exposures, each delivering an absorbed dose of 3 Gy, conducted to serve as a reference for verifying the calibration of the dose reader used. The irradiations were performed in an accredited dosimeter calibration laboratory, ensuring the traceability and reliability of the obtained results. The uniformity in the absorbed dose readings for all MTS-N dosimeters reflects the accuracy of the measurement system, demonstrating that the RISØ TL/OSL DA-20 reader was properly calibrated. The observed values in the table show a minimal variation of approximately 6%, indicating consistent performance within the expected calibration parameters.

The Table 2 presents the results obtained from the exposure of MTS-N type thermoluminescent dosimeters, positioned stationary on the dosimetry rod at a distance of 1 meter, with the aim of calibrating the absorbed dose of 25 Gy.

Table 2: Dosimetry at a distance of 1 meter with stationary dosimeters exposed to an absorbed dose of 25 Gy.

Dosimeter	Measure	Absorbed Dose		
id	**Counts**	**Gy**	**Mean (Gy)**	**Position**
1	3,572E+07	24,1	25,1	Frontal
2	3,675E+07	24,9		
3	3,858E+07	26,1		
4	3,923E+07	26,6	26,4	Right
5	3,858E+07	26,1		
6	3,915E+07	26,5	26,4	Posterior
7	3,758E+07	25,5		
8	4,005E+07	27,1		
9	3,988E+07	27,0	25,6	Left
10	3,582E+07	24,3		
Mean	3,814E+07	25,8		
s	1,587E+06	1,1		
s (%)	4,16%	4,16%		

The measured absorbed dose varied between 24.1 Gy and 27.1 Gy, with a mean value of 25.8 Gy (±1.1 Gy). This variation suggests a relatively homogeneous dose distribution, with some fluctuations that may be attributed to factors such as the position of the dosimeters and small variations in the exposure process. The uncertainty of 4.16% associated with the measurement of the absorbed dose indicates that the results are sufficiently precise for the calibration of the dosimetry system.

Table 3 presents the results obtained from the exposure of the case containing blood components, along with MTS-N thermoluminescent dosimeters.

Table 3: Dosimetry results for the case containing blood components from the date of 09/13/2023.

Dosimeter	Measure	Absorbed Dose		
id	**Counts**	**Gy**	**Mean (Gy)**	**Position**
1	3,692E+07	25,0	25,1	Frontal
2	3,562E+07	24,1		
3	3,850E+07	26,1		
4	3,737E+07	25,3	25,3	Right

Dosimeter	Measure	Absorbed Dose		
5	3,719E+07	25,2		
6	4,085E+07	27,7		
7	3,833E+07	26,0	27,1	Posterior
8	4,093E+07	27,7		
9	3,839E+07	26,0		
10	3,513E+07	23,8	24,9	Left
Mean	3,792E+07	25,7		
s	1,923E+06	1,3		
s (%)	5,07%	5,07%		

The absorbed dose measured by the dosimeters ranged from 23.8 Gy to 27.7 Gy, with a mean value of 25.7 Gy (±1.3 Gy). This variation suggests a relatively homogeneous dose distribution, with some fluctuations that may be attributed to factors such as the position of the dosimeters and self-shielding effects of the blood component bags. The uncertainty of 5.07% indicates that the results are sufficiently precise to be used as a reference in the validation process of the absorbed dose in the blood components. The analysis of the data presented in the table shows a reasonably homogeneous distribution of the absorbed dose across the different dosimeter positions, with slight variations associated with the different locations on the exterior of the container.

Table 4 presents the results obtained from the exposure of MTS-N thermoluminescent dosimeters, positioned stationary in the blood component case at a distance of 1 meter, with the objective of quantifying the absorbed dose.

Table 4: Second dosimetry results for the case containing blood components from the date of 11/14/2023.

Dosimeter	Measure		Absorbed Dose	
id	**Counts**	**Gy**	**Mean (Gy)**	**Position**
1	3,774E+07	25,6		
2	3,458E+07	23,4	24,5	Frontal
3	3,637E+07	24,6		
4	3,732E+07	25,3	25,3	Right

Dosimeter	Measure	Absorbed Dose		
5	3,726E+07	25,2		
6	3,608E+07	24,4	25,0	Posterior
7	3,653E+07	24,7		
8	3,799E+07	25,7		
9	3,738E+07	25,3	24,0	Left
10	3,344E+07	22,7		
Mean	3,647E+07	24,7		
s	1,453E+06	1,0		
s (%)	3,98%	3,98%		

The absorbed dose measured by the dosimeters ranged from 22.7 Gy to 25.7 Gy, with a mean value of 24.7 Gy (± 1.0 Gy). The observed variation suggests a relatively homogeneous dose distribution, with small fluctuations that may be attributed to factors such as the positioning of the dosimeters, as the dose distribution was not completely uniform across all positions. Data analysis indicates that the measurements taken at different dosimeter positions (frontal, right, posterior, and left) show no significant discrepancies, suggesting that the dosimetry system is functioning consistently across all directions. The uncertainty associated with the absorbed dose measurement, 3.98%, is within acceptable limits for calibration processes, indicating that the results obtained are sufficiently precise and reliable for the intended application.

4. CONCLUSIONS

After the linearity evaluation tests, adaptation of filtrations (UV340 and PMMA filters), and calibration, the system demonstrated suitable technical capability for application as a dosimetry method for the irradiation of blood derivatives (blood) at LIG/CDTN. It can serve as an auxiliary method alongside those already applied in the sector, such as Fricke, Red Perspex, among others.

ACKNOWLEDGMENT

The authors are grateful to the National Council for Scientific and Technological. Development (CNPq), the Coordination for the Improvement of Higher Education Personnel. (CAPES), The Minas Gerais State Research Support Foundation (FAPEMIG), The National Nuclear Energy Commission (CNEN) for supporting the study.

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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