Thermoluminescent characteristics of Actinolite-Teflon composites for gamma high-doses

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In this work a preliminary study of the thermoluminescent (TL) dosimetric properties of the Brazilian actinolite:Ca2(Mg,Fe)5(Si8O22)(OH)2 (silicate of the Jade family) was undertaken for gamma high-doses. Actinolite occurs in several regions in the world. In this work actinolite in the form of rude mineral from Governador Valadares, Minas Gerais, Brazil, was studied. The natural actinolite samples were powdered, and the selected grains were mixed with Teflon in the proportion 2 (Teflon):1 (Actinolite). The mixture was pressed and sintered for production of pellets of composites Actinolite - Teflon. The glow curves present two peaks at 125°C and 210°C. The TL response reproducibility presents a maximum variation coefficient of 4.8%. The calibration curve is linear between 0.5Gy and 1kGy for pellets irradiated with gamma radiation (60Co) and between 0.5Gy and 10Gy for pellets irradiated with X-rays (33keV). The TL response presents an energy dependence of 26% for X-rays between 27 and 41keV.

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1 Introduction

The continuous use of ionizing radiations in processes associated to medical, industrial, agriculture and research applications has motivated the development of new thermoluminescent materials applied to high-dose dosimetry. Solid-state techniques based on thermoluminescence (TL) dosimetry are relatively inexpensive methods.

Developments of silica-based materials suitable for thermoluminescence dosimetry (TLD) have been studied by several authors. Many materials as fluorides, borates, oxides, sulphates and silicates present thermoluminescent properties [1]. McLaughlin et al. [2] described the main kinds of high-dose dosimeters, discussing their advantages and disadvantages; however, they need to combine characteristics that limit their use in the radiation dosimetry [3]. Additionally, most of the current detectors present high cost. The silicates represent 92% of the whole percentage volume of the minerals of the earth crust [4], and therefore there is a wide field of studies of new materials for radiation dosimetry. The dosimetric properties of Jade were already studied using the thermoluminescent technique, showing its potential use for high-dose dosimetry [5].

Recently, TL properties of manufactured composites with a mixture of Topaz-Teflon have been studied with the aim of developing a new solid-state dosimeter [6]. The objective of this work was to study the dosimetric properties of actinolite:Ca2(Mg,Fe)5(Si8O22)(OH)2, a Brazilian silicate of the Jade family, for gamma high-doses.

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2 Materials and methods

Actinolite, \( \text{Ca}_2(\text{Mg,Fe})_5(\text{Si}_8\text{O}_{22})(\text{OH})_2 \), is a silicate of the Jade family and belongs to the amphibole group. Actinolite occurs in several regions in the world, in dolomites and magnesian calcareous formations. The best deposits are in Canada (British Columbia), Russia (Siberia), USA (Alaska and California) and New Zealand. In this work actinolite was acquired in the form of rude mineral with quartz inclusions from Governador Valadares, Minas Gerais, Brazil.

The sample was cleaned with a nylon brush and alcohol isopropilic solution. Then, actinolite samples were separated from quartz optically using a geological hammer with vidia tip and a magnifying geologic glass. The ferromagnetic minerals presented in the samples were extracted with a Frantz Isodynamic magnetic separator. The Frantz separator was adjusted for an angle of 25° of longitudinal inclination, 10° of lateral inclination and current between 0.5 and 1.5 A.

The actinolite crystal was powdered, and grains with diameter between 0.074 and 0.177 mm were selected to be mixed with Teflon. The mixture Actinolite-Teflon was manually prepared in the proportion of 2(Teflon):1(Actinolite) in open atmosphere of nitrogen. The mixture was pressed with a nominal pressure of \( 1.6 \times 10^{11} \text{ N/m}^2 \) (Fred Frey model FC5), and pellets of Actinolite-Teflon of 50 mg with 6 mm of diameter and 0.8 mm of thickness were produced. The pellets were sinterized at 300 °C/1h, followed by a 400°C/1.5 h thermal treatment, and submitted to a slow cooling down in the oven. For reutilization and to avoid residual TL, the pellets were thermally treated at 300°/1 h.

The samples were irradiated with gamma radiation \((^{60}\text{Co}, \text{Gamma-Cell system})\) and X-rays. The irradiations with X-rays were made using a Pantak/Seifert (160HS) system, with radiation qualities of RQR3, RQR5, RQR7, RQR9 and RQR10 established at the Calibration Laboratory/IPEN (effective energies between 27 and 41 keV, voltages between 50 and 150 kV, half-value layers between 1.79 and 4.73 mmAl and air kerma rates between 24.06 and 175.19 mGy/min) as recommended by the IEC 61267 (1994) standard [7].

The TL glow curves were obtained for doses from 0.5Gy to 20kGy, using a Harshaw TL reader of Nuclear Instruments Systems, model 2000 A/B; the data acquisition was performed using a virtual instrument (ADC-212 Pico Technology Ltd.) and a personal microcomputer.

3 Results

3.1 Glow curve

Figure 1 presents the TL glow curve of a pellet of Actinolite–Teflon composite treated at 300 °C/1h and irradiated with 10 kGy \((^{60}\text{Co})\). The glow curve presents clearly two peaks at 125 °C (peak 1) and 210 °C (peak 2). Peak 2 is the most prominent. Peak 2 presents a TL intensity about two times more intense than the peak 1. The dosimetric study was performed with TL peak 2. The peak positions are independent of the absorbed dose. The TL intensity increases in function of absorbed dose.

![Fig. 1 TL glow curve of an Actinolite–Teflon pellet irradiated with 10 kGy \((^{60}\text{Co})\).](image-url)
3.2 Response reproducibility For the reproducibility experiment of the TL response, a group of ten numbered pellets of Actinolite–Teflon composites were submitted to the same conditions of thermal treatment at 300 °C/1h (defined for reutilization); irradiation at 10 Gy (\(^{60}\)Co); and TL reading. This experiment resulted in maximum and minimum variation coefficients of 1.4% and 4.8%, integrating the charge between 50 °C and 300 °C in the glow curves.

3.3 Lower detection limit The lower detection limit for the TL pellets of Actinolite–Teflon composites, defined as three standard deviations of five measurements of their mean zero dose reading (thermal treatment at 300 °C/1h and non-irradiated samples, expressed in units of absorbed dose) was determined as 6.70 mGy.

3.4 Calibration curves The calibration curve of the pellets of Actinolite–Teflon was obtained using gamma and X radiations. In both cases the pellets were thermally treated at 300 °C/1h before irradiation. Figure 2a presents the TL response in terms of integrated charge between 50 °C and 300 °C as a function of the absorbed dose of the Actinolite–Teflon pellets irradiated with gamma radiation (\(^{60}\)Co) and doses between 0.5 and 20 kGy. The curve presents linearity between 0.5 Gy and 1 kGy, and than supralinearity and a tendency to saturation. Figure 2b presents the TL response in terms of integrated charge between 50 °C and 300 °C as a function of the absorbed dose (Gy) of the Actinolite–Teflon pellets irradiated with X-rays (33 keV). The calibration curve presents linearity between 0.5 Gy and 10 Gy.

3.5 Energy dependence The performance of the TL response of Actinolite–Teflon pellets was studied in relation to their energy dependence for X-radiation. The TL response was measured from samples irradiated with 1 Gy of X-rays between 27 keV and 41 keV in air. These samples exhibit considerable energy dependence, as shown in Fig. 3, that has to be taken into consideration when evaluating doses. The maximum value of the energy dependence was 26% in the studied energy range.

Fig. 2 Calibration curve of Actinolite–Teflon pellets irradiated with: a) \(^{60}\)Co, and b) X-rays (33 keV).
4 Conclusions  The dosimetric properties of Actinolite-Teflon pellets produced at IPEN studied in this work show the possibility of their application as radiation detectors for high-dose dosimetry of X-rays and gamma radiation, for absorbed doses between 10 Gy and 1 kGy. Similar results were obtained for Jade-Teflon pellets [5]. The results obtained are in agreement with most of the TLDs used commercially.

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References


Fig. 3 Energy dependence of TL response of Actinolite–Teflon pellets irradiated with 1Gy of X-rays.