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ISSN 1350-4487

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# Radiation Measurements

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Volume 46 Issue 12
December 2011

SPECIAL ISSUE
Proceedings of the 16th Solid State Dosimetry Conference, September 19–24, Sydney, Australia

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Radiation Measurements 46 (2011) 1847–1850

Contents lists available at ScienceDirect

Radiation Measurements

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# Measuring TL and OSL of beta radioisotopes inside a glove box at a radiopharmacy laboratory

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ARTICLE INFO

*Article history:*
Received 3 November 2010
Received in revised form
29 April 2011
Accepted 8 May 2011

*Keywords:*
Luminescence optically stimulated dosimetry
Thermoluminescence dosimetry
Beta radioisotopes
Individual dosimetry

ABSTRACT

Beta radiation emitters have been intensively used in therapeutic protocols, causing the increase of the radiation exposure of the workers. The thermoluminescent (TL) technique is largely utilized for the monitoring of beta radiation doses of workers. However, recently, the optical stimulated luminescence (OSL) technique has been shown useful for individual dosimetry and for beta radiation. In this study, the results obtained using $Al_2O_3$:C (OSL) and $CaSO_4$:Dy (TL) detectors to measure beta absorbed doses inside a glove box at a radiopharmacy laboratory were compared.

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## 1. Introduction

The use of beta radiation emitters in therapeutic protocols has increased in the last years. This fact implies in the increase of workers exposed to this kind of radiation. Usually, in radiopharmaceutical production plants, workers handle radioactive materials, causing exposure of their extremities, including an inhomogeneous dose distribution in hands and fingers (Mancosu et al., 2010).

The thermoluminescent (TL) technique is largely utilized to evaluate beta radiation doses. Cecatti and Caldas (2006) proposed a dosimetric methodology, using TL and $CaSO_4$:Dy pellets, for monitoring workers exposed to $^{153}$Sm sources at a Nuclear Medicine service.

However, recently, the optical stimulated luminescence (OSL) technique has been shown useful for individual dosimetry (Botter-Jensen et al., 2003), specially using $Al_2O_3$:C as OSL detectors. The efficiency of this material for beta radiation was presented by Akselrod et al. (1999); another study showed that $Al_2O_3$:C is effective as dosimeter in several different applications (McKeever et al., 2004).

Commercial dosimeters of $Al_2O_3$:C have been developed and tested, but most of these tests have been performed with gamma beams. Beta radiation dosimetry might be performed with $Al_2O_3$:C detectors, if they are sufficiently thin to avoid radiation attenuation (Akselrod et al., 1999). The dosimeter thickness is also important to allow a satisfactory accuracy of the measured doses, despite the incident radiation angle or the beta energy. Previous studies (Akselrod et al., 1999; Pinto and Caldas, 2009) showed that $Al_2O_3$:C dosimeters present a very high energy dependence. Therefore, it is necessary to correct the doses obtained by using energy dependency curves.

The objective of this work was to determine the absorbed doses using $Al_2O_3$:C and $CaSO_4$:Dy detectors and the OSL and TL techniques, respectively, and to compare the results when both materials are utilized as radiation detectors inside a glove box, in the case of $^{177}$Lu and $^{90}$Y radioisotopes at the Radiopharmacy Center of IPEN.

## 2. Materials and methods

The OSL measurements were obtained using single Nanodot dosimeters of $Al_2O_3$:C and the MicroStar portable reader, both from Landauer. These detectors have a layer of $Al_2O_3$:C sandwiched between two layers of polyester, with a total thickness of 0.3 mm and diameter of 0.7 mm (Landauer, 2006). The detectors were covered with filters to avoid their exposure to light and the consequent fading effect of their response. The detectors were optically treated at $26 \times 10^3$ lux during 12 h prior to each utilization. A Delta OHM radiometer, model D09721, LUX LP 9021PHOT sensor, was utilized to determine the light level (Gronchi et al., 2007).

Thin thermoluminescent dosimeters (TLDs) of $CaSO_4$:Dy, with dimensions of 6.0 mm in diameter and 0.2 mm in thickness, produced at the Dosimetric Materials Laboratory of IPEN, were

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doi:10.1016/j.radmeas.2011.05.025

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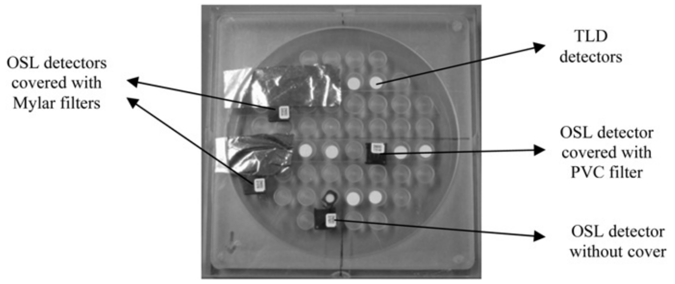


**Fig. 1.** Phantom with the $Al_2O_3$:C and $CaSO_4$:Dy + Teflon detectors, positioned for irradiation.

utilized. All TL measurements were obtained using a Harshaw TLD Reader, model 3500. After the irradiations, the pellets were thermally treated at 300 °C during 1 h, for their re-utilization. The TL and OSL measurements were always taken immediately after the irradiations. These dosimeters were irradiated at the Radiopharmacy Laboratory.

The beta radiation sources utilized were $^{177}$Lu maximum beta radiation energy = 0.497 MeV) and $^{90}$Y (maximum beta radiation energy = 2.24 MeV), positioned inside a glove box. For the irradiations, four Nanodot and eight TLDs were positioned on a polymethylmethacrylate (PMMA) phantom (120 mm × 120 mm × 15 mm), as shown in Fig. 1. The phantom with the detectors was positioned inside a glove box, in front of the beta sources of $^{177}$Lu and $^{90}$Y, one at each time, at a distance of 10 cm. One OSL detector was exposed directly to the beta sources, without filter cover. In the case of the $^{90}$Y, the detector was kept in the dark. Two OSL detectors were covered with Mylar filters of superficial density (SD) of 1.72 mg cm$^{-2}$ and 3.53 mg cm$^{-2}$, and one detector was covered only with the manufacturer's PVC cover. The TLDs were exposed directly to the beta sources, without filter cover. The experiments took place separately, first with the $^{177}$Lu beta source and later with the $^{90}$Y source. Irradiation time intervals were 19 h in the case of the $^{177}$Lu source and 72 h in the case of the $^{90}$Y source. The number of detectors used in this study was limited by the glove box size.

For the characterization process, the OSL and TL detectors were exposed to the $^{90}$Sr + $^{90}$Y, $^{85}$Kr and $^{147}$Pm standard sources of the BSS1 secondary standard from Buchler GmbH, Germany, and of the BSS2 secondary standard from Isotrak, all sources calibrated at the primary standard laboratory, Physikalisch-Technische Bundesanstalt (PTB), Germany. The BSS2 radiation sources characteristics can be seen at Table 1.

In the case of the BSS1 system only the $^{90}$Sr + $^{90}$Y source (1850 MBq, 1981) was utilized in this work (Table 1).

## 3. Results

The reproducibility study of the OSL response was obtained using the beta radiation standard source of $^{90}$Sr + $^{90}$Y of the BSS2 system, and the reproducibility of the TL response was obtained irradiating

**Table 1**
Characteristics of the beta radiation sources: BSS1 and BSS2 systems utilized in this work.

| Source | BSS1 system | BSS2 system | | |
|---|---|---|---|---|
| | $^{90}$Sr + $^{90}$Y | $^{147}$Pm | $^{85}$Kr | $^{90}$Sr + $^{90}$Y |
| Nominal activity (MBq) | 1850 | 3700 | 3700 | 460 |
| Mean beta energy (MeV) | 0.80 | 0.06 | 0.14 | 0.80 |
| Absorbed dose rate in air (μGy s$^{-1}$) | 70.60 ± 0.71 | 2.35 ± 0.05 | 39.7 ± 0.5 | 16.46 ± 0.22 |
| Calibration distance (cm) | 30 | 20 | 30 | 30 |
| Reference date | 04/02/1981 | 19/11/2004 | 30/11/2004 | 08/12/2004 |

the samples with the $^{90}$Sr + $^{90}$Y standard source of the BSS1 system. In the case of the TL response the reproducibility was determined after five irradiations (1 Gy), reading and thermal treatments, consecutively. The maximum deviation of the measurements was obtained from the relative deviation of the mean reading of five irradiations, and the associated uncertainty was the standard deviation of the mean reading of all irradiations. The maximum deviation was 4.1%, and the associated uncertainty was 8.7% (Antonio et al., 2010). The reproducibility of the OSL response was obtained after ten series of irradiations (6 mGy), measurements and optical treatments obtaining a maximum deviation of 4.9% and an associated uncertainty of 2.8% (Pinto and Caldas, 2009).

The lower detection limit for TLDs was obtained by the variability of the TL response of non-irradiated $CaSO_4$:Dy samples. For its determination, the TL response of the pellets without irradiation (which is added to three times the standard deviation of these non-irradiated samples) was taken into account. The value obtained is multiplied by the individual calibration factor of each pellet, and then the lower detection limit was obtained as 56 μGy (Antonio et al., 2010). The lower detection limit of OSL detectors was

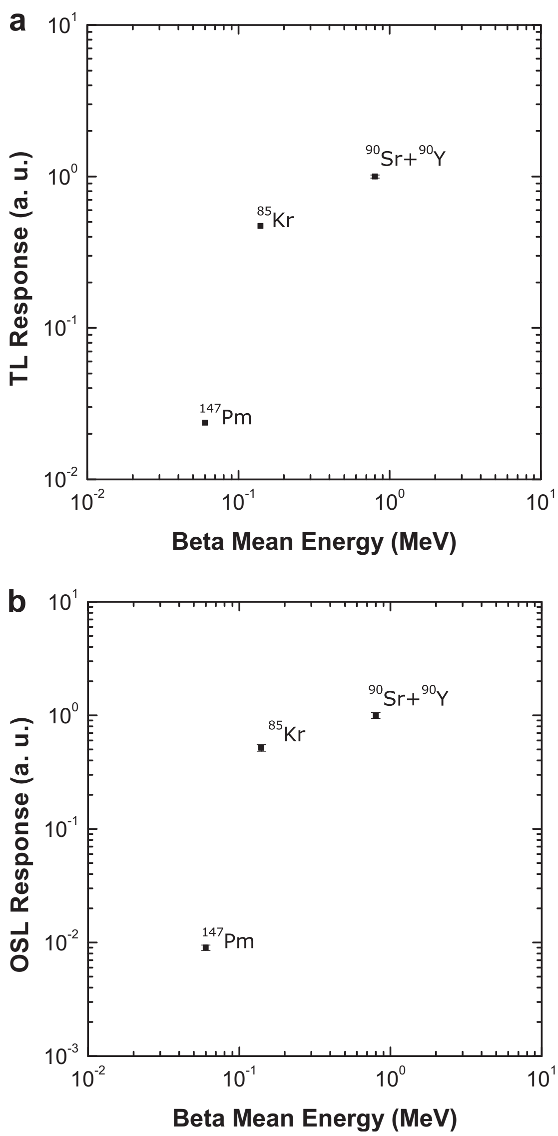


**Fig. 2.** Energy dependence of: (a) TL response of $CaSO_4$:Dy dosimeters, and (b) OSL response of $Al_2O_3$:C Nanodot detectors, to beta irradiation.

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determined graphically, by checking the point where the OSL response becomes constant. The curve provided a value of 130 μGy, as the limit of detection. The detection limit reported by the manufacturer (Landauer, 2006) is 200 μGy, for beta radiation.

The energy dependence of the response of both TL and OSL detectors was obtained using the three sources of the BSS2 system (Fig. 2). The Nanodot OSL detectors were irradiated with $^{90}Sr + ^{90}Y$ (2 mGy), $^{85}Kr$ (6 mGy) and $^{147}Pm$ (25 mGy). During the irradiations the detectors were kept in the dark with no coverings. Previous studies showed that the use of filters does not influence the energy dependence. Eight TL dosimeters were irradiated in the same conditions of the OSL detectors. The energy correction factors for TLDs were 0.89 for $^{177}Lu$, and 1.28 for $^{90}Y$, and for OSL detectors the correction factors were 0.87 and 1.22 for $^{177}Lu$ and $^{90}Y$, respectively.

The dose–response curves (Fig. 3) were previously obtained for the $Al_2O_3$:C detectors by Pinto and Caldas (2009) and for the $CaSO_4$:Dy pellets by Antonio et al. (2010), irradiating the samples with doses between 0.5 mGy and 2 Gy, and using the $^{90}Sr + ^{90}Y$ sources of the BSS1 and BSS2 systems; the results agree with those

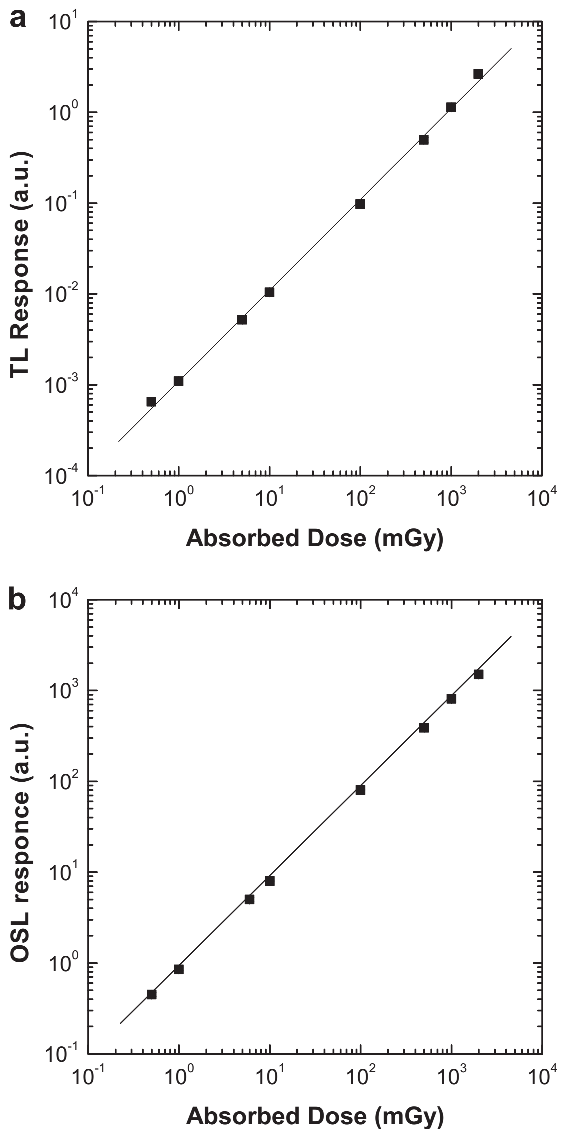


**Fig. 3.** Dose-response curves obtained for: (a) $CaSO_4$:Dy dosimeters exposed to $^{90}Sr + ^{90}Y$ beta source (BSS1 system) and (b) $Al_2O_3$:C detectors exposed to $^{90}Sr + ^{90}Y$ beta source (BSS1 system: 0.5 mGy–10 mGy and BSS2 system: 100 mGy to 2 Gy).

**Table 2**
Absorbed doses obtained using $Al_2O_3$:C Nanodot and $CaSO_4$:Dy detectors exposed to $^{177}Lu$ and $^{90}Y$ radiations, and using the Mylar filters. SD: Superficial density.

| Beta source | Absorbed dose (mGy) | | | Difference (%) |
|---|---|---|---|---|
| | TL | OSL | | |
| $^{177}Lu$ | 5.80 ± 0.10 | Filter 1 SD = 1.72 mg cm$^{-2}$ | 5.20 ± 0.04 | 10 |
| | | Filter 2 SD = 3.53 mg cm$^{-2}$ | 5.30 ± 0.16 | 9 |
| | | No cover | 4.90 ± 0.14 | 16 |
| | | PVC cover | 4.60 ± 0.20 | 21 |
| $^{90}Y$ | 2100 ± 120 | Filter 1 SD = 1.72 mg cm$^{-2}$ | 2009 ± 193 | 4 |
| | | Filter 2 SD = 3.53 mg cm$^{-2}$ | 2060 ± 154 | 2 |
| | | No cover | 2009 ± 121 | 4 |
| | | PVC cover | 1560 ± 134 | 26 |

from other authors (Yukihara and McKeever, 2008). They are shown here, because these data are necessary for the determination of the absorbed doses in this work.

The dose–response curve of the $CaSO_4$:Dy dosimeters presented a linear behavior between 1 mGy and 1 Gy, and the dose–response curve of the $Al_2O_3$:C detectors presented a linear behavior between 0.5 mGy and 2 Gy. Using the dose–response curves and the energy-dependence curves, the absorbed doses were determined for the cases of TL and OSL detectors exposed to the sources of $^{177}Lu$ and $^{90}Y$ (Table 2).

In the case of the $^{177}Lu$ source, differences of 16% and 21% can be observed among the absorbed doses obtained by TL and OSL techniques for the detectors without cover and with PVC cover, respectively. The maximum variation between the two techniques was 26%, in the case of the $^{90}Y$ source, for the PVC covered detector. These differences in absorbed doses obtained were expected, since the PVC cover attenuates the beta radiation, and the detectors without cover are directly exposed to light, with consequent fading. This fading effect was less significant in the case of the $^{90}Y$ source due to the experimental set-up, which was kept in a dark environment during the irradiation.

The detectors covered with Mylar filters presented a maximum variation of 10% between the TL and OSL techniques for the $^{177}Lu$ source and superficial density of 1.72 mg cm$^{-2}$.

## 4. Conclusions

The results obtained for the TL and OSL detectors show agreement within 10%, for the OSL detectors covered with Mylar filters. The results show the possibility of the application of TL and OSL detectors in the monitoring of extremities of workers exposed to beta radiation at Nuclear Medicine services.

## Acknowledgements

The authors thank Dr. Helen J. Khoury for the Harshaw TLD Reader, model 3500, and CNPq, FAPESP, CAPES and MCT (Project INCT in Radiation Metrology for Medicine), for partial financial support.

## References

Antonio, P.L., Pinto, T.C.N.O., Caldas, L.V.E. Comparison between TL and OSL measurements at a calibration procedure simulation of clinical applicators. In: Proceedings of the 1st Symposium on Solid State Dosimetry and Applications. May 26 to 28, Recife, 2010. Pernambuco, Brazil.
Akselrod, A., Akselrod, M.S., Larsen, N.A., Banerjee, D., Botter-Jensen, L., Christensen, P., Lucas, A.C., McKeever, S.W.S., Yoder, R.C., 1999. Optically

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stimulated luminescence response of $Al_2O_3$ to beta radiation. Radiat. Prot. Dosim. 85 (1–4), 125–128.
Botter-Jensen, L., McKeever, S.W.S., Wintle Elsevier, A.G. (Eds.), 2003. Optically Stimulated Luminescence Dosimetry.
Cecatti, S.G.P., Caldas, L.V.E., 2006. Preliminary dosimetric characterization of thermoluminescent materials for beta radiation monitoring at nuclear medicine services. Radiat. Prot. Dosim. 120 (1–4), 307–311.
Gronchi, C.C., Cecatti, S.G.P., Pinto, T.C.N.O., Caldas, L.V.E. Light induced fading of the OSL response of Al2O3:C detectors. In: Proceedings of the International Nuclear Atlantic Conference, September 29–October 5, 2007. Santos, Brazil.
Landauer, 2006. User Manual in Ligth Systems. Laudauer, Illinois.
Mancosu, P., Cantone, M.C., Veronese, I., Giussani, A., 2010. Spatial distribution of beta extremity doses in nuclear medicine: a feasibility study with thin $\alpha$-$Al_2O_3$:C TLDs. Phys. Med. 26 (1), 44–48.
McKeever, S.W.S., Blair, M.W., Bulur, E., Gaza, R., Kalchgruber, R., Klein, D.M., Yukihara, E.G., 2004. Recent advances in dosimetry using the optically stimulated luminescence of $Al_2O_3$:C. Radiat. Prot. Dosim. 109 (4), 269–276.
Pinto, T.C.N.O., Caldas, L.V.E. Characterization of OSL commercial dosimeters using a hand phantom, in standard beta radiation beams. In: Proceedings of the International Nuclear Atlantic Conference. September 27–October 02, 2009. Rio de Janeiro, Brasil.
Yukihara, E.G., McKeever, S.W.S., 2008. Optically stimulated luminescence (OSL) dosimetry in medicine. Phys. Med. Biol. 53 (20), 351–379.