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Luminescent response from BeO exposed to alpha, beta and X radiations

D.P. Groppo*, L.V.E. Caldas

Instituto de Pesquisas Energéticas e Nucleares/ Comissão Nacional de Energia Nuclear (IPEN-CNEN/SP), Av. Prof. Lineu Prestes, 2242, São Paulo 05508-000, Brazil

HIGHLIGHTS

- Dosimetric characterization of BeO detectors using the TL and OSL techniques.
- The characterization tests were performed in alpha, beta and X radiation beams.
- The luminescent response of BeO samples was better for the OSL technique.

Keywords:
Thermoluminescence
Optically stimulated luminescence
BeO
Alpha radiation
Beta radiation
X radiation

ABSTRACT

This work presents the TL and OSL response of beryllium oxide detectors exposed to alpha, beta and X radiation beams. The samples were characterized, and they presented good reproducibility, good linearity interval, low energy dependence, and an acceptable fading. The luminescent response was better for the OSL technique.

1. Introduction

In the medical field, ionizing radiation is used both for therapeutic and diagnostic purposes, over a wide range of radiation doses. Also, in order to ensure that the objective of each radiation practice type is achieved, detailed studies of detectors and devices in different types of radiation beams are necessary. In solid state dosimetry, besides the thermoluminescent technique (TL), the optically stimulated luminescence (OSL) is currently one of the most promising dosimetric techniques (Botter-Jensen et al., 2003).

Beryllium Oxide (BeO) is not only a good material for TL dosimetry, but it has also been studied as OSL dosimeter (Bulur et al., 1998; Sommer et al., 2007; Watanabe et al., 2010; Yukihara, 2011). This material presents advantages such as a high sensitivity to ionization radiation, linear dose response and an effective atomic number (Z_{eff} = 7.2) near that of human soft tissue (Z_{eff} ~ 7.6). Although a lot is already known about the dosimetric properties of beryllium oxide, in this work, a dosimetric characterization of BeO samples was performed using the techniques of thermoluminescence (TL) and optically stimulated luminescence (OSL) for alpha, beta and X radiations to demonstrate the different behaviour of their response, using the same measuring reader.

* Corresponding author. Tel.: +55 11 3133 9716; fax: +55 11 3133 9671.
E-mail addresses: dpgroppo@ipen.br (D.P. Groppo), lcaldas@ipen.br (L.V.E. Caldas).

2. Materials and methods

2.1. BeO samples

The BeO samples were in the form of discs of 4 mm in diameter and 0.8 mm in thickness, weighing (27.9 ± 0.45) mg; they consist of pressed pellets with some impurities. For the determination of the elements present in the composition of the BeO samples, an analysis using X-ray fluorescence (XRF spectrometer EDX-720, Shimadzu Co.) was performed. Elements such as K (791 ppm), Si (722 ppm), Al (229 ppm), Mn (105 ppm) and Fe (104 ppm) were found (Groppo, 2013). Before the characterization tests, the samples were heated at 750 °C during 15 min.

2.2. Irradiations

The following radiation systems were utilized: reference X radiation qualities established at the Calibration Laboratory of IPEN (LCI) using the International Electrotechnical Commission recommendations IEC 61267 (IEC, 2005), and beta and alpha sources ($^{90}Sr+^{90}Y$ and ^{241}Am) available in the TL/OSL reader system. The X-ray unit was a Pantak Seifert, model ISOVOLT 160HS, that operates

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Table 1
Characteristics of standard X radiation beams, diagnostic radiology level, established at the Pantak/Seifert system (ISOVOLT HS 160 model), according to IEC 61267 (IEC, 2005). The tube current was 10 mA in all cases (Lucena, 2010).

Radiation quality	Generating potential (kV)	Additional filtration (mmAl)	Half-value layer (mmAl)	Mean energy (keV)	Air kerma rate (mGy min^{-1})
RQR 3	50	2.4	1.78	32.21	22.4 ± 0.2
RQR 5	70	2.8	2.58	40.08	38.6 ± 0.3
RQR 8	100	3.2	3.97	49.95	69.3 ± 0.5
RQR10	150	4.2	6.57	61.39	120.0 ± 1.0

from 5 to 160 kV. The samples were localized at a distance of 1 m from the X-ray tube. The characterization tests performed were response reproducibility, dose–response curve, energy dependence and thermal fading. The energy dependence was determined only for standard beams of X radiation. The characteristics of these beams are shown in Table 1 (Lucena, 2010) and the reference quality was RQR 5. The alpha radiation absorbed dose rate was 45 mGy/s and the beta radiation absorbed dose rate was 0.1 Gy/s, according to the manufacturer's manual (obtained for quartz at the same sample position). The activities of alpha and beta sources were respectively 10.7 MBq and 1.48 GBq according to the calibration certificate (06/10/2010). To determine the exposure time, a correction due to the radioactive decay was applied for the measurement date.

2.3. TL and OSL measurements

All measurements were taken using a RISÖ TL/OSL system, model DA-20, in continuous wave OSL mode (CW-OSL), with blue LEDs for stimulation. For the measurements, an UV transmitting broad-band glass filter Hoya U-340 (7.5 mm thick) was used in front of the photomultiplier tube. Each OSL measurement was carried out during 100 s of LED stimulation with a power of 90%. The TL measurements were performed with a linear heating rate of 10 Ks^{-1} up to 450 °C. The TL emission was always integrated in the temperature interval between 150 °C and 300 °C, and, the OSL response was always integrated from 0 s to 100 s, in both cases after subtracting the background signal. All measurements were carried out 1 day after the irradiation. Each sample was individually calibrated with an absorbed dose of 1 Gy (RQR5). All stated relative values in this work are related to this calibration.

2.4. Bleaching

For each cycle of irradiation and TL measurement, the samples were submitted to a thermal treatment of 750 °C during 15 min; however, each cycle of irradiation and OSL measurement was followed by a bleaching of 30 min in a home-made light box (blue LED system, 420–500 nm; 2.5 W; 7000 lux). The illuminance level (in lux) was obtained using a LP9021 PHOT sensor connected to a DELTA OH radiometer (model 9721) positioned at the same location as the samples during the bleaching process.

3. Results

3.1. TL emission curves and OSL decay curves

The TL emission curves and the OSL decay curves were obtained by irradiating the samples at a dose of 1 Gy. The TL and OSL curves obtained for alpha, beta and X radiations are presented in Fig. 1.

To determine the reproducibility of the luminescent response for the TL and OSL techniques, 10 samples were studied, and the samples underwent 10 cycles of irradiation, thermal/optical stimulated luminescence measurement and bleaching process. The samples were irradiated with a dose of 1 Gy, evaluated and then treated for new measurements. The irradiations were carried out in alpha, beta and X (RQR 5) radiation beams. For each sample and radiation type, a calibration factor was determined and applied to all measurements.

The reproducibility of the TL and OSL responses showed a maximum coefficient of variation of 3.6%; 2.2%; 2.8% (TL) and 2.8%; 4.2%; 2.7% (OSL), for alpha, beta and X radiations, respectively.

3.2. Dose-response curves

The dose–response curves were obtained by the luminescent response as a function of absorbed dose (Gy). The studied range of the dose–response was established by the limitations of each radiation type. Thus, for alpha radiation the absorbed dose range was from 0.2 Gy to 200 Gy, for beta radiation it was from 0.1 Gy to 200 Gy, and for X radiation (RQR 5 quality), from 0.01 Gy to 1 Gy. The results obtained for the TL and OSL techniques (alpha, beta and X radiations) are shown in Figs. 2 and 3. A summary of these results is presented in Table 2.

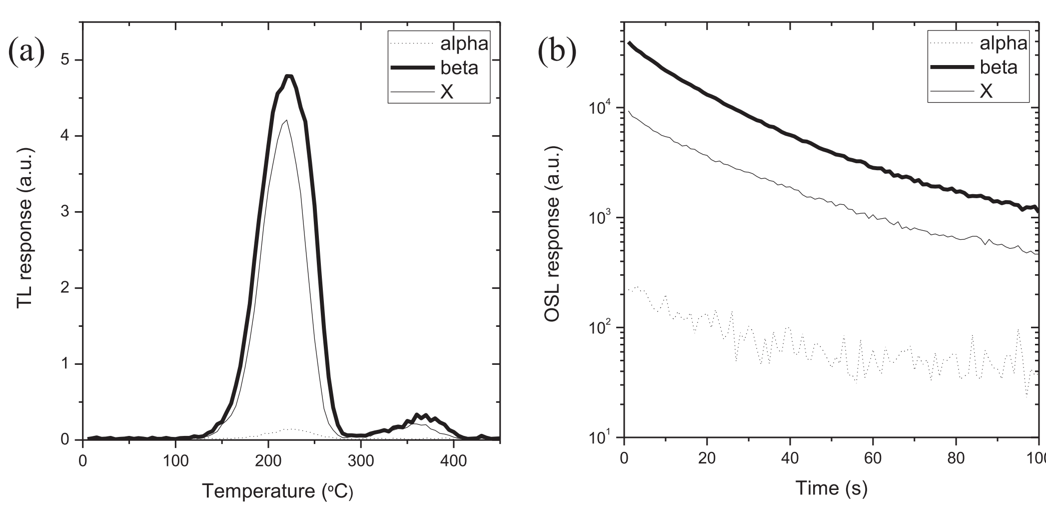

Fig. 1. (a) TL glow curve for a linear heating rate of 10 K s^{-1} up to 450 °C (b) OSL decay curves for BeO samples irradiated with an absorbed dose of 1Gy of alpha, beta and X radiation (RQR5).

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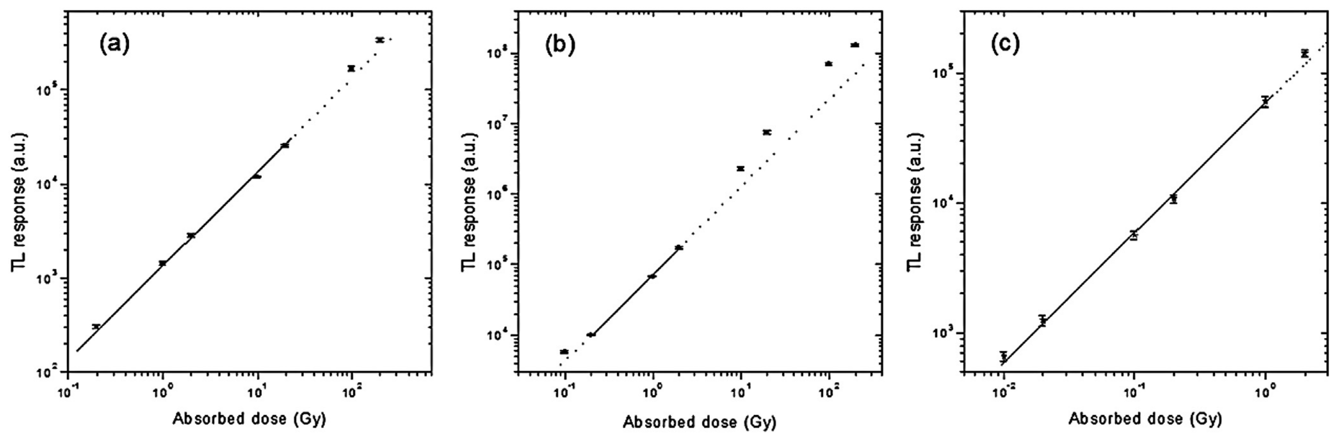

Fig. 2. TL dose–response curves for samples of BeO exposed to (a) alpha (0.2 Gy–200 Gy), (b) beta (0.1 Gy–200 Gy) and (c) X (0.01 Gy–2 Gy) radiations.

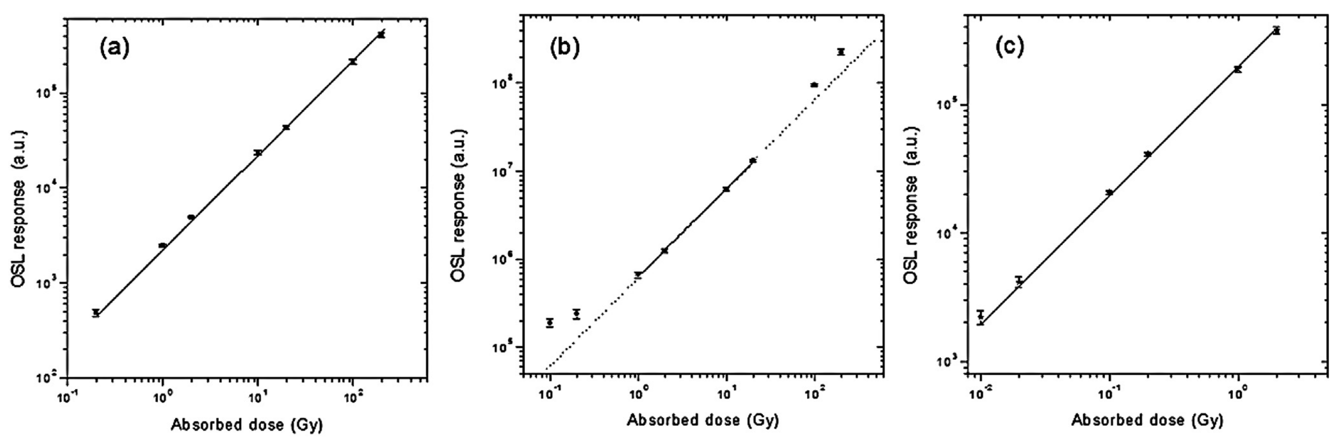

Fig. 3. OSL dose–response curves for samples of BeO exposed to (a) alpha (0.2 Gy–200 Gy), (b) beta (0.1 Gy–200 Gy) and (c) X (0.01 Gy–2 Gy) radiations.

3.3. *Thermal fading*

The stability of TL and OSL response of BeO samples exposed to alpha, beta and X radiations was investigated during 4 months. Each measuring group consisted of three BeO samples that were exposed to an absorbed dose of 1 Gy. For the evaluation with X radiation, the samples were exposed to the RQR5 beam quality. After BeO sample irradiation, they were stored under light protection until the measurements during 10 min, 6 h, 24 h, 48 h, 168 h and 1, 2, 3 and 4 months. In the case of short storage time (10 min and 6 h), the samples were irradiated and measured one by one. The TL and OSL responses obtained for alpha, beta and X radiations are illustrated in Figs. 4 and 5.

3.4. *Energy dependence*

Four standard qualities of X-radiation (RQR3, RQR5, RQR8 and RQR10) established at the Pantak/Seifert system were used in this study, which was conducted with 8 samples; the measurements were taken 1 day after irradiation. The BeO samples were exposed to the X radiation beam qualities of diagnostic radiology, and subsequently their TL and OSL responses were evaluated. For all radiation qualities, the correction factors were normalized to the results obtained for the RQR5 beam. Table 3 shows the results for the energy dependence of TL and OSL responses.

Table 2
Linearity range of TL and OSL response of BeO samples for alpha, beta and X radiations.

Luminescent technique	Linearity range (Gy)		
	Radiation type		
	Alpha	Beta	X
TL	0.20–20.00	0.20–2.00	0.01–1.00
OSL	0.20–200.00	1.00–20.00	0.01–2.00

4. Discussion

In Fig. 1, all BeO samples showed the same TL behaviour, with a dosimetric main peak at approximately 220 °C and a second peak at 380 °C. The response depends on the radiation type for both TL and OSL techniques. For all OSL curves a reduction of 50% in the intensity is observed in about 12 s. The BeO response was shown to be more sensitive to beta radiation, followed by X radiation and alpha radiation. It was possible to check the influence of the particle attenuation inside the detector; the alpha radiation presents a sensibility approximately 4% of the sensibility to X radiation. Since it is a surface interaction (with the contribution of only 2% of the volume in signal), the real dose depends strongly on several factors such as: geometry and construction of the alpha source, distance between source and sample, humidity and air pressure. The way to control these factors was always taking measurements at the same conditions. However, the beta radiation should also have shown a lower sensibility to X radiation (not as much as alpha radiation), but the study demonstrated another behaviour.

The dose–response curves showed a greater linear range for the OSL technique than for the TL technique. The absorbed doses of

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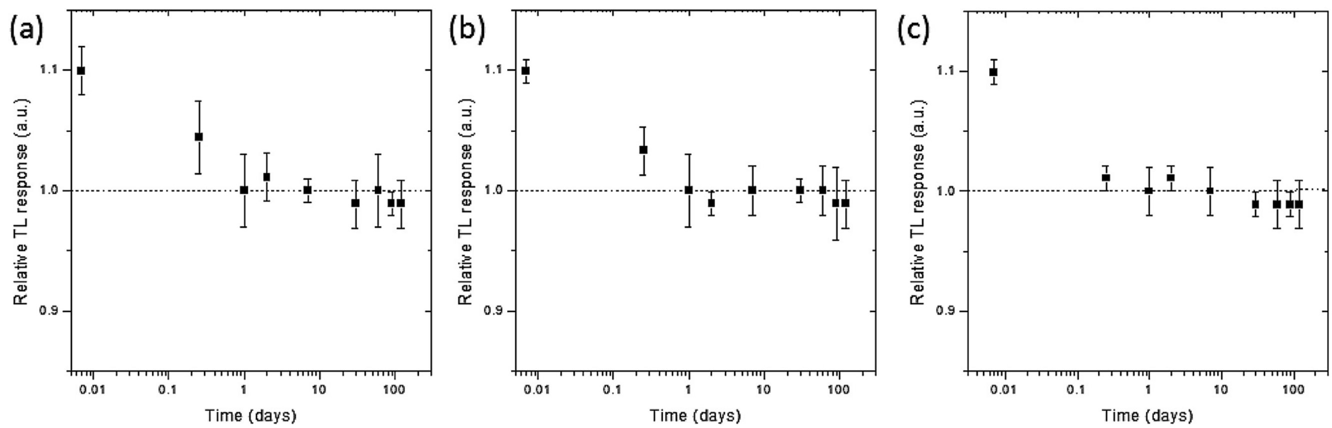

Fig. 4. Thermal fading of TL response of BeO samples exposed to (a) alpha, (b) beta and (c) X radiations. The dotted lines represent the normalization of the signal to storage of one day.

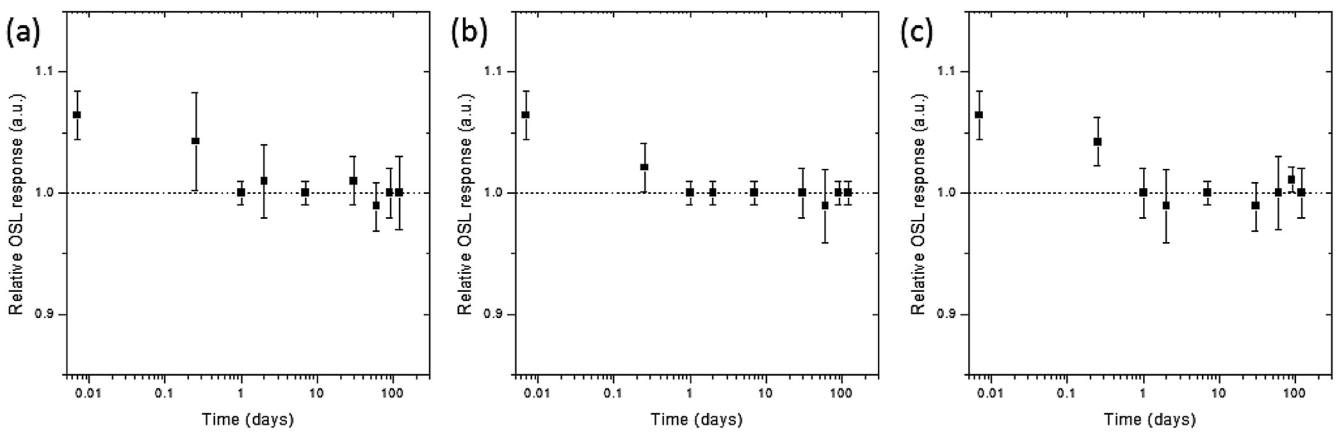

Fig. 5. Thermal fading of OSL response of BeO samples exposed to alpha, beta and X radiations. The dotted lines represent the normalization of the signal to storage of one day.

0.1 Gy and 0.2 Gy of beta radiation were not within the range of linear OSL response, and the absorbed dose of 0.1 Gy did not appear within the range of linear TL response: these results may be disregarded because the time intervals for obtaining these irradiation doses were too short, only 1 s and 2 s, respectively. Most curves presented a supralinear behaviour; however, it was possible to verify some regions of linear behaviour. In this case, all fits showed a linear correlation coefficient greater than 0.998.

The thermal fading of the TL response on the first day was 9% for the three types of radiations. After this period, the response is nearly stable with a long term fading of approximately 1% in 4 months. The fading of the OSL response after 24 h was approximately 6% compared to the first measurement. The OSL response remained constant showing a negligible fading with a long term fading test in 4 months. The decay of the TL and OSL responses to X-rays is more abrupt in the first 6 h compared to alpha and beta radiations.

Table 3
TL and OSL calibration coefficients and correction factors for BeO samples irradiated in X radiation beams (RQR).

Technique	TL		OSL	
Radiation quality	Calibration coefficient (μGy/cps)	Correction factor	Calibration coefficient (μGy/cps)	Correction factor
RQR 3	13.3 ± 0.2	0.89	2.7 ± 0.1	1.00
RQR 5	15.0 ± 0.4	1.00	2.7 ± 0.1	1.00
RQR 8	14.4 ± 0.6	0.95	2.7 ± 0.1	1.00
RQR10	13.2 ± 0.2	0.88	2.5 ± 0.1	0.93

The maximum energy dependence of the TL response of BeO samples exposed to the RQR beams was 12%. On the other hand, the energy dependency in the case of OSL technique was only 7%. Studies by Jahn et al. (2013) and Sommer et al. (2007) with Thermalox 995™ (BeO) for X radiation beams (with effective energies similar to those studied in this work, but from the N-series spectra (narrow spectra)) showed an energy dependence of approximately 12%, using the OSL technique.

5. Conclusion

The dosimetric characteristics obtained in this work show the application possibility of BeO samples in radiation dosimetry for beta and X radiations, considering the studied dose ranges, for diagnostic radiology and radiation therapy dosimetric procedures. In general, the luminescent response was better for the OSL technique: greater range of linearity, lower energy dependence of luminescent response and a lower fading than the characteristics presented by the TL technique, for the same material.

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