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Finnish spectrolite as high-dose gamma detector

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HIGHLIGHTS

- The luminescent signal of the spectrolite was studied in this work.
- Spectrolite pellets were obtained using two different Teflon concentrations.
- TL and OSL responses were evaluated for high-doses of gamma radiation.
- The results showed that the samples are useful in high-dose gamma dosimetry.

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ABSTRACT

A natural material called spectrolite, from Finland, was studied in this work. The purpose was to test it in gamma radiation beams to verify its performance as a high-dose detector. From this material, pellets were manufactured with two different concentrations of Teflon and spectrolite, and their responses were verified using two luminescent techniques: thermoluminescence (TL) and optically stimulated luminescence (OSL). The TL and OSL signals were evaluated by means of characterization tests of the material response, after exposure to a nominal absorbed dose interval of 5 Gy to 10 kGy. The results obtained, for both concentrations, showed a good performance of this material in beams of high-dose gamma radiation. Both techniques were utilized in order to investigate the properties of the spectrolite+Teflon samples for different applications.

1. Introduction

The thermoluminescence (TL) and the optically stimulated luminescence (OSL) are two of the main used luminescence techniques, for the study of the response of irradiated materials. These phenomena have been discussed by different authors in relation to their applications, in several research areas, including a comparison between their advantages and disadvantages (McKeever and Moscovitch, 2003; Olko, 2010).

Although the OSL technique is nowadays almost as utilized as the TL technique, the former presents some advantages in relation to the TL technique as it requires no sample heating, the samples may be evaluated several times (depending on the used reading parameters), and OSL is a relatively cheaper method than TL (Bøtter–Jensen et al., 2003).

Different studies were performed and reported about natural materials for use in radiation dosimetry (Yoshimura and Yukihara, 2006; Mamani, 2007; Melo, 2007). More recently, the research with these kinds of materials was continued. Several types of silicates were investigated, and the results obtained using the luminescent techniques were shown in different applications: D'Amorim et al. (2014) performed characterization tests of the OSL signal of α-spodumene in order to verify its application in gamma dosimetry, which was testified; Schmidt and Kreutzer (2013) verified the OSL signal of the silex for possible use in archeological dosimetry; Discher and Woda (2013) analyzed the TL properties of glass (with silicate) displays from mobile phones planning to use them as accident dosimeter. Vila (2012) investigated the TL and OSL responses of silicates and calcium carbonates for use in high-dose dosimetry.

In the present study, a natural material called spectrolite, from Finland, and from the silicate family, was studied in relation to its dosimetric properties after exposure to gamma radiation.

2. Experimental

This study was undertaken using spectrolite, from the group of silicates (tectosilicates).

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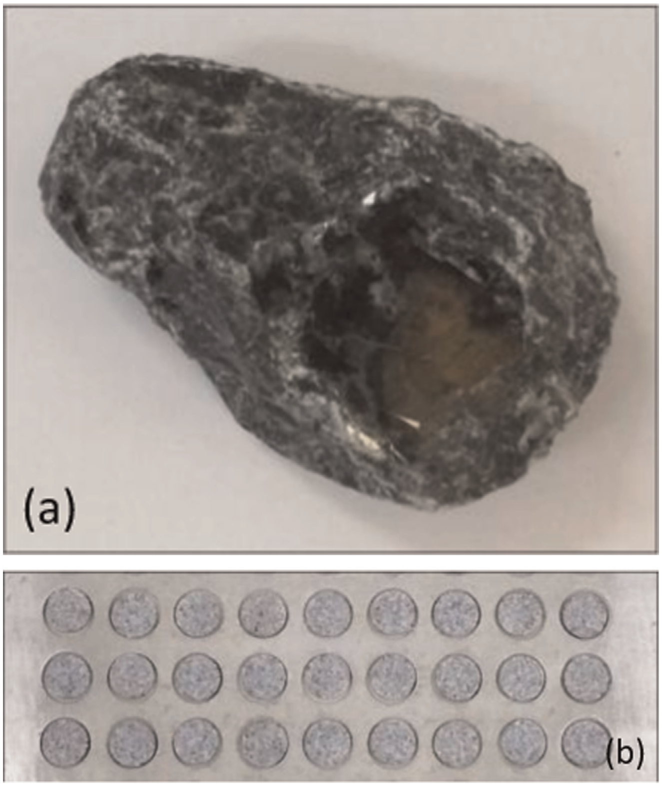

Fig. 1. Spectrolite: (a) natural material and (b) sinterized pellets.

A spectrolite stone (Fig. 1a) was crushed into small pieces and then pulverized, using a mortar and a pestle porcelain. The grain size check was performed using two sieves (74 μm and 177 μm). The powder obtained was weighed, washed and placed in the drier for about 24 h. After this time, it was mixed with two different amounts of Teflon, in proportions of 1 (Teflon):1 (spectrolite) and 2 (Teflon):1 (spectrolite) (Fig. 1b). These mixtures were made using liquid nitrogen to ensure their homogeneity. Both materials were then weighed in portions of 20 mg, for the production of pellets with 6.0 mm in diameter and 0.8 mm in thickness, using a uniaxial press with a pressure of approximately 5 kPa. The pellets were then subjected to a heat treatment of 350 °C for 30 min and 400 °C for 3 h, to ensure greater uniformity in the material and also mechanical strength.

The TL and OSL responses of the samples were determined using the reader system composed by the TL/OSL meter and control Risø, model TL/OSL-DA-20. The TL and OSL measurements of the samples were taken using the specific parameters for each technique. In the case of the TL readings, a sample heating rate of 10 °C/s and a final temperature of 400 °C were used. For the OSL measurements, blue LEDs with optical power of 90% were used; in this case, a stimulation time of 50 s was adopted; a filter basket Hoya U-340 was used in front of the photomultiplier. For the measurements of both techniques, a black mask with a central orifice of 5.0 mm in diameter was used between the photomultiplier and the filter. This accessory was important to avoid the saturation of the photomultiplier signal.

The spectrolite+Teflon pellets were irradiated using a source of cobalt-60, Gamma-Cell, model 220, Atomic Energy of Canada LTD (60.77 TBq, December 2012), of the Radiation Technology Center, at IPEN.

3. Results

The spectrolite+Teflon pellets were submitted to the characterization tests of their responses, using both TL and OSL techniques in all the cases, and for the two different concentrations. The characterization tests performed were: TL glow curve, OSL signal decay, reproducibility, dose–response curves, lower detection limit and fading.

3.1. *TL glow curve and OSL signal decay*

The TL glow curve and the OSL signal decay were obtained after irradiating the spectrolite+Teflon samples at the ^{60}Co source beam, with an absorbed dose of 1 kGy.

Fig. 2a shows the TL glow curve. A dosimetric peak can be observed at about 210 °C. Fig. 2b presents the OSL signal decay after the detector irradiation to the same absorbed dose as in the case of the TL signal.

3.2. *Reproducibility of TL and OSL responses*

The reproducibility study of the material response was performed irradiating 40 pellets of each concentration in a procedure

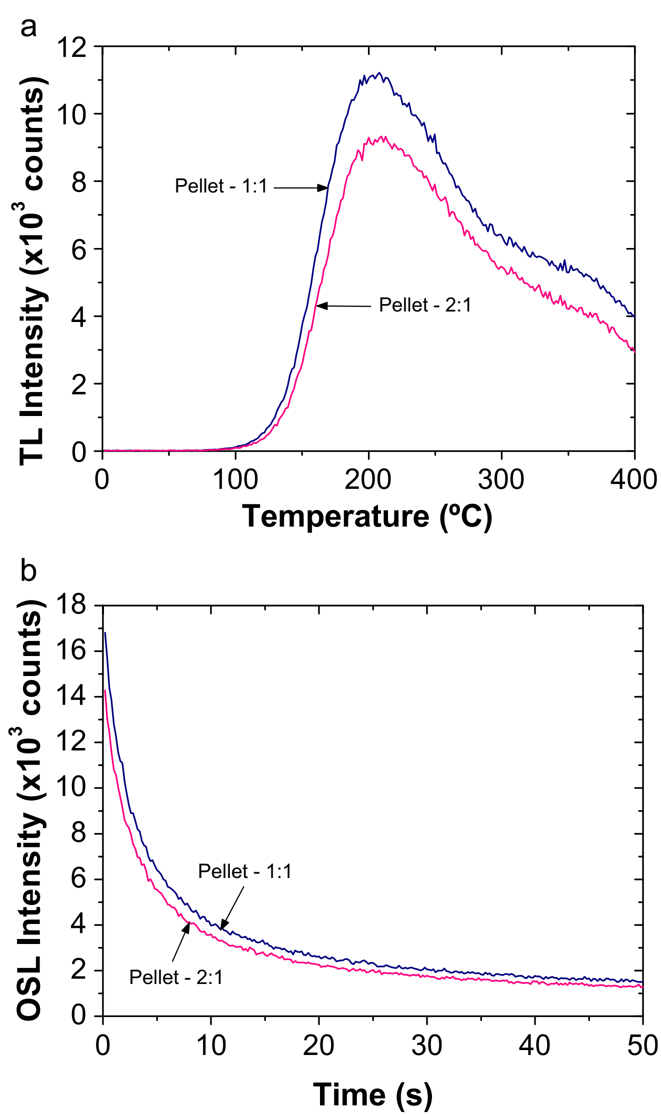

Fig. 2. TL and OSL response of the spectrolite+Teflon detectors: (a) TL glow curve and (b) OSL signal decay, obtained after the irradiation of the material to 1 kGy.

of three cycles of irradiation, signal evaluation, and thermal treatment. The samples were irradiated with an absorbed dose of 1 kGy (^{60}Co source).

The results obtained for the TL technique were reproducibility of 4.2% and 4.9% (maximum standard deviations of 5.8% and 6.2%) for concentrations of 1:1 and 2:1, respectively. For the OSL signal, the results were: 2.5% and 2.4% (maximum standard deviations of 5.9% and 6.8%) for samples with concentrations of 1:1 and 2:1.

Vila (2012) determined the reproducibility of the TL and OSL responses for silicate dosimeters, as tremolite, diopside and rhodonite. For the TL signal, a minimum value of 1.3% (tremolite) and a maximum value of 9.8% (diopside) were obtained. In the case of the OSL response, the minimum value of 2.5% (rhodonite) and the maximum value of 10.4% were revealed.

Discher and Woda (2013) obtained a reproducibility of the TL signal of 3%, at a Gamma-Cell irradiator for glass dosimeter.

The results obtained in this work, for TL and OSL techniques were within the values demonstrated by Vila (2012), for high-doses of gamma radiation. The study performed by Discher and Woda (2013) with the TL technique, presented a lower value in relation to that obtained in this work (but it may still be considered acceptable, because it is lower than 5.0%).

3.3. Dose–response curves

The TL and OSL responses of spectrolite+Teflon samples were obtained for eight absorbed dose values. For this study, the pellets were irradiated in the dose interval from 5 Gy to 10 kGy (^{60}Co).

In the case of TL response, the maximum standard deviations obtained in all measurements were 6.3% (dose of 1 kGy), and 6.8% (dose of 100 Gy), for the samples with concentrations of 1:1 and 2:1, respectively. For the OSL response, these results were 6.6% (dose of 5 kGy), and 5.6% (dose of 1 kGy), for the concentrations of 1:1 and 2:1, respectively.

The results of this study, for both concentrations of spectrolite+Teflon, showed a similar behavior using the TL (Fig. 3a) and OSL (Fig. 3b) techniques, presenting an initial linear behavior and then a tendency to saturation.

Dose–response curves were also taken by Vila (2012), for both TL and OSL techniques. For the TL response, Vila (2012) obtained linearity in an interval from 50 Gy to 1 kGy (tremolite), and from 10 Gy to 1 kGy (diopside); for rhodonite, a sublinearity from 1 Gy to 20 kGy was observed. In the case of the OSL response, Vila (2012) achieved the following results: linearity from 50 Gy to 1 kGy (tremolite), and from 50 Gy to 2 kGy (rhodonite), and sublinearity from 1 Gy to 20 kGy (diopside).

Comparing the TL results of the present work with those obtained by Vila (2012), for silicate materials, it is possible to verify a linear behavior in the range, for spectrolite, from 1 Gy to 500 Gy, for the concentration of 1:1; for rhodonite, Vila (2012) observed a sublinearity in this region. For the case of the OSL signal, a linearity behavior from 5 Gy to 50 Gy (1:1 and 2:1) was verified in the present work. In the same interval, Vila (2012) obtained sublinearity for rhodonite.

3.4. Lower detection limit

The determination of the lower detection limit (also called minimum detectable dose) was performed by studying the variation among the TL and OSL readings of non-irradiated detectors (zero-dose reading, and after thermal treatment). This limit is a dosimetric characteristic of the material, and its value is applied as a correction in all the readings after irradiation.

The lower detection limit was obtained for the spectrolite+Teflon samples using the method of taking three times the standard deviation of non-irradiated pellets (Pagonis et al., 2006), and the results were 1.2 Gy (1:1) and 1.3 Gy (2:1) for the TL detectors, and 3.4 Gy (1:1) and 4.6 Gy (2:1) for the OSL detectors.

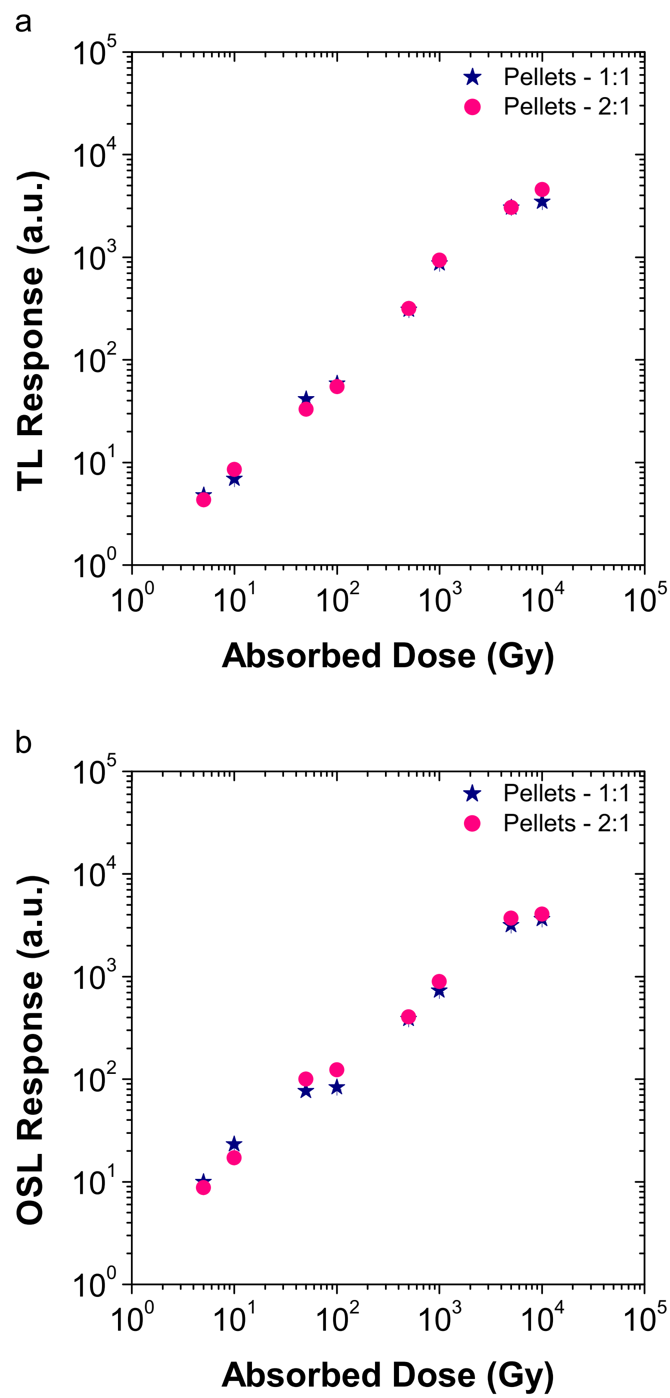

Fig. 3. Dose–response curves of the TL and OSL responses: (a) TL and (b) OSL.

As the objective of this work was to verify the possibility of using these samples in high-dose gamma dosimetry, the results obtained in this study meet the established purposes.

The procedure used to determine the lower detection limit was the same used by Vila (2012) for the tremolite, diopside and rhodonite materials. In his work, Vila (2012) obtained a maximum result of 2.0 Gy for tremolite and the TL technique, and 52.9 Gy for rhodonite and the OSL technique. Therefore, the results obtained in the present work agree with those ones determined by Vila (2012), for both TL and OSL responses.

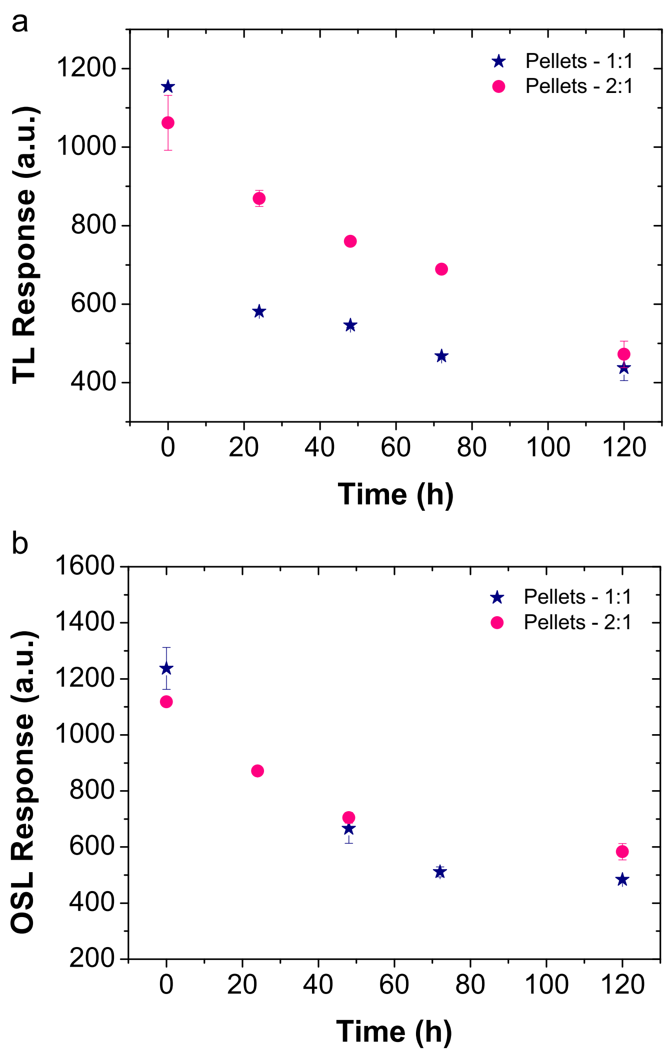

Fig. 4. Fading of the response: (a) TL and (b) OSL.

Table 1
Remaining signal (in %) of the TL and OSL response of the spectrolite pellets (concentrations of 1:1 and 2:1).

Time (h)	Fading (%)			
	TL response		OSL response	
	1:1	2:1	1:1	2:1
0	100	100	100	100
24	50.4	81.8	–	73.1
48	47.4	66.1	53.8	59.2
72	40.5	64.9	41.3	–
120	37.9	44.4	39.1	49.1

3.5. Fading

The TL and OSL fading (Fig. 4a and b) was determined after the irradiation of the samples with an absorbed dose of 1 kGy, in time periods of 24 h, 48 h, 72 h and 120 h after the irradiation step. The maximum standard deviations obtained after 120 h at the TL measurements were 7.4% and 7.1%, for the samples with concentrations of 1:1 and 2:1, respectively. For the OSL response, these results were 7.9% (48 h), and 5.0% (120 h), for the concentrations of 1:1 and 2:1, respectively.

In Table 1, the fading obtained for the TL and OSL responses of the spectrolite samples, in both concentrations of 1:1 and 2:1 can be observed, in terms of the remaining signal (in %).

The results determined in each time interval after the irradiations were normalized to zero time (initial reading, immediately after irradiation). For the concentration of 1:1, a fading of 62% of the TL signal was verified after 120 h; for the concentration of 2:1, the fading was 56%. In relation to the OSL response, a fading of 61% was observed for the concentration of 1:1, and of 51% for 2:1, both after 120 h. This demonstrates that, in these cases, the read-out has to be made quickly or at a determined time interval after the irradiation. In this work, all the readings were taken 1 h after the irradiations.

The results obtained in this work show that the spectrolite, in both concentrations, presents a fading of the TL signal higher than that showed for other silicate materials, for example the tremolite, diopside and rhodonite, studied by Vila (2012). The fading after 120 h was 91%, 44% and 76%, for tremolite, diopside and rhodonite, respectively. For the case of the OSL signal, the results obtained in the present work showed an agreement with those presented by Vila (2012), which showed a loss of the OSL signal of 38%, 31% and 47%, for tremolite, diopside and rhodonite, respectively, also after 120 h.

4. Conclusions

The characterization tests of the TL and OSL responses performed with the spectrolite pellets (TL glow curve and OSL signal decay, reproducibility, dose–response curves, lower detection limit and fading) in two different concentrations (1:1 and 2:1) show that these samples may be useful for high-dose gamma dosimetry, using both luminescent techniques. The results obtained in this work agree with those reported by other authors and for other kinds of silicates. Thus, it is possible to conclude that spectrolite presents a potential use in high-dose dosimetry, taking into account the fading effect by controlling the evaluation time after irradiation.

Acknowledgments

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