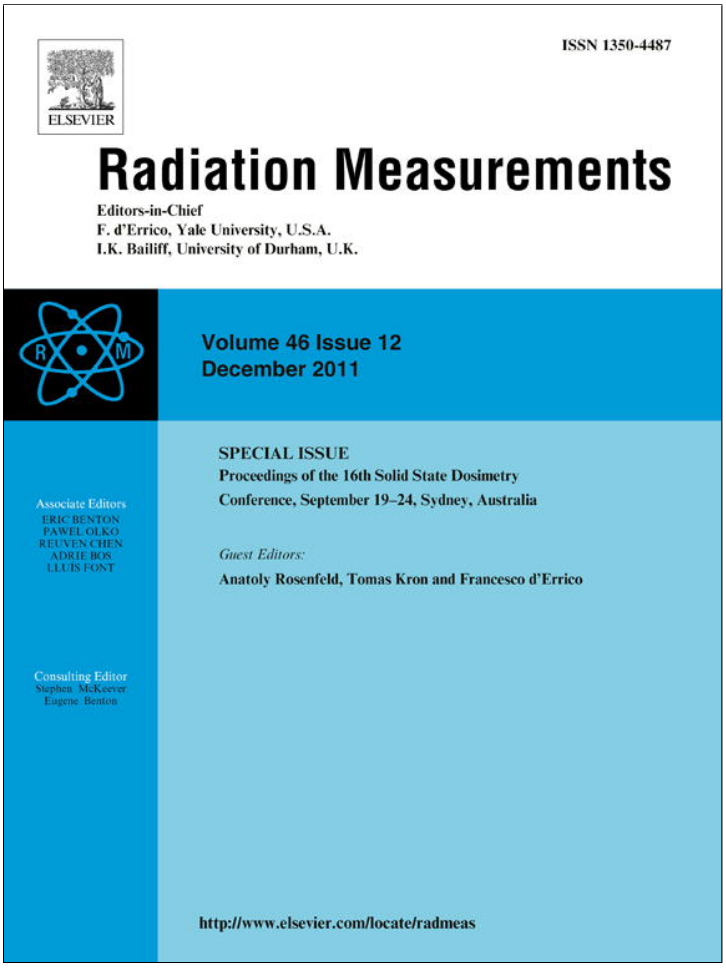
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Onyx as radiation detector for high doses

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ABSTRACT

A study of the thermoluminescent (TL) characteristics of white, black and stripped onyx samples is reported in this work. Onyx is a variety of chalcedony, a form of quartz. The onyx stone is considered nobler than marble. The irradiations were performed using a Gamma-Cell 220 system (^{60}Co). The TL emission curves presented two peaks around 150 °C and 210 °C for all samples. The dose–response curves showed a sublinear behavior between 0.5 Gy and 5 kGy, and the lower detection limit for the white onyx pellets was 1.5 mGy. The main dosimetric characteristics were studied, and the material showed good performance for high dose dosimetry.

1. Introduction

High dose dosimetry has been studied using different types of materials. Stones from different Brazilian mines have been tested using the thermoluminescent technique (TL) to verify the possibility of their usefulness for high dose dosimetry, such as quartz (Navarro et al., 2002), amethyst (Rocha et al., 2003), topaz (Souza et al., 2002), jade (Melo et al., 2004), and jasper (Teixeira and Caldas, 2007).

Since the eighties the silicates have been used as a research source for solid state dosimetry (McKeever, 1985). They are abundant and the volume of these minerals in the earth crust represents approximately 92% (Klein and Dana, 2002).

Some studies of glasses, silicates and sands applied to dosimetry have already been published, and they are also promising (Teixeira and Caldas, 2002; Melo et al., 2004; Teixeira et al., 2008).

Onyx is a variety of chalcedony, a form of quartz. The colors of their tracks are white and/or black. The onyx stone is considered nobler than marble. A study of the thermoluminescent response of onyx samples is reported in this work in order to find an alternative material for dosimetry for high doses. There is a special interest because the onyx is found in nature in abundance in Brazil and of very low cost. In industrial plants (high doses) the dosimeters are usually disposable, and the fore low cost materials become of interest.

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2. Materials and methods

The samples for this study were prepared from three different types of onyx from Brazilian mines: white, black and stripped. An analysis of the main elements of the onyx samples was obtained by neutron-activation analysis technique at the Radiochemistry Department of IPEN. Results are given in Table 1. This analysis was performed to identify which are the chemical elements in the sample, and to justify in a future study which of these elements is responsible for the TL signal.

The samples were powdered, and grains with diameter between 0.074 and 0.177 mm were selected to be mixed with Teflon in the proportion of 2(Teflon):1(onyx) in open atmosphere of nitrogen. The Teflon was used as a binder for the production of more uniform pellets, which are easier to handle, and can be reused (Souza et al., 2002).

The mixture was pressed (Fred Frey model FC5), and pellets of onyx–Teflon of 50 mg with 6 mm of diameter and 2 mm of thickness were produced.

For reutilization and to avoid residual TL, the pellets were thermally treated at 300 °C/1 h, in air, as suggested by Rocha et al. (2003), Souza et al. (2002) and Melo et al. (2004). This thermal treatment is enough to remove all deep traps contained in the samples.

The irradiations were performed at the Center for Radiation Technology of IPEN in air (room temperature) using a Gamma-Cell 220 system (^{60}Co) in the dose interval of 5 Gy–30 kGy, and

Table 1
Results of neutron-activation analysis of onyx samples.

Element (mg kg^{-1})	White onyx	Black onyx	Stripped onyx
Ba	–	300 ± 15	16.2 ± 0.2
Ca	8.2 ± 0.7	1626 ± 136	11.3 ± 0.7
Cs	0.05 ± 0.01	0.48 ± 0.04	–
Hf	0.08 ± 0.01	0.16 ± 0.02	0.073 ± 0.006
Na	627 ± 13	154 ± 13	1078 ± 106
Sb	–	1.06 ± 0.04	6.2 ± 0.9
Zn	2.86 ± 0.08	11.8 ± 0.4	28 ± 2
U	–	0.48 ± 0.03	0.9 ± 0.1
Fe	–	7100 ± 96	6036 ± 81

a Panoramic Yoshizawa Kiko Do Ltd. System (^{60}Co) in the dose interval of 0.1–10 Gy, at the distances of 10 and 40 cm from the sources, respectively.

The evaluation of the onyx pellets was carried out using a thermoluminescent reader (Harshaw Chemical Co., model 2000 A/B) with a heating rate of 10 °C/s. All TL measurements were integrated between 50 °C and 300 °C. The glow curves were obtained using a PicoLog program (PLW32).

All TL measurements were taken from ambient temperature up to 300 °C, using a constant flow of N_2 of 4 L/min. To avoid effects of thermal fading of the TL response of the onyx samples, all measurements in this work were taken exactly 1 h after the irradiation.

3. Results

The dosimetric properties were studied in this work for the verification of the possibility of use of onyx pellets for high dose dosimetry.

3.1. TL glow curves

Fig. 1 shows the thermoluminescent glow curves of the onyx samples, irradiated with a dose of 10 kGy.

The curves present two peaks at 150 °C and 210 °C for all three kinds of onyx samples. The first peak is not considered for dosimetry due to its fast fading nature. To remove the TL peak 1 (150 °C) from the onyx samples, thermal treatments at 130 °C during different time intervals were tested (Fig. 2). From this test the thermal treatment at 130 °C for 5 min was selected for the rest of this work.

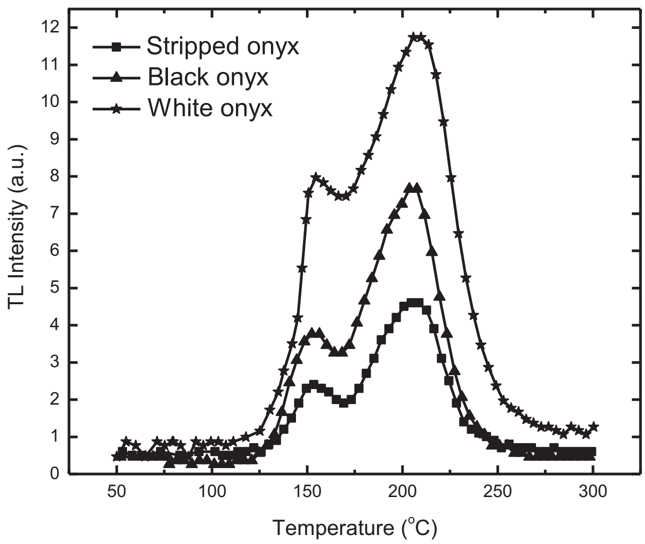

Fig. 1. TL glow curves of onyx–Teflon pellets irradiated with 10 kGy (^{60}Co).

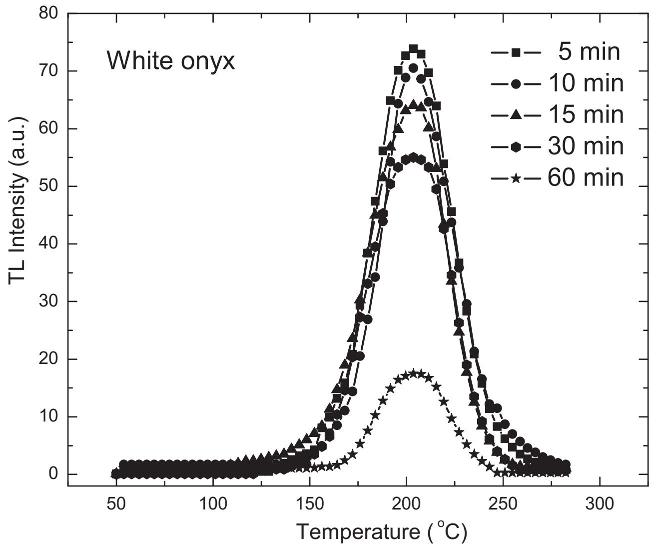

Fig. 2. TL glow curves of white onyx–Teflon pellets irradiated with 0.5 kGy (^{60}Co) and thermally treated at 130 °C during different time intervals.

The white onyx pellets presented the maximum TL intensity in relation to the TL response of the black and stripped onyx samples.

Fig. 3 presents the TL glow curves of the composites of white onyx–Teflon pellets (50 mg), treated at 300 °C/1 h, irradiated (^{60}Co) with absorbed doses of 0.1 , 1 and 5 kGy, and thermally treated at 130 °C/5 min, showing the increase in the TL intensity.

3.2. Reproducibility of TL response

The TL measurements were taken in the interval from 50 °C to 300 °C. Five pellets of each type of material were utilized. They were treated at 300 °C/1 h (reutilization temperature), and they were irradiated with an absorbed dose of 1 kGy (^{60}Co). This procedure was repeated five times for each pellet.

The reproducibility in this experiment is given by the percentage variation coefficient (CV%), that is the quotient between the standard deviation of the measurements and the average of measurements of each pellet.

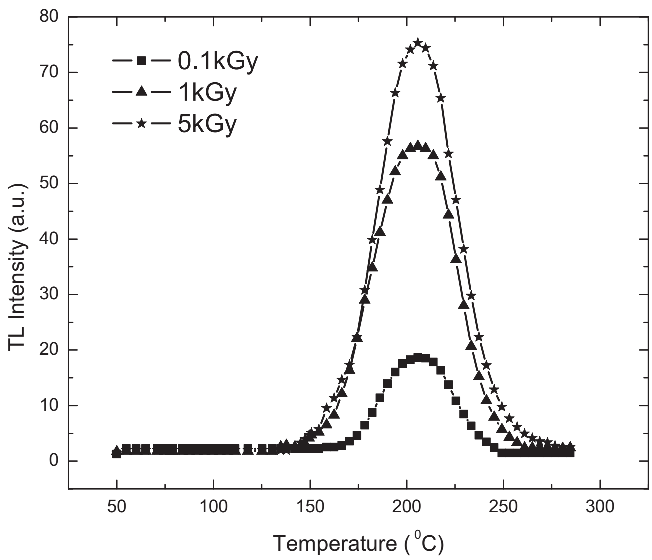

Fig. 3. TL glow curves of white onyx–Teflon pellets treated at 300 °C/1 h, irradiated with different absorbed doses and treated at 130 °C/5 min.

Table 2
TL response reproducibility as CV_{Max} (%) of onyx–Teflon pellets.

Samples		CV_{max} (%)
Onyx–Teflon	White	5.4
	Black	5.8
	Stripped	6.5

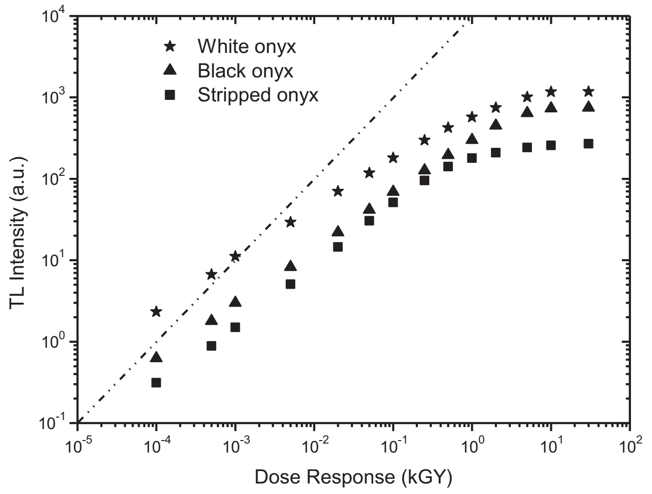

Fig. 4. Dose–response curves of onyx samples for ^{60}Co radiation. Measurements were taken after irradiation and thermal treatment of 130 °C/5 min. The maximum uncertainty of these data was 3%.

The maximum values are presented in Table 2. The results of CV_{max} (%) do not exceed 8% for the three types of onyx samples.

3.3. Lower detection limit

The lower detection limit for the TL onyx–Teflon samples, defined as three standard deviations of five measurements of their mean zero dose reading (thermal treatment at 300 °C/1 h of non-irradiated samples, expressed in units of absorbed dose) was determined for all onyx samples (white, black and striped) as suggested by Rocha et al. (2003); Melo et al., 2004, 2007. The values obtained for the lower detection limits were: 1.5 mGy, 0.2 and 0.3 Gy for the white, black and stripped onyx samples respectively.

3.4. Dose–response curves

The dose–response curves of the onyx samples were obtained using gamma radiation (^{60}Co). Fig. 4 presents the TL dose–response curves of the onyx–Teflon pellets, treated at 300 °C/1 h and irradiated with absorbed doses between 0.1 Gy and 30 kGy. All measurements were taken after irradiation and thermal treatment of 130 °C/5 min.

The dose–response curves of all onyx samples suggest a sub-linear behavior in the studied dose interval. These curves indicate that the materials (black and stripped samples) are useful between 0.1 Gy (lowest dose included in this study) and 5 kGy (saturation dose), in the case of white onyx samples no saturation was achieved until 10 kGy.

4. Conclusions

The TL emission curves of the samples exposed to gamma doses showed two TL peaks at 150 °C and 210 °C. The dose–response curves obtained in this work demonstrate that all three types of onyx samples may be applied for high dose dosimetry following the dosimetric recommendations of McLaughlin et al. (1989). The results show that the white onyx samples presented higher radiation sensitivity than the other onyx samples. The basic advantage of onyx samples is their very low cost compared with other materials already used in the production of dosimetric pellets. The onyx material can be found in abundance in Brazil.

All three kinds of tested onyx samples showed their usefulness as irradiation indicators and as high dose radiation detectors.

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