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Study of the luminescent behavior of Spectrolite + Teflon pellets in $^{90}Sr + ^{90}Y$ beams

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HIGHLIGHTS

- The physical and chemical structures of powdered Spectrolite were investigated.
- Spectrolite + Teflon pellets were studied in concentration of 1:1.
- Characterization tests of the TL and OSL responses were performed.
- The samples were exposed to a $^{90}Sr + ^{90}Y$ source.
- The material presents usefulness as beta radiation dosimeter.

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ABSTRACT

The Spectrolite, from the silicate family, a variety of Labradorite, was already studied in relation to its thermoluminescence (TL) and optically stimulated luminescence (OSL) responses, in high-dose gamma radiation fields; the results indicated their good application as gamma radiation detectors. In the present work, the analyses performed to investigate powdered Spectrolite are presented, by means of the XRD, SEM and EDX techniques. The luminescent behavior of Spectrolite + Teflon samples, in the concentration of 1:1, was studied in beta radiation beams ($^{90}Sr + ^{90}Y$), using the luminescent phenomena of TL and OSL. The results showed adequate TL and OSL reproducibility of the samples; the dose–response curves for both techniques presented a linear behavior in a range from 0.5 Gy to 1 kGy, and the fading showed that after 150 h there were 46.7% and 31.6% of the remaining signal of samples for TL and OSL responses, respectively. Therefore, the Spectrolite + Teflon pellets may be used in beta radiation dosimetry.

1. Introduction

Spectrolite, a variety of Labradorite, from the silicate family, is very common in Finland. This gemstone has the labradorescence characteristic, which is a play of colors in bright metallic tones, mainly blue and green effects, in a grey background (this color effect is only seen at the polished surface of the stones). The most appreciated stone is that in which it is possible to observe all the spectrum colors (Hall, 1997).

Different materials (as for example Quartz, Rhodonite and Diopside) have been tested in ionizing radiation beams of a $^{90}Sr + ^{90}Y$ source by different research groups in several countries, all of them with different objectives and applications, related to their luminescent properties. The thermoluminescence (TL) and the optically stimulated luminescence (OSL) are two important techniques used in this research area.

Vila (2012) studied the TL and OSL responses of natural materials as Rhodonite and Diopside for their use in beta radiation dosimetry.

Pellets of two different concentrations of Spectrolite (from Finland) and Teflon (1:1 and 1:2) were already studied in relation to their TL and OSL responses at the Radiation Metrology Department of IPEN, in high-dose gamma radiation fields (Antonio and Caldas, 2015). The results on the dosimetric characteristics of the

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Spectrolite + Teflon pellets indicated their good application as gamma radiation detectors.

In this work, the objective was to verify the possibility of the application of Spectrolite + Teflon pellets, in the concentration of 1:1, as efficient radiation detectors for beta radiation dosimetry, in a dose interval of 100 mGy–1 kGy.

2. Materials and methods

Initially, the powdered Spectrolite material was analysed using the techniques of X-ray diffraction (XRD), with a diffractometer Equinox 1000 INEL (with CuKa radiation (λ = 1.5418° A), with the X-rays tube operating at 30 kV/30 mA), scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDX) techniques, using a SEM with an energy dispersive X-ray microanalyser Vega 3 SEM, Tescon, operating with a tungsten filament.

Spectrolite + Teflon pellets in a proportion of 1:1 and dimensions of 6.0 mm in diameter and 0.8 mm in thickness (weight of 50 mg) were used in this work. From the natural material, the samples were produced at the Dosimetric Material Laboratory of IPEN; this procedure was already described by Antonio and Caldas (2015).

The Spectrolite + Teflon pellets were irradiated using a ^{90}Sr + ^{90}Y source from the TL/OSL Risø System, model TL/OSL-DA-20, with an absorbed dose rate of 0.1 Gy/s (10.06.2010). This system was used to evaluate the TL and OSL responses of the pellets, which were obtained using the following parameters: sample heating rate of 10 °C/s and final temperature of 400 °C, for the TL measurements, and blue LEDs (optical power of 90%) and stimulation time of 50 s for the OSL readings. A black mask with a central orifice of 10 mm in diameter was used between the photomultiplier and the filter, in order to avoid the saturation of the photomultiplier signal.

After the OSL evaluation and the subsequent TL measurement, the Spectrolite + Teflon pellets were thermally treated at 400 °C during 1 h, before their reutilization.

3. Results

Spectrolite, in powder, was investigated in relation to its structural and chemical characteristics, using the XRD, SEM and EDX techniques. Afterwards, the following dosimetric parameters were obtained: TL glow curve, OSL signal decay, reproducibility of TL/OSL responses, dose–response curves, lower detection limits and fading of the TL/OSL signals.

3.1. X-ray diffraction (XRD)

The crystalline structure of Spectrolite was verified using the diffractometer, and the result is presented in Fig. 1. It was possible to observe a crystalline system with intense peaks in 23° 2θ, 27° 2θ, 48° 2θ, 54° 2θ e 85° 2θ. The full width at half maximum of the diffraction peaks was used to determine the crystallite size described by the Scherrer equation (Kumar et al., 2012; Anis-ur-Rehman et al., 2013). An average crystallite size of 26.13 nm was obtained.

3.2. Scanning electron microscope (SEM)

The morphology of the Spectrolite grains was analysed using a scanning electron microscope. It was possible to observe that the grains of micrometer order present irregular morphology and well-defined edges, which is a strong characteristic of a crystalline system. Fig. 2 shows that the particles are large, formed by agglomerates of small particles. This analysis agrees with the result obtained with XRD, which showed an average crystallite size of 26.13 nm.

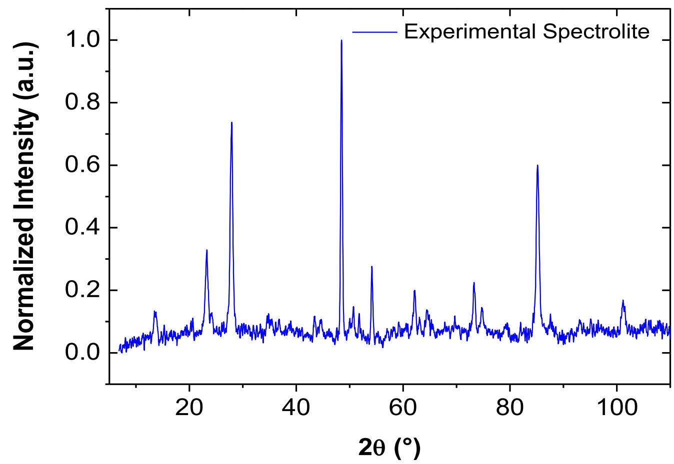

Fig. 1. X-ray diffraction results of the powdered Spectrolite.

3.3. Energy dispersive X-ray spectroscopy (EDX)

For the chemical composition of powder Spectrolite, EDX measurements were carried out, and the results are shown in Table 1, obtained during the measurement. The peak position and its intensity provide information about the identity and the amount of atoms, respectively. It was possible to observe a predominant presence of $NaAlSi_3O_8$, in a percentage of 92.3%. In addition to this composite, there are several impurities, as Ca (6.3%), Na (4.1%), Fe (1.1%) and Mg (0.3%).

3.4. TL glow curve/OSL signal decay

During the TL measurements with absorbed doses from 0.1 Gy to 1 kGy (^{90}Sr + ^{90}Y source), the glow curves were obtained (Fig. 3a). From the TL glow curves, a dosimetric peak at about 190 °C can be observed. In the same conditions of irradiation, the OSL signal decay was determined for the Spectrolite + Teflon pellets (Fig. 3b).

In the case of irradiation with a ^{60}Co source, a dosimetric peak was observed in the same pellets of Spectrolite + Teflon at about 210 °C (Antonio and Caldas, 2015). For other silicates, Vila (2012) obtained two TL peaks for Rhodonite, one at 142 °C and another at 213 °C, and three TL peaks for Diopside, at 209 °C, 288 °C and 375 °C.

3.5. Reproducibility of TL and OSL responses

The reproducibility of the TL and OSL responses was one of the performed characterization tests of the Spectrolite + Teflon pellets. In this and in the following studies, 10 pellets were utilized with the TL technique and 15 pellets with the OSL technique. The TL measurements were taken immediately after the sample irradiations, and the samples were thermally treated (400 °C/1 h) in five cycles. For the OSL readings, the same procedure was adopted in six cycles. In this test, the pellets were irradiated with an absorbed dose of 10 Gy (^{90}Sr + ^{90}Y source).

The obtained reproducibility of the signal of the Spectrolite + Teflon samples was 1.0%, for the TL response, and 2.5% for the OSL measurements.

As an comparison, Vila (2012) obtained reproducibility values of 2.5% for Rhodonite and 4.3% for Diopside, with the TL technique, and 2.5% for Rhodonite and 9.4% for Diopside, using the OSL

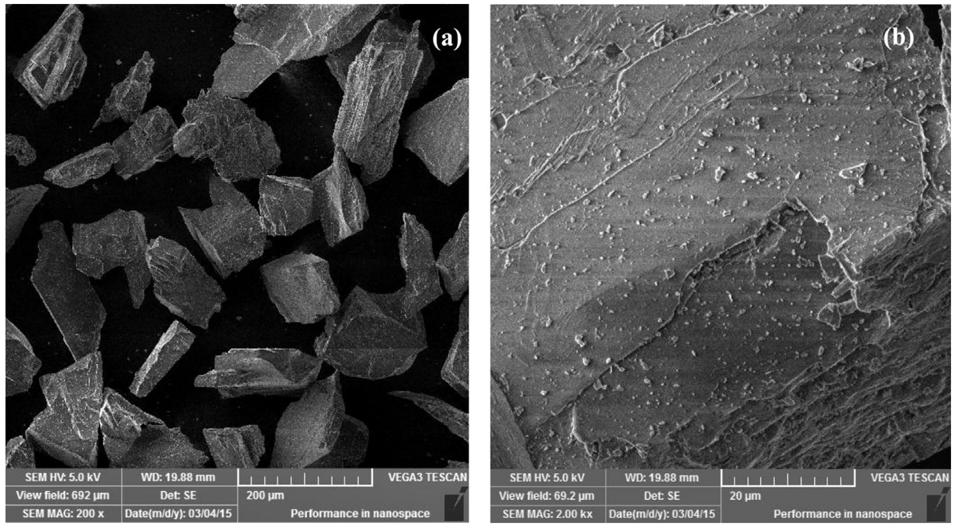

Fig. 2. Micrographs of powdered Spectrolite: (a) increase – 200 x; and (b) increase – 2.00 kx.

Table 1
The chemical composition (%) obtained for the Spectrolite by the EDX measurements.

Chemical element	Percentage (%)	
	Weight, Wt	Standard deviation
O	54.8	5.8
Si	20.4	3.3
Al	13.0	2.4
Ca	6.3	1.3
Na	4.1	2.0
Fe	1.1	0.9
Mg	0.3	1.0
Mn	0.0	0.0

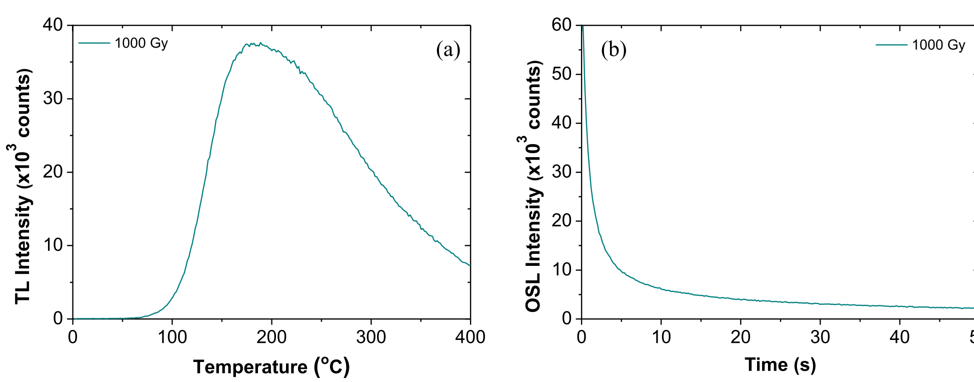

Fig. 3. TL and OSL signals of Spectrolite + Teflon pellets exposed to a $^{90}Sr + ^{90}Y$ source: (a) TL glow curve; (b) OSL signal decay.

technique, after irradiation with a $^{90}Sr + ^{90}Y$ source and an absorbed dose of 20 Gy.

3.6. Lower detection limit (LDL)

The study for the determination of the lower detection limits was performed taking TL and OSL measurements of the Spectrolite + Teflon pellets after the thermal treatment (400 °C/1 h) and without irradiation of the samples. This dosimetric characteristic was investigated using the procedure described by Pagonis et al. (2006), a method of taking three times the standard deviation of non-irradiated pellets response.

For the TL response, the LDL obtained was 0.45 Gy, while for the OSL response, the LDL was 2.97 Gy. Similar results were reported by Vila (2012): a LDL of 0.44 Gy for Rhodonite and 0.40 Gy for Diopside, with the TL technique. For the OSL technique, a LDL of 8.91 Gy for Rhodonite and 6.39 Gy for Diopside were obtained.

3.7. Dose–response curves (TL and OSL)

The TL and OSL responses of Spectrolite + Teflon pellets were verified in function of the variation of absorbed dose from 0.1 Gy to 1 kGy, to the $^{90}Sr + ^{90}Y$ source.

The maximum standard deviation obtained with the TL technique, during the measurements, was 6.3% (absorbed dose of 0.5 Gy), and for the OSL technique this value was 8.2% (1 Gy). Fig. 4 presents the dose–response curves for both luminescent techniques.

The Spectrolite + Teflon samples present a linear behavior for both techniques of TL and OSL. This characteristic can be observed from the third point of the curves, in an interval of absorbed dose from 0.5 Gy to 1 kGy. In the case of the TL, the two initial experimental points (0.1 Gy and 0.2 Gy) cannot be considered, because these values are below of the lower detection limit (0.45 Gy). For

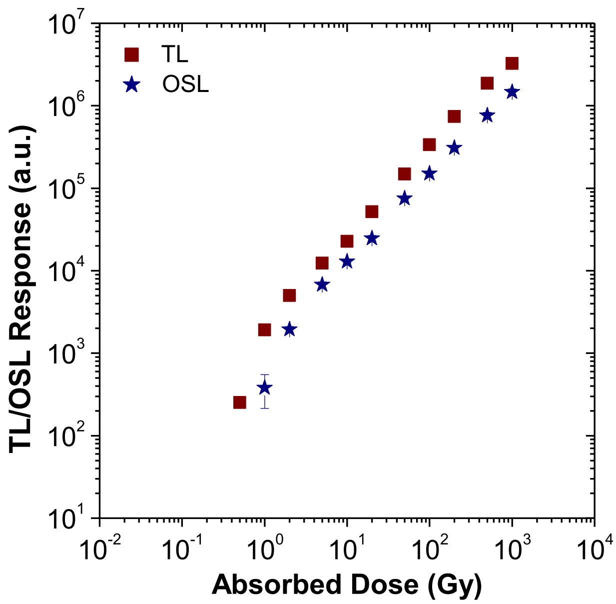

Fig. 4. Dose–response curves of the Spectrolite + Teflon pellets ($^{90}Sr + ^{90}Y$): (a) TL, and (b) OSL.

the OSL, the two first points are also out of the linear region of the curve. However, even though the lower detection limit is 2.97 Gy, the values from the absorbed dose of 0.5 Gy can already be considered linear.

Using the same type of source, Vila (2012) obtained a sublinear behavior for the Rhodonite and Diopside samples in an interval of absorbed dose of 100 mGy–20 Gy, for both TL and OSL techniques.

3.8. Fading

The fading of the TL and OSL responses of the Spectrolite + Teflon samples was studied irradiating the pellets with an absorbed dose of 20 Gy ($^{90}Sr + ^{90}Y$). The measurements were immediately taken after the irradiation (time considered as 0 h) and after 24 h, 48 h, 72 h and 150 h. Fig. 5 shows the fading of the TL/OSL response in function of post-irradiation time.

The maximum standard deviations obtained in the measurements in the whole period were: 16.0% and 16.2% for the TL and OSL responses, respectively, and 150 h post-irradiation.

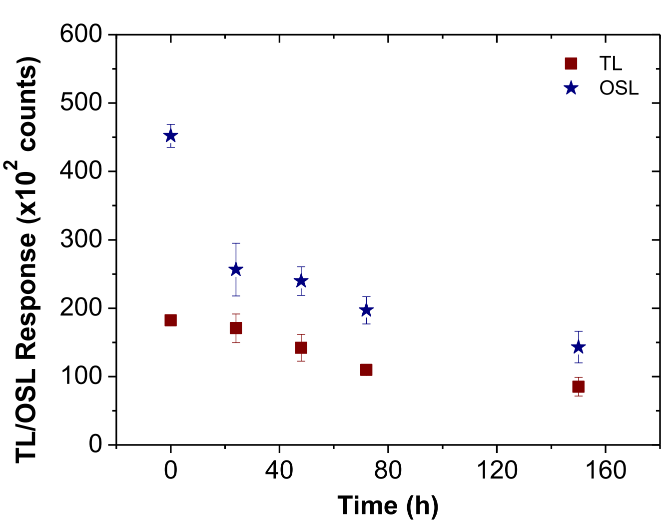

Fig. 5. Fading of the Spectrolite + Teflon pellets after irradiation with a $^{90}Sr + ^{90}Y$ source: (a) TL, and (b) OSL technique.

Table 2
Fading of the TL and OSL responses represented by the remaining signals (in %), for the Spectrolite + Teflon pellets.

Time (h)	Fading (%)	
	TL response	OSL response
0	100	100
24	93.6	56.8
48	77.9	53.0
72	60.2	43.6
150	46.7	31.6

The fading results with the TL and OSL techniques, in percentage and in relation to the remaining signal of the pellets, are presented in Table 2: the values determined in each time interval were normalized to the initial reading.

It is possible to observe that the fading of the OSL signal is higher than of the TL signal, remaining a minimum signal of 31.6% after 150 h post-irradiation. In relation to the OSL response, a fast decay after 24 h can be observed, remaining only 56.8% of the initial signal.

Rhodonite and Diopside are other two materials that had their fading already presented in literature. Vila (2012) verified a remaining TL response of 60% for Rhodonite and 26% for Diopside, after 168 h of exposure to the $^{90}Sr + ^{90}Y$ source, and a remaining OSL response of 37% for Rhodonite and 38% for Diopside after the same time. These results are similar to those of the present study.

4. Conclusions

Initially, the powdered Spectrolite was investigated in relation to its structure and chemical composition. The XRD technique revealed a crystalline system with some intense peaks. The SEM showed that the material has irregular morphology and well-defined edges, and the EDX proved the predominant presence of $NaAlSi_3O_8$.

In order to evaluate the dosimetric properties of the Spectrolite + Teflon pellets, in the proportion of 1:1, characterization tests were performed, after exposure of the samples to a $^{90}Sr + ^{90}Y$ source.

The reproducibility study provided adequate results, showing that the TL and OSL responses are stable. The dose–response curves for both luminescent techniques showed a linear behavior in a range from 0.5 Gy to 1 kGy. From the fading study, it could be observed that after 150 h it is still possible to observe remaining signals of the samples for TL and OSL responses.

The techniques and procedures used in this work allow to consider the Spectrolite + Teflon pellets, in concentration of 1:1, as adequate radiation detectors for beta radiation dosimetry, because the samples presented necessary and important characteristics for the material to be used as dosimeter, for both luminescent techniques, TL and OSL. In the case of the OSL response, it can be advantageous to evaluate the signal within 24 h after irradiation.

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