TL response of $CaSO_4$:Eu,Ag detectors in $^{90}Sr/^{90}Y$ beta radiation beam

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Abstract

The results of the TL response of the $CaSO_4$:Eu,Ag detectors in the $^{90}Sr/^{90}Y$ beams of the BSS2 system of the LCI/ IPEN are presented. The TL glow curves were obtained from doses between 30 mGy and 500 mGy. The detectors showed a good reproducibility of the TL response. The calculated calibration factor was (1.166 ± 0.024) x10^{-3} mGy/a.u. and the factor determined by linear fitting was (1.120 ± 0.014) x10^{-3} mGy/a.u., showing a difference of only 3.9%. The lower limit of detection was (4.96 ± 0.06) mGy. The detectors indicated the appropriate sensitivity for $^{90}Sr/^{90}Y$ beta radiation. Preliminary results show suitable dosimetric characteristics for the establishment of a transfer system for beta dosimetry of $^{90}Sr/^{90}Y$ beams.

Index Terms: beta radiation, TL detector, $CaSO_4$:Ag,Eu, $^{90}Sr/^{90}Y$

1. Introduction

The extrapolation chamber is the primary instrument for measurements in beta radiation beams [1]. These measurements should be taken under laboratory reference conditions of temperature, pressure and humidity. In addition, the extrapolation chamber must be handled with extreme care, because it is very heavy and its entrance window is very delicate. Thermoluminescence (TL) may be an alternative method for beta dosimetry to constitute a beta-radiation transfer system.

TL has already been used in applications of beta radiation [2-5]. This kind of radiation has a low penetration power; therefore, the choice of the dosimeter material is very important [6-9]. The dosimeter response depends on the energy range of the beta radiation. However, dosimeters intended to measure doses of this radiation should be as thin as possible compared to the ranges of all the electron energies of interest [5, 10].

For the calibration of beta radiation fields, thin thermoluminescent dosimeters of materials with low atomic number, such as LiF, $Li_2B_4O_3$, $Mg_2B_4O_7$, Al_2O_3, among others may be used [11]. Some types of fine detectors have been prepared with TL high-sensitivity phosphors such as $Mg_2B_4O_7$:Dy, $CaSO_4$:Dy, Al_2O_3:C and LiF:Mg,Cu,P. The high sensitivity of the phosphor is very important because the required surface density results in a very small amount of luminescent material [12].

$CaSO_4$ doped with Rare Earths (RE) has been widely studied in some works as a thermoluminescent material [13-14]. Calcium sulfate doped with dysprosium ($CaSO_4$:Dy) is a material already well studied in beta radiation beams [3, 5, 9, 15]. Calcium sulfate doped with europium ($CaSO_4$:Eu) presents a suitable TL response [16]. The addition of silver to $CaSO_4$:Eu allows the increase of the TL intensity [17-18].

The objective of the present work was to perform a TL response analysis of $CaSO_4$:Eu,Ag detectors in $^{90}Sr/^{90}Y$ beams, for the establishment of a transfer system or alternative/complementary method for beta radiation dosimetry.

2. Materials and methods

For the dosimetric characterization of the detectors, the $^{90}Sr/^{90}Y$ source of the Beta Secondary Standard BSS2 of the Calibration Laboratory (LCI) of the IPEN/CNEN was used. The main characteristics of this source are the following: 460 MBq of nominal activity; 0.8 MeV of average beta energy and 10,483 days of half-life. The calibration date was 11/19/2004. The calibration distance was 11 cm without the use of the beam flattening filter [19].

The dosimetric system consists of the detectors, the TL reader, the thermal treatment system and auxiliary materials that allow performing the luminescent dosimetry.

The $CaSO_4$:Eu:Ag detectors were produced by stages in the Laboratory of Medical Physics (LFM) of the Department of Physics (DFI) of the Federal University of Sergipe (UFS) and in the Laboratory of Dosimetric Materials (LMD) of the Radiation Metrology Center (CMR) of IPEN. The crystals of $CaSO_4$:Eu:Ag were produced by a route based on the mixture of Calcium Carbonate ($CaCO_3$), Sulfuric Acid (H_2SO_4), Europium Oxide (Eu_2O_3) and silver metal particles Ag^0. The dopants were incorporated in the proportion of 0.1 mol %. For the production of the pellets, powdered Polytetrafluoroethylene (Teflon) was added in the proportion of 1:1 for the mass of the phosphor and the mass of Teflon. The detectors have 6 mm in diameter, 1 mm in thickness and 40 mg in mass [17].

For the TL measurements, the RISÖ TL/OSL-DA20 system was used. The system allows up to 48 samples to be individually heated at any temperature up to 700 °C. The measurements were performed in a vacuum chamber. The emitted luminescence was measured by a light detection system, composed of a photomultiplier valve and suitable detection filters [20]. Figure 1 shows the RISÖ TL/OSL-DA20 measuring system of LCI/IPEN.

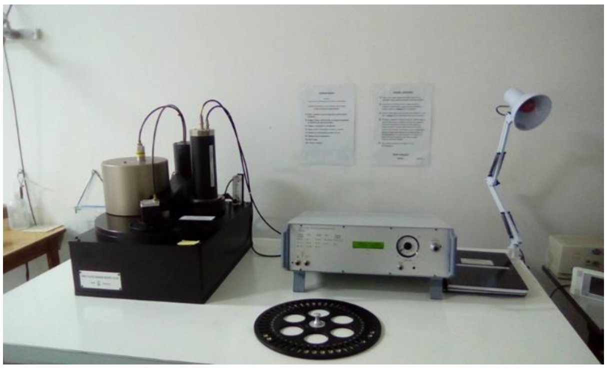

Figure 1: *RISÖ TL/OSL-DA20 measuring system of the Calibration Laboratory IPEN/CNEN/SP.*

The thermal treatment was performed in a furnace manufactured by the Institute of Radioprotection and Dosimetry (IRD), CNEN, in Rio de Janeiro. The established heat treatment was 1h at 400 °C.

Figure 2 shows the holder for irradiation of the detectors and the support for performing the thermal treatment. The holder for the irradiation is made of polymethylmethacrylate (PMMA), and it has the following dimensions: 110 mm in width and length, and 18 mm in depth. It allows the irradiation of 25 detectors. The holder cover is a 0.015 mm Hostaphan sheet. The support for the heat treatment is a circular aluminum plate.

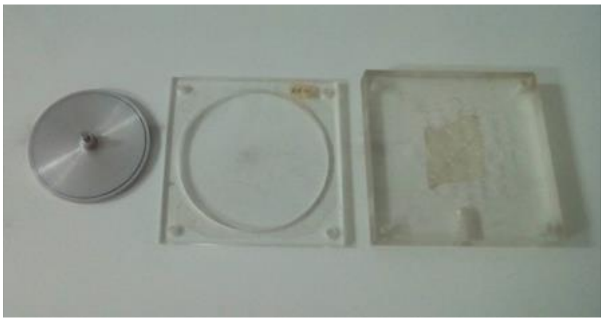

Figure 2: *Circular aluminum plate for thermal treatment (left). PMMA holder and cover for irradiation of detectors (right).*

3. Results and discussion

For the evaluation of the reproducibility of the detectors, thirty detectors were used. They were irradiated with a dose of 1 Gy of the RISÖ system $^{90}Sr/^{90}Y$ source. The TL response was considered as the integral under the whole glow curve. After irradiation, the TL reading, the thermal treatment and the reading of the background were performed. This procedure was repeated for 5 cycles. Twelve detectors of this batch were chosen for the study of TL response. Table 1 shows the mean values of the TL response, the standard deviation and the coefficient of variation (C.V.) of the chosen detectors.

Table 1. *Reproducibility of $CaSO_4$:Eu:Ag TL detectors.*

Detector number	Mean values of the TL response (a.u.)	Standard deviation (a.u.)	Coefficient of variation (%)
1	1.38 $x10^6$	2.08 $x10^4$	1.51
2	1.42 $x10^6$	1.13 $x10^4$	0.80
3	1.43 $x10^6$	1.83 $x10^4$	1.27
4	1.38 $x10^6$	1.31 $x10^4$	0.95
5	1.45 $x10^6$	2.08 $x10^4$	1.43
6	1.42 $x10^6$	1.88 $x10^4$	1.33
7	1.37 $x10^6$	1.92 $x10^4$	1.40
8	1.39 $x10^6$	2.58 $x10^4$	1.84
9	1.40 $x10^6$	2.97 $x10^4$	2.11
10	1.35 $x10^6$	2.33 $x10^4$	1.73
11	1.38 $x10^6$	2.04 $x10^4$	1.48
12	1.42 $x10^6$	1.29 $x10^4$	0.90

In order to consider that the detectors have a good reproducibility, the recommended coefficient of variation should be less than 5% [21]. The results of Table 1 are in agreement with these recommendations.

Figure 3 shows the TL glow curves of $CaSO_4$:Eu:Ag detectors. The detector 1 was chosen arbitrarily for the representation. The dose range considered was 30 mGy up to 500 mGy.

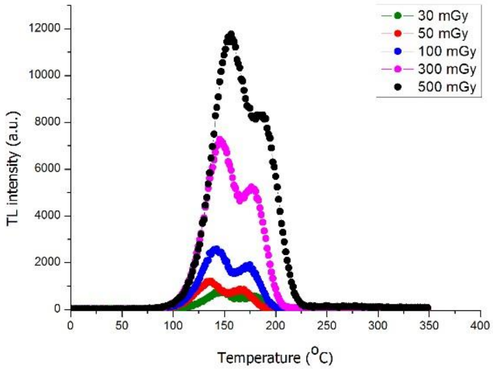

Figure 3: *TL glow curves of the $CaSO_4$:Eu:Ag detectors in BSS2 $^{90}Sr/^{90}Y$ radiation beam, for doses of 30 mGy up to 500 mGy.*

To obtain the TL response curves as a function of the absorbed dose of the $CaSO_4$:Eu:Ag detectors, they were irradiated in the BSS2 $^{90}Sr/^{90}Y$ radiation beam with doses of 30 mGy up to 500 mGy. The dose range for the study was established, considering the irradiation times of the BSS2 system [19]. Figure 4 shows the dose-response curve of the $CaSO_4$:Eu:Ag detectors in the range of the aforementioned doses.

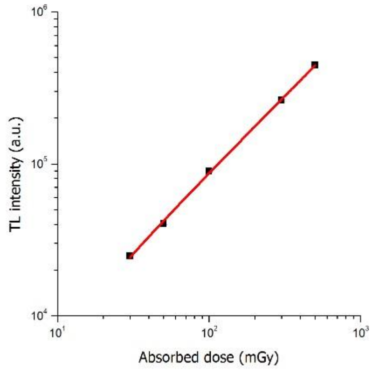

Figure 4: *TL dose-response curve of $CaSO_4$:Eu:Ag detectors in BSS2 $^{90}Sr/^{90}Y$ radiation beam. The maximum uncertainty was 2.6%.*

The curve was fitted linearly by a computational program and the R^2 correlation coefficient was 0.99828. The detectors showed a linear behavior in the studied dose range. The calibration factor was determined by linear fitting, and it was determined by Equation 1:

$$F_c = 1/c \qquad (1)$$

where c is the slope of the fitted line.

The calibration factor can also be determined as the ratio between the absorbed dose and the mean value of the TL measurements at each point of the calibration curve [21].

The determined calibration factor was (1.166 ± 0.024) x10^{-3} mGy/a.u. and the factor determined by linear fit was (1.120 ± 0.014) x10^{-3} mGy/a.u. The calibration factors obtained by both methods are in good agreement. The difference between them was only 3.9%.

The lower detection limit (LDL) is the minimum dose that can be detected by luminescent material [21]. The LDL is important in low dose measurements where the dosimeter signal is almost equal to the background signal. The LDL was determined by Equation 2:

$$LDL = 3 * \sigma_{BKG} * F_c \qquad (2)$$

where σ_{BKG} is the standard deviation of the zero dose reading [21].

Table 2 shows the values of the material TL sensitivity for each detector. For this test, a dose of 50 mGy was chosen. The detectors show an appropriate sensitivity for ^{90}Sr/^{90}Y beta radiation, suggesting a potential use of these detectors for beta dosimetry with also the other BSS2 radiation sources (^{85}Kr and ^{147}Pm).

Table 2. *Intrinsic sensitivity of $CaSO_4$:Eu:Ag detectors for TL response (No. –Detector number).*

No.	TL sensivity	No.	TL sensivity
1	(2.10 ± 0.03) x10^4	7	(2.07 ± 0.03) x10^4
2	(2.22 ± 0.03) x10^4	8	(1.80 ± 0.03) x10^4
3	(1.99 ± 0.03) x10^4	9	(2.02 ± 0.03) x10^4
4	(1.99 ± 0.03) x10^4	10	(2.01 ± 0.03) x10^4
5	(2.15 ± 0.03) x10^4	11	(1.92 ± 0.03) x10^4
6	(2.15 ± 0.03) x10^4	12	(1.84 ± 0.03) x10^4

4. Conclusions

The analysis of the TL response of the $CaSO_4$:Eu:Ag detectors in ^{90}Sr/^{90}Y radiation bemas was performed. The TL glow curves for doses between 30 mGy and 500 mGy were obtained. The reproducibility of the response, the calibration factor, the lower limit of detection and the intrinsic sensitivity of the detectors were determined.

The preliminary results of the tests carried out show suitable dosimetric characteristics for the establishment of a transfer system or alternative/ complementary method for dosimetry of beta radiation.

5. Acknowledgements

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6. References

[1] Böhm, J. The National Primary Standard of the PTB for realizing the unit of the absorbed dose rate to tissue for beta radiation. Braunschweig, Germany: Physikalisch-Technische Bundesanstalt, PTB-Dos-13, 1986.

[2] Caldas, L.V.E. Some calibration and dosimetry methods for beta radiation. Ph.D. Thesis, Physics Institute/Sao Paulo University (In Portuguese), 1980.

[3] Conteno, G., Malisan, M.R., and Padovani, R. “Response of thermoluminescence dosimeters to beta radiation and skin dose measurement”, Phys. Med. Biol., Vol. 29, 1984, p. 661-678.

[4] Cross, W.G. “Empirical expressions for beta ray point source dose distributions”, Radiat. Prot. Dosim., Vol. 69, 1997, p. 85-96.

[5] Kumar, M., Rakesh, R.B., Sneha, C., Ratna, P., Bakshi, A.K., and Datta, D. “Beta response of $CaSO_4$:Dy based thermoluminescent dosimeter badge and its angular dependence studies for personnel monitoring applications”, Radiat. Prot. Environ., Vol. 39, 2016, p. 132-137.

[6] IAEA, INTERNATIONAL ATOMIC ENERGY AGENCY. Calibration of Photon and Beta Ray Sources used in Brachytherapy. Vienna: IAEA, 2002 (IAEA-TECDOC-1274).

[7] ICRU, INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. Dosimetry of Beta Rays and Low-Energy Photons for Brachytherapy with Sealed Sources, Vol. 4, n. 2, Bethesda, M.D.: ICRU, 2004 (ICRU Report n. 72).

[8] Oliveira, M.L., and Caldas, L.V.E. “Performance of thin $CaSO_4$:Dy pellets for calibration of a ^{90}Sr+^{90}Y source”, Nucl. Instr. Meth. Phys. Res., Vol. 580, 2007, p. 293-295.

[9] Antonio, P.L., Oliveira, M.L., and Caldas, L.V.E. “Thin $CaSO_4$:Dy thermoluminescent dosimeters for calibration of ^{90}Sr+^{90}Y applicators”, Appl. Radiat. Isot., Vol. 70, 2012, p. 790-793.

[10] Kumar, M., Dhabekar, B., Menon, S., Bakshi, S., Udhayakumar, J., M. Chougaonkar, P., and Mayya, Y. “Beta response of $LiMgPO_4$:Tb,B based OSL discs for personnel monitoring applications”, Radiat. Prot. Dosim., Vol. 155, n. 4, 2013, p. 410–417.

[11] ICRU, INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. Dosimetry of External Beta Rays for Radiation Protection. Bethesda: ICRU, 1997. (ICRU Report 56).

[12] Akselrod, A., Akselrod, M.S., Agersnap Larsen, N., Banerjee, D., Botter-Jensen, L., Christensen, P., Lucas, A.C., McKeever, S.W.S., and Yoder, R.C. “Optically stimulated luminescence response of Al_2O_3 to beta radiation”, Radiat. Prot. Dosim., Vol. 85, n. 1-4, 1999, p. 125-128.

[13] Yamashita, T., Nada, N., Onishi, H., and Kitamura, S. “Calcium sulphate phosphor activated by thulium or dysprosium for thermoluminescence dosimetry”, Health Phys., Vol. 21, 1971, p. 295–300.

[14] Kása, I., Chobola, R., Mell, P., Szakács, S., and Kerekes, A. “Preparation and investigation of thermoluminescence properties of $CaSO_4$:Tm,Cu”, Radiat. Prot. Dosim. Vol. 123, 2007, p. 32-35.

[15] Campos, L.L., and Lima, M.F. “Thermoluminescent $CaSO_4$:Dy teflon pellets for beta radiation detection”, Radiat. Prot. Dosim., Vol. 18, n. 2, 1987, p. 95-97.

[16] Deng, W., and Goldys, E.M “Plasmonic approach to enhanced fluorescence for applications in biotechnology and the life sciences”, Langmuir, Vol. 28 (27), 2012, p.10152-10163.

[17] Junot, D. O., Couto dos Santos, M. A., Souza, D. N., Vasconcelos, D. F., Caldas, L.V.E., and Chagas, M. A. P. “Silver addition in $CaSO_4$:Eu, TL and TSEE properties”, Radiat. Meas., Vol. 46, 2011, p.1500–1502.

[18] Junot, D. O., Couto dos Santos, M. A., Antonio, P.L., Caldas, L.V.E., and Souza, D. N. “Feasibility study of $CaSO_4$:Eu, CaSO4:Eu,Ag and $CaSO_4$:Eu,Ag(NP) as

thermoluminescent dosimeters", Radiat. Meas., Vol. 71, 2014, p. 99-103.
[19] BSS2. Beta Secondary Standard 2. Operation manual. Isotrak. QSA Global GmbH, 2005.
[20] DTU Nutech. Guide to "The Risö TL/OSL Reader". Denmark: DTU Nutech, 2015.
[21] Furetta, C. Questions and Answers on Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL). London: World Scientific Publishing, 2008.