Correlation between OSL signal bleaching of the Al_2O_3:C detectors and effectiveness of illumination time for different doses in beta dosimetry

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Abstract

The Optically stimulated luminescence (OSL) technique has already became a successful tool in personal dosimetry, geological and archeological dating, and in radiation diagnostic imaging (Akselrod et al., 2007). High sensitivity, precise delivery of light, fast readout times, simpler readers and easier automation are the main advantages of OSL in comparison with thermoluminescent dosimetry (TLD) (Akselrod et al., 2007; Yukihara and McKeever, 2011; Bøtter-Jensen et al., 2003). Many dosimetry materials exhibit a variation in readout with light exposure (including both visible and UV radiation energy) which may cause problems in dosimetry. The Al_2O_3:C is very sensitive to UV and visible light; after heat treatment is necessary to store it in a sealed package to any interference from external light. The correlation between OSL signal bleaching of the Al_2O_3:C detectors and effectiveness of illumination time for different doses in beta dosimetry was investigated for doses from 1 to 10 Gy. The best combination between dose and bleaching time of the Al_2O_3:C detectors was analyzed.

Key words: OSL, Al_2O_3:C, bleaching time, beta radiation

1. Introduction

Al_2O_3:C, initially developed as a TL dosimeter, has exceptional dosimetric properties. These include very high sensitivity to ionizing radiation, a relatively simple glow curve with a peak at a ~ 177°C, a linear response over 6 orders of magnitude in dose, low background, low fading during storage in the dark, a simple emission band centered at 420 nm, and a relatively low effective atomic number (Akselrod et al., 1990; Yukihara et al., 2004). The Al_2O_3:C is a highly sensitive radiation detector material that has shown to be excellent in dose determination using OSL (McKeever et al., 1996; Bøtter-Jensen e McKeever, 1996). One such application that has motivated this study is dose verification in radiotherapy of cancer patients. Radiotherapy is subject to strict precision requirements because small deviations in the target dose may cause more damaging than curative (Edmund e Andersen, 2007).

The Al_2O_3:C currently used in personal dosimetry is grown in the form of single crystals. Single crystals of 5 mm in diameter by 0.9 mm thickness cut from boules have been widely used in TL dosimetry since the 1990s (Yukihara and McKeever, 2011).

Al_2O_3:C single crystals can be annealed (heated to high temperature) or bleached (illuminated with light of appropriate wavelength) to empty the trapping centers associated with the OSL signal and erase the OSL signal due to natural background radiation or previous irradiation (Yukihara and Mckeever, 2011). Annealing is important to reset the crystal's sensitivity. Sensitivity changes in Al_2O_3:C are observed and have been attributed to a build-up of electrons and holes in deep traps and associated change in concentration of defects. Based on the understanding of the influence of deep traps on the sensitivity of Al_2O_3:C, heating the crystal to 900°C for 15 minutes is recommended after each use (Yukihara and Mckeever, 2011; Yukihara et al., 2004). Yukihara and his collaborators investigated the TL and OSL response to high-energy heavy-charged particles (Yukihara et al., 2004). The Al_2O_3:C (Luxel^{TM}) dosimeters were bleached overnight using light from a halogen lamp filtered by a yellow glass filter (Yukihara et al., 2004). If the crystal has not been irradiated with a high dose, heating with a lower temperature (400 or 500°C) will empty the trapping centers associated with the main OSL signal, but deep traps will remain unaffected and the crystal's sensitivity may change with the accumulated dose (Yukihara and Mckeever, 2011).

Bleaching of the Al_2O_3:C detectors is effective in emptying the trapping centers associated with the main OSL signal. First of all, illumination with light sources having short wavelength components (λ < 450 nm) should be avoided to prevent photo-ionization of defects in the crystal, which in turn can generate free electrons, giving rise to a light-induced OSL signal, and to prevent photo-transfer from charges in deep traps to the dosimetric traps. Second, the spectrum of the bleaching light should be similar to the spectrum of the light used for readout (Yukihara and Mckeever, 2011).

The single crystals have the advantage that they can be used almost indefinitely, since the detector can be annealed to reset its sensitivity. The disadvantage is the inherent variability in sensitivity from crystal to crystal due to inhomogeneities in the concentration of defects, especially along the length of the original crystal boule. For this reason, pre-selection of the detectors or individual detector calibration is necessary to achieve good precision (Bøtter-Jensen et al., 2003; Yukihara and McKeever, 2011). The annealing recommendations of Al_2O_3:C detectors manufacturer are: heating to a temperature of 800°C in a time of 10 to 15 minutes (after total dose above 0.10 Gy).

This work aimed to study the correlation between OSL signal bleaching of the Al_2O_3:C detectors and effectiveness of illumination time with blue LED lamp after irradiation for different doses in beta dosimetry. The Al_2O_3:C detectors were illuminated for increasing times using blue LED lamp coupled in a dark box and the OSL signals were obtained for different beta doses.

2. Experimental

2.1 Materials and irradiation process

Seventy two Al_2O_3:C dosimeters (TLD-500) provided by Rexon TLD System, Inc. (USA) with following dimensions: 0.9 mm thickness and 5 mm of diameter were used. The beta irradiations and readings were performed using a ^{90}Sr-^{90}Y beta source (dose rate: 0.1 Gy/s) accommodated inside an automated RisØ TL/OSL DA-20 reader. The OSL decay curves were obtained for the following doses: 1, 5 and 10 Gy (Fig. 2-4).

2.2 OSL measurements

The Al_2O_3:C dosimeters were stimulated with the blue LED (NICHIA, type NSPB - 500AS), in a constant illumination intensity mode (CW), with an emission peak of 470 nm and it was used an Hoya U-340 filter at the detection window. In CW-OSL, aperture of appropriate diameter was used to protect the photomultiplier tube (PMT). For the OSL readings, the analyses using the CW-OSL signal integrated over the period of stimulation (60 s).

2.3 Bleaching time

The bleaching time was realized in a box completely sealed with a blue LED lamp at the top (Fig. 1). The light exposure time to blue LED lamp was varied for the following times: 1 minute, 10 minutes, 1 hour, 3 hours, 12 hours and 24 hours. Each presented value (Fig. 1-4) represents the average of four OSL readings.

(a) **(b)** **(c)**

Fig. 1: (a) Dark box built for Al_2O_3:C dosimeters illumination; (b) Dark box with blue LED lamp at the top; (c) Al_2O_3:C dosimeters illuminated with a blue LED lamp (specifications: 127 V and 2,2 W).

3. Results and Discussion

Figures 2-4 presents the OSL decay curves of Al_2O_3:C dosimeters according to the reading time for the following beta radiation doses: 1, 5 and 10 Gy, respectively. It can be observed that the OSL signal of Al_2O_3:C dosimeters decreases with increasing blue light exposure time. Figure 5 compares the doses with light exposure time to blue LED lamp. In Fig. 5 can be noted that the OSL signal is proportional to the radiation dose.

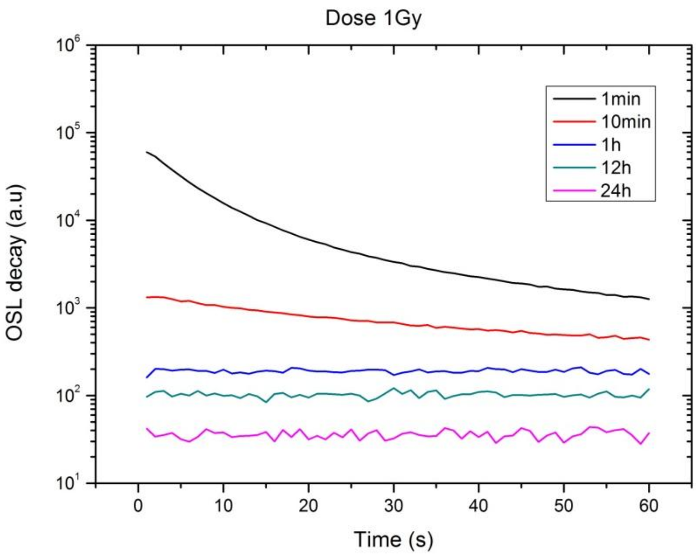

Fig. 2: OSL decay curve of Al_2O_3:C dosimeters for beta radiation dose of 1 Gy.

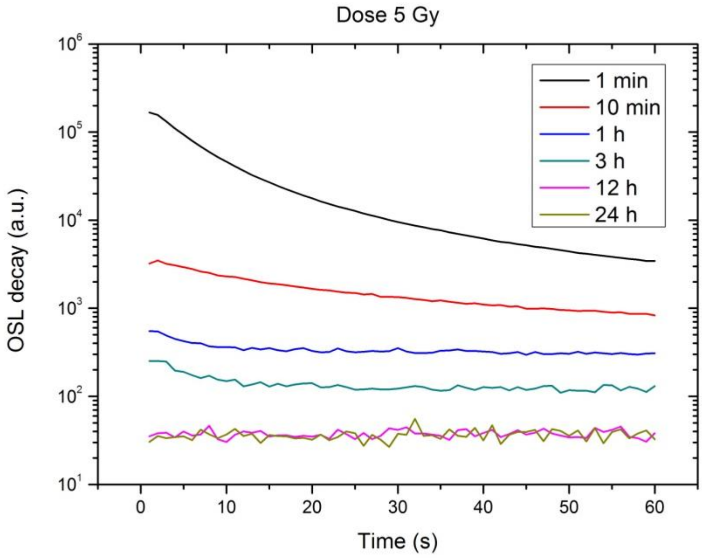

Fig. 3: OSL decay curve of Al_2O_3:C dosimeters for beta radiation dose of 5 Gy.

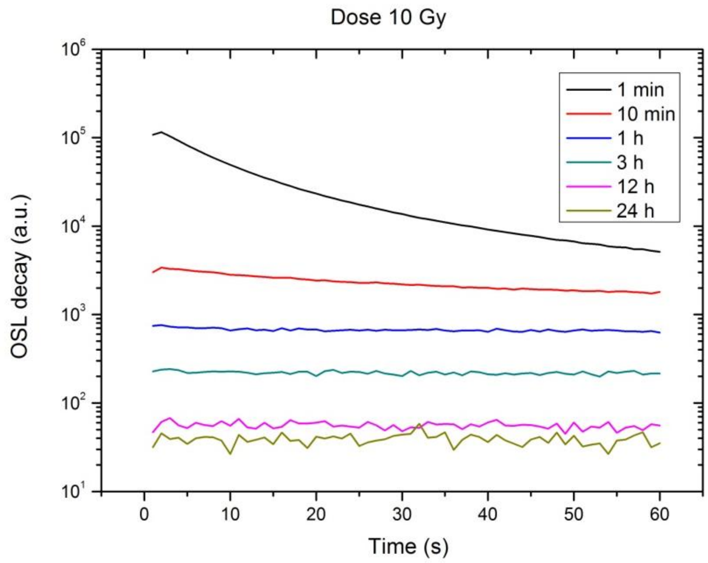

Fig. 4: OSL decay curve of Al_2O_3:C dosimeters for beta radiation dose of 10 Gy.

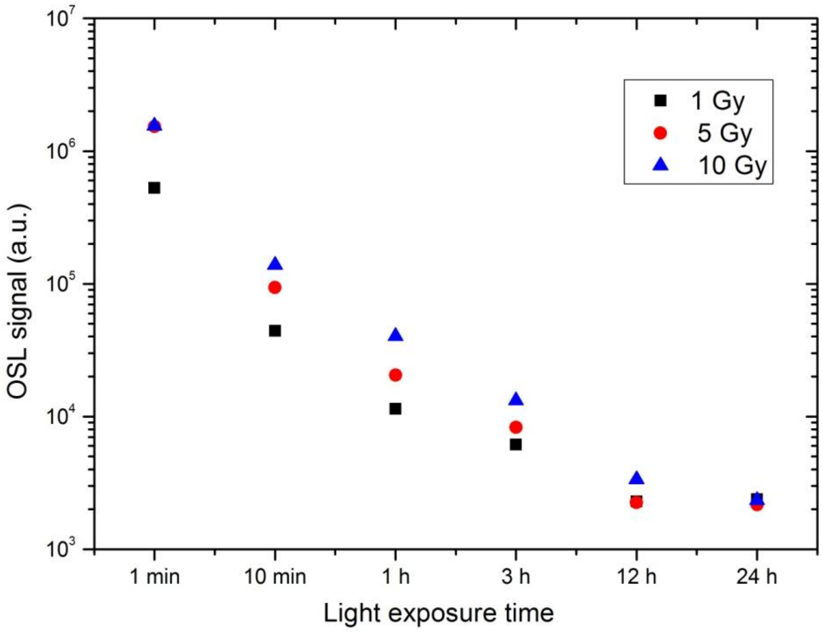

Fig. 5: OSL decay curve of Al_2O_3:C dosimeters according to beta radiation doses and light exposure time.

The literature recommends that the upper detection limit of Al_2O_3:C dosimeters is up to 10 Gy (Yukihara and Mckeever, 2011), therefore this work was made up to this dose level. The obtained results indicate that exposure time of 24 h to blue LED promotes a good bleaching and low residual signal (same order of reader background) for beta doses from 1 up to 10 Gy.

4. Conclusions

The OSL signals are stimulated with blue LED in the OSL reader, for this reason the dosimeters were illuminated with blue light after irradiation for beta dosimetry. The illumination with blue LED lamp for 24 h promotes an efficient bleaching in the Al_2O_3:C dosimeters for beta doses up to 10 Gy, with low residual signal, with the same order of reader background. This work presented a alternative method for annealing/bleaching of Al_2O_3:C dosimeters and demonstrated to be very effective because do not need a heat treatment in an oven.

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References

Akselrod, M.S.; Kortov, V.S.; Kravetsky, D.J.; Gotlib, V.I. Highly sensitive thermoluminescent anion-defect α-Al_2O_3:C single crystals detectors. Radiat. Prot. Dosim., n. 33, p. 119-122, 1990.

Akselrod, M. S.; Bøtter-Jensen, L.; Mckeever, S. W. S. Optically stimulated luminescence and its use in medical dosimetry. Radiat. Meas., v. 41, p. S78-S99, 2007.

Bøtter-Jensen, L.; McKeever, S. W. S. Optically stimulated luminescence dosimetry using natural and synthetic materials. Radit. Prot. Dosimetry, n. 65. p. 273-280, 1996.

Bøtter-Jensen, L.; McKeever, S.W.S.; Wintle, A.G. Optically Stimulated Luminescence Dosimetry.Amsterdam: Elsevier; 2003.
Edmund, J. M.; Andersen, C. E. Temperature dependence of the Al_2O_3:C response in medical luminescence dosimetry. Radiat. Meas., n. 42, p. 177-189, 2007.
McKeever, S. W. S.; Akselrod, M.; Markey, B. Pulsed optically stimulated luminescence dosimetry using α- Al_2O_3:C. Radiat. Prot. Dosimetry, n. 65, p. 267-272, 1996.
Yukihara, E. G.; Gaza, R.; McKeever, S. W. S.; Soares, C. G. Optically stimulated luminescence and thermoluminescence efficiencies for high-energy heavy charged particle irradiation in Al_2O_3:C. Radiat. Meas., n. 38, p. 59-70, 2004.
Yukihara, E. G.; McKeever, S. W. S. Optically stimulated luminescence – Fundamentals and applications, John Wiley & Sons, Oklahoma, 2011.