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Study of the dosimetric properties of $CaSO_4$:Dy using OSL technique

P.B.R. Gasparian,[a,*] A.L.M.C. Malthez,[b] E.M. Yoshimura,[c] N.K. Umisedo[c] and L.L. Campos[a]

[a] *Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN, Av. Prof. Lineu Prestes, 2242, Cidade Universitária, São Paulo, Brazil*

[b] *Federal University of Technology – Parana, Av. Desembargador Westphalen, 637, Physics Academic Department, Curitiba, Brazil*

[c] *Institute of Physics, University of Sao Paulo, Rua do Matão 1371, Sao Paulo, Brazil*

E-mail: patricia.gasparian@cnen.gov.br

Abstract: Calcium sulfate doped with dysprosium ($CaSO_4$:Dy) has been used for personal dosimetry using the thermoluminescence (TL) technique for decades and its TL properties are well-known. Considering the advantages of the OSL technique (relatively simple and faster readout and detector reusability) and the potential application of $CaSO_4$:Dy as an OSL detector, this study aimed to investigate the dosimetric properties of $CaSO_4$:Dy using the OSL technique. The present study was carried out using $CaSO_4$:Dy pellets prepared at IPEN irradiated and read in a TL/OSL Risø reader with blue light stimulation and Hoya U-340 filter. OSL dosimetric properties essentially dose response, reproducibility, and fading characteristics were evaluated. Moreover, TL and OSL signals were compared to study the correlation between OSL signals and TL peaks. $CaSO_4$:Dy OSL response is linear from 0.1 to 10 Gy and shows reproducibility better than 5%. The low-temperature TL peak is unstable; however, the OSL signal seems to be associated with higher-temperature peaks.

Keywords: Dosimetry concepts and apparatus; Materials for solid-state detectors; Radiation monitoring; Solid state detectors

*Corresponding author.

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1 Introduction

Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) techniques are both luminescence techniques largely applied for radiation measurements. TL technique first studies date the late 1940s and LiF soon emerged as a TL detector. Since then, the TL technique has been successfully used for various dosimetric applications with several well-known and characterized suitable materials. OSL technique has known for more than 70 years [1, 2]. It was first developed and established for retrospective dosimetry, known as OSL dating [3]. Later, in the early 2000s, it has caught the attention of the radiation dosimetry research community after the study of the OSL properties of a recently developed material, Al_2O_3:C, for TL measurements [4]. Today, the OSL technique using Al_2O_3:C detectors is popular and well established for personal, environmental, and medical dosimetry [5–7].

The materials applied in OSL and TL dosimetric systems are passive solid-state radiation detectors. TL and OSL techniques are similar from a physical aspect, the main difference is in the stimulus employed for the luminescent emission; TL signal is measured using thermal stimulation after the dosimetric material (or detector) has been exposed to ionizing radiation, while the OSL technique obtains the OSL signal by applying optical stimulation with appropriated wavelength [1]. Due to the optical nature of the process, the OSL technique presents some advantageous characteristics over the TL technique, as the speed of readout. In addition, the no-heating process avoids a change of sensitivity of the material [8]. However, the main disadvantage of OSL dosimetry is the small number of well-characterized and suitable materials. Today, mainly Al_2O_3:C and BeO are well developed for OSL radiation dosimetry usage and have commercial dosimetric systems available [7].

For that reason, several researchers are studying the production of new dosimetric materials exploring the OSL technique. Among natural materials with possible applicability in dosimetry, the natural fluoride rocks composed of calcium fluoride and natural salt has shown potential [9]. In the artificial materials category, calcium sulfate ($CaSO_4$) with several types of dopants has been produced and its respective OSL signal has been investigated. For instance, Guckan et al. investigated the OSL dosimetric properties of $CaSO_4$:Eu [10] and Junot et al. studied the potential of new $CaSO_4$ based detectors with different combinations of impurities, using TL and OSL techniques [11]. TL properties of $CaSO_4$ with different impurities have been extensively studied [13–16] and $CaSO_4$ doped with dysprosium ($CaSO_4$:Dy) has been used for personal dosimetry with thermoluminescence (TL) technique for decades and its TL properties are well-known [12].

Whereas the good dosimetric properties of $CaSO_4$:Dy as TL detector are known, the OSL properties, as far as we know, are not fully described in the literature. There is a lack of essential information on the OSL signal from $CaSO_4$:Dy that could or not result in its application as an OSL detector (OSLD). The radiation detectors applied for dose measurements should:

i present a linear dose response in the range that it will be used,

ii have a sensitivity to the energies and types of radiation that are known and suitable for use,

iii have a stable signal or low degradation of signal with storage time (low fading) and

iv provide reproducible response considering the same irradiation conditions [1].

Considering the advantages of the OSL technique and the potential applicability of $CaSO_4$:Dy with the OSL technique for radiation dosimetry, this study aimed to investigate the basic dosimetric properties of this material regarding its OSL signal. In addition, a study of the correlation between OSL and TL signals was carried out to a better understanding of the OSL properties.

2 Materials and methods

The present study was carried out using $CaSO_4$:Dy pellets, produced at IPEN (Instituto de Pesquisas Energéticas e Nucleares in Brazil), used for decades as TL detector, mainly in individual monitoring. The pellets are $CaSO_4$:Dy compressed with Teflon in disk shape with 6.0 mm diameter and 0.5 mm thickness [12].

The OSL readouts were performed in two automated Risø TL/OSL DA-20 Readers with blue light stimulation and Hoya U-340 (300–380 nm) glass filters. The total power at the sample position is 80 mW/cm^2 for both readers. Additionally, irradiations used the built-in ^{90}Sr/^{90}Y beta source (dose rate 0.1 Gy/s in reader 1 and 12 mGy/s in reader 2). TL measurements, when necessary, were obtained using a 5°C/s heating rate. Irradiations and OSL readouts were performed at room temperature.

The OSL initial intensity (S_i) from $CaSO_4$:Dy detectors was estimated through the integral of the OSL decay curve from 0 to 10 s subtracted the background.

The thermal treatment for $CaSO_4$:Dy detectors irradiated with doses up to 0.1 Gy was conducted in a Risø reader using the preheat function at 300°C (5°C/s heating rate) for 15 minutes. The thermal treatment for $CaSO_4$:Dy detectors irradiated with high doses (tested up to 8 Gy) was performed in an oven (model EDGCON 3P) at 300°C for 15 h.

Regarding the study of change of OSL response with thermal treatment, we performed a reproducibility test. In this test, five irradiated detectors with doses up to 0.1 Gy suffer five sequentially cycles of heating at 300°C for 15 minutes followed by irradiation and OSL measurement. A first OSL readout after preheating of detectors was made to measure the background signal. Finally, the reproducibility was evaluated for each detector by comparison of the OSL signal obtained in each cycle with its OSL signal measured for the first cycle.

Similarly, another reproducibility test was performed for $CaSO_4$:Dy detectors irradiated with higher doses. Four cycles of heating at 300°C for 15 hours in the oven, followed by irradiation and OSL measurement were performed sequentially with three detectors. For each cycle, the detectors were transferred from the oven to the reader (after cooling to room temperature) without exposure to light.

The dose response of $CaSO_4$:Dy was evaluated by exposing the pellets to doses ranging from 0.1 to 10 Gy. The detectors were previously selected by sensitivity (10%), then two detectors were irradiated with each dose and the OSL initial intensities were plotted as a function of the absorbed dose. A linear fit ($y = bx$) was done and evaluated using the R-square value.

We evaluated the fading of the OSL signal from $CaSO_4$:Dy as a function of storage time over one month. The pellets were selected by sensitivity (11%) and were irradiated with the same dose (1 Gy) in the reader. Except for three samples that were read immediately after irradiation, the rest were stored in a container sealed from light. After the time intervals of 24 h, 1 week, 2 weeks, 3 weeks, and 4 weeks, the OSL of three samples was recorded.

Aiming to verify if there is a correlation between TL peaks and the OSL signal of $CaSO_4$:Dy detectors, three pellets were irradiated in the reader (0.12 Gy) and the OSL signal was obtained. After preheating at 300°C for 15 minutes in the reader to erase the signal, the process was repeated with the inclusion of TL measurement with final temperatures of 100°C and 400°C before the OSL readout. We compared the shape of the three OSL curves (without previous TL, with TL up to 100°C before OSL reading and with TL up to 400°C before OSL reading), for each detector, estimating the percentage of the OSL signal remaining in the detector after TL in comparison with the OSL signal without previous TL stimulation.

It is important to mention that regardless of the very good reproducibility results, after all, thermal treatments performed in the present study, the background OSL curve was recorded to confirm that the signal was erased and to check that there was no change in detector sensitivity. The tail of the OSL curves after irradiation was also monitored to confirm that there was no influence of hard to bleach deep traps.

3 Results

3.1 Reproducibility of $CaSO_4$:Dy detectors

Figure 1 shows four OSL curves recorded for the same detector irradiated with 0.12 Gy and heating at 300°C for 15 minutes between each cycle of measurements. It can be seen, through the consistency of the signals, that the thermal treatment does not affect the sensitivity of the detector. The OSL initial intensity (integral of the first 10 s) obtained for each reading is included in the graphic.

When comparing the OSL signal estimated in each cycle relative to the first OSL measurement, the maximum value of difference was 4.6%.

Preliminary studies have shown that for higher doses, the longest thermal treatment (300°C for 15 hours) is necessary to erase the signal.

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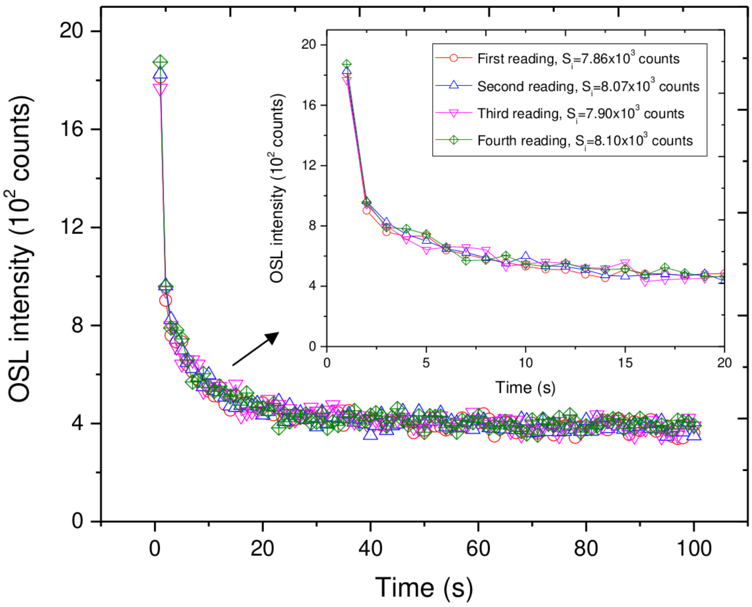

Figure 1. Reproducibility- $CaSO_4$:Dy OSL curves recorded for the same detector irradiated with 0.12 Gy and thermal treatment with heating at 300°C for 15 minutes between each cycle of measurements. The label shows the OSL initial intensity (Si) of each reading.

Figure 2 shows three OSL curves from the same detector irradiated with 8 Gy, with heating at 300°C for 15 hours between each cycle of measurements. The OSL initial intensity obtained for each cycle is included in the graphic. We confirmed that the sensitivity of the detector is not affected by the thermal treatment.

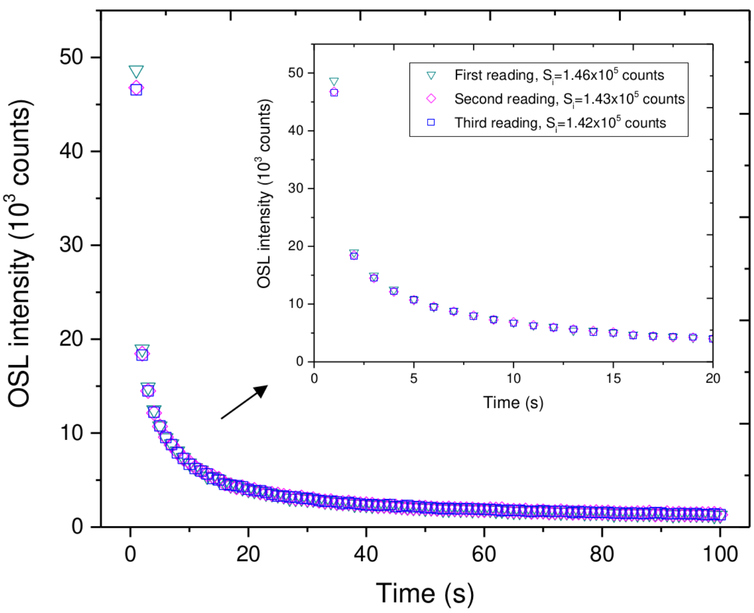

Figure 2. Reproducibility- $CaSO_4$:Dy OSL curves recorded for the same detector irradiated with 8 Gy and thermal treatment with heating at 300°C for 15 hours between each cycle of measurements. The label shows the OSL initial intensity (Si) of each reading.

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Those three OSL signals of each detector were compared to the reference OSL signal of the respective detector and the maximum disagreement observed was 5.9%.

3.2 Dose response of $CaSO_4$:Dy detectors

The dose response of $CaSO_4$:Dy detectors was evaluated for absorbed doses from 0.1 to 10 Gy. Measurements show that the OSL from $CaSO_4$:Dy responds linearly to dose in that range. Figure 3 demonstrates the OSL signal (integrated first 10 s subtracted the background) versus absorbed dose, and the linear fitting parameters. The R-square value of 0.9933 confirms linearity in the dose range of 0.1 to 10 Gy.

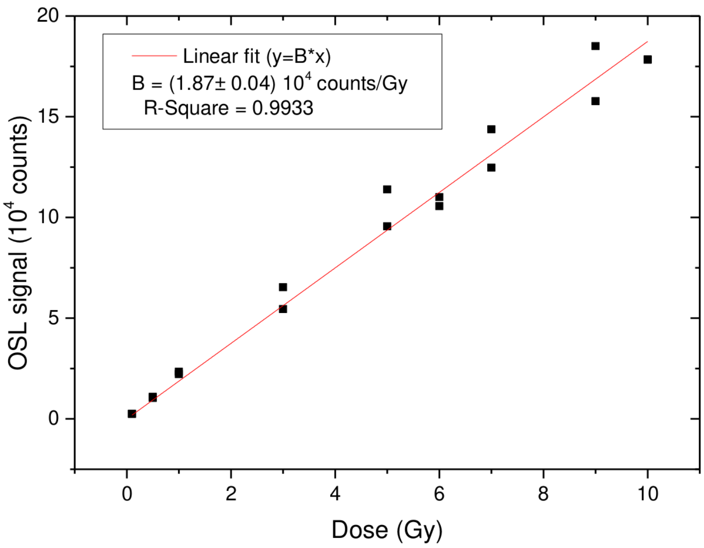

Figure 3. Linear dose response of $CaSO_4$:Dy detectors. Two detectors were evaluated for each absorbed dose value. The OSL signal corresponds to the integrated first 10 s subtracted the background.

3.3 Fading of the OSL signal of $CaSO_4$:Dy detectors

Figure 4 presents the relative loss of OSL signal (relative to the OSL signal obtained immediately after irradiation) over time for $CaSO_4$:Dy detectors.

Results show significant fading on the first day after irradiation (50%). For measurements that require good accuracy, as dose measurements in radiotherapy or individual monitoring, the loss of signal over time and stability of signal should be taken into account. Usually, a correction factor can be adopted, to correct for the signal loss with time. In this study, it was observed that the OSL signal fading of $CaSO_4$:Dy detectors stabilizes on the second day following irradiation.

3.4 Effect of TL measurement on OSL signal of $CaSO_4$:Dy detectors

Figure 5 shows the comparison of three OSL curves of a $CaSO_4$:Dy detector irradiated with 0.1 Gy without previous TL, with TL up to 100°C before OSL reading and with TL up to 400°C before OSL reading.

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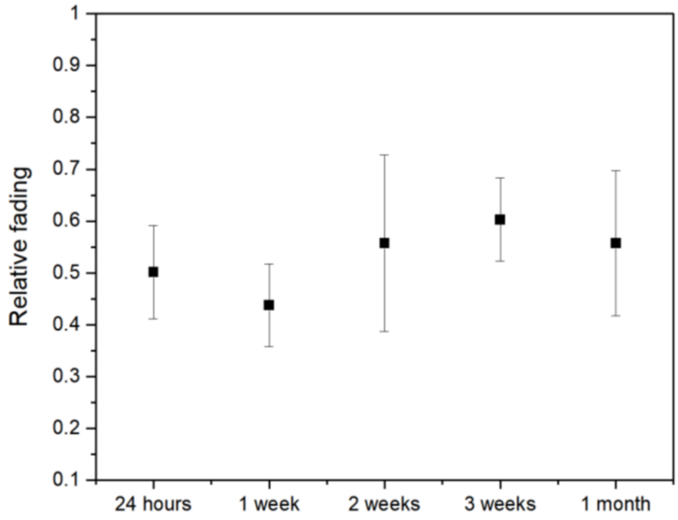

Figure 4. Storage fading of OSL signal from $CaSO_4$:Dy detectors demonstrated by the relative OSL signal obtained after different periods (average of three detectors).

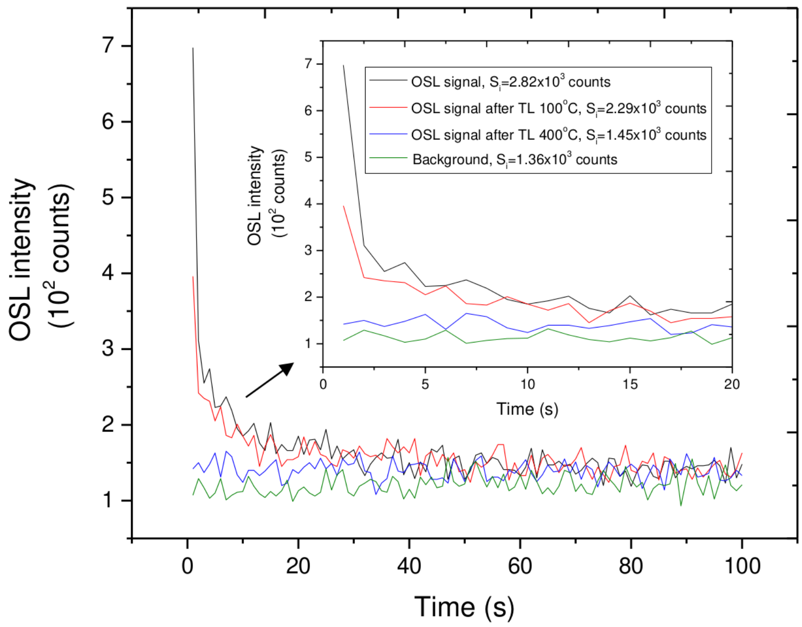

Figure 5. Comparison between OSL curve of $CaSO_4$:Dy irradiated with 0.1 Gy and its OSL curve after TL up to 100°C measurement and its OSL curve after TL up to 400°C measurement. The label shows the OSL initial intensity (Si) of each reading.

We estimated the percentage of the OSL signal remaining in the detector after TL measurements from the average of the OSL signal of three detectors compared to the OSL signal without previous thermal stimulation. After the TL readouts up to 100°C and 400°C the signal in the detectors remains $(64 \pm 1)\%$ and $(6 \pm 1)\%$, respectively. The OSL signal likely corresponds to the same traps involved in the dosimetric TL peak (200–350°C) and this correlation should be further studied.

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4 Conclusion

The dosimetric properties of $CaSO_4$:Dy pellets investigated in this study reinforce the potential application of $CaSO_4$:Dy as an OSL detector for radiation dosimetry. The results show that $CaSO_4$:Dy OSL detectors present good reproducibility and linear dose response in the dose range of 0.1–10 Gy. In addition, the fading study performed over 1 month shows that although in the first 24 hours fading was about 50%, the loss of signal is stable after the first day. The traps involved in the OSL signal probably are the same as the TL dosimetric peak and it needs deeper study. In addition, the storage fading is high in the first hour after irradiation, which indicates adequate treatment should be investigated to empty shallow traps before OSL measurement. In this study, it was possible to conclude that $CaSO_4$:Dy detectors can be suitable for OSL dosimetry in the range of dose studied.

Acknowledgments

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Data availability. The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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