



Application of jade samples for high-dose dosimetry using the EPR technique

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ABSTRACT

The dosimeter characteristics of jade samples were studied for application in high-dose dosimetry. Jade is the common denomination of two silicates: jadeite and actinolite. The EPR spectra of different jade samples were obtained after irradiation with absorbed doses of 100 Gy up to 20 kGy. The jade samples present signals that increase with the absorbed dose (*g*-factors around 2.00); they can be attributed to electron centers. The EPR spectra obtained for the USA jade samples and their main dosimetric properties as reproducibility, calibration curves and energy dependence were investigated.

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1. Introduction

Jade is the common denomination of two silicates: jadeite [NaAl(Si₂O₆)] and actinolite [Ca₂(Mg,Fe)₅(Si₄O₁₁)₂(OH)₂], which belong, respectively, to the subclasses of pyroxenes and amphiboles (Zhao et al., 1994). Green materials were acquired as jade with origin in New Zealand, Austria and USA.

The dosimetric properties of these materials were already studied using the thermoluminescence technique, showing their potential use for high-dose dosimetry (Melo et al., 2004). At the Metrology Laboratory of IPEN, São Paulo, glasses, sand and Brazilian natural stones have been studied in relation to their dosimetric properties for high-doses using different techniques (Caldas and Teixeira, 2002; Quezada and Caldas, 1999; Rocha et al., 2002; Souza et al., 2002; Teixeira et al., 2005). EPR properties received a great attention in literature; Ikeya (1993) identified the main paramagnetic defects in silicates.

In the present work jade samples were studied using the electronic paramagnetic resonance (EPR) technique to investigate potential applications in gamma radiation dosimetry. There is no evidence in the literature about jade applications in radiation dosimetry using the EPR technique; only crystallographic aspects of synthetic samples were compared to natural ones (Deer et al., 1966).

2. Materials and methods

Jade samples originating from New Zealand (NZL), Austria (AUS) and United States of America (USA) were studied. The

chemical composition of these jade samples can be seen in Table 1. All samples were initially cleaned, pulverized, and grain diameters between 0.074 and 0.177 mm were obtained. The samples were thermally treated at 300 °C during one hour in open atmosphere, defined for their reutilization. The irradiation of the samples were performed using a Gamma-Cell 220 system (⁶⁰Co, dose rate of 3.28 kGy/h) of the Center for Radiation Technology, IPEN. The electronic paramagnetic resonance (EPR) measurements were carried out using a Bruker EMX spectrometer with a rectangular cavity (ER4102 SY), at room temperature, microwave frequency of 100 kHz and field modulation amplitude of 0.1 T, and using an average sample mass of (150+1)mg. This EPR spectrometer belongs to the Multi-user Group of the Institute of Physics, University of São Paulo.

3. Results

The EPR spectra of different jade samples were obtained after irradiation with absorbed doses of 100 Gy up to 20 kGy.

Fig. 1 shows the EPR spectra of the jade samples in the form of powder, treated thermally at 300 °C/1 h and irradiated with 5 kGy of ⁶⁰Co. The magnetic field was varied from 500 to 6500 G to obtain the whole spectra of the EPR samples, and to identify the EPR characteristic peaks of each sample (Figs. 2a, 3a, 4a). These measurements were taken with a standard Mn²⁺ sample, which has six well-defined EPR peaks (Ikeya, 1993).

The EPR spectrum of each sample was obtained varying the magnetic field from 3000 to 4000 G (Figs. 2b, 3b, 4b), to identify the characteristic *g*-factor, shown in Figs. 2c, 3c, 4c. The EPR spectra of jade samples AUS and NZL are similar. The difference lies in the values of the *g*-factor or magnetic field (Gauss). The difference between the signal intensities of the two EPR peaks is very discreet.

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Table 1
Chemical composition for the individual jade samples (AUS, NZL, USA).

Element (%)	Jade samples		
	AUS	NZL	USA
Mg	13.2 ± 0.3	12.1 ± 0.3	14.2 ± 0.4
Ca	5.8 ± 0.4	6.6 ± 0.7	9.8 ± 0.7
Fe	3.72 ± 0.07	–	0.64 ± 0.01

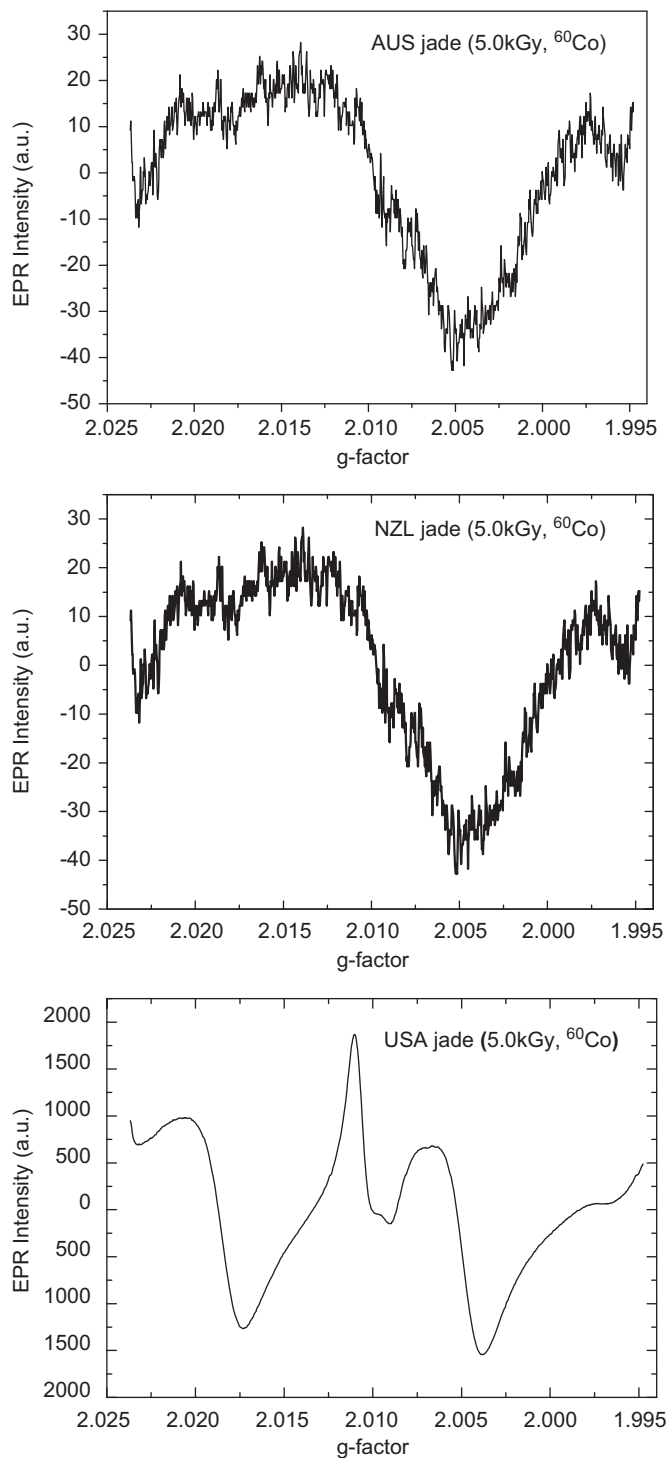


Fig. 1. EPR spectra of jade samples (AUS, NZL, USA) treated at 300°C/1h and irradiated with 5 kGy (⁶⁰Co).

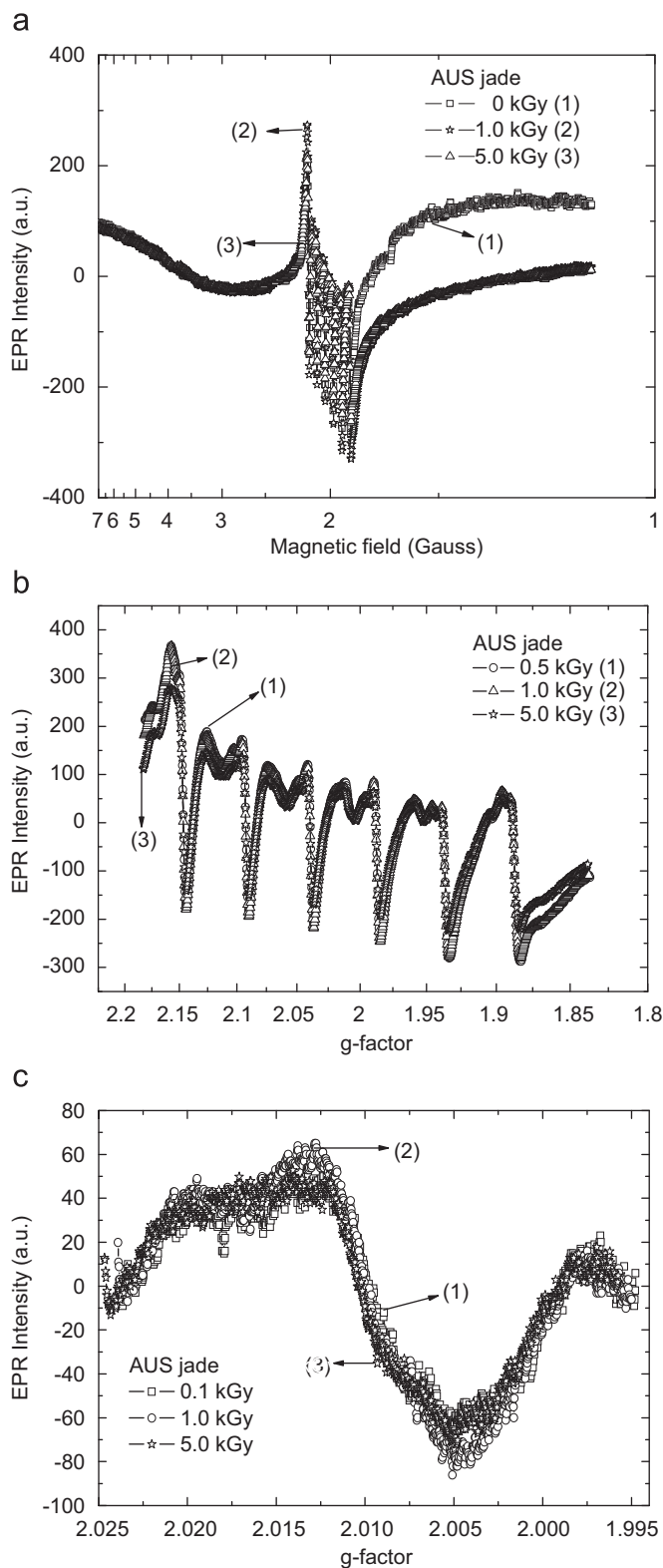


Fig. 2. EPR spectra in different intervals of measurement of jade AUS irradiated with various absorbed doses (⁶⁰Co).

Moreover, the EPR spectrum of the USA jade sample presents a more complex signal than of the other two samples (AUS and NZL), and its signal is 50 times greater than that of jade AUS. The EPR spectra of all jade samples present a characteristic signal of the Mn²⁺ ion, which is the sextet observed in the range of values

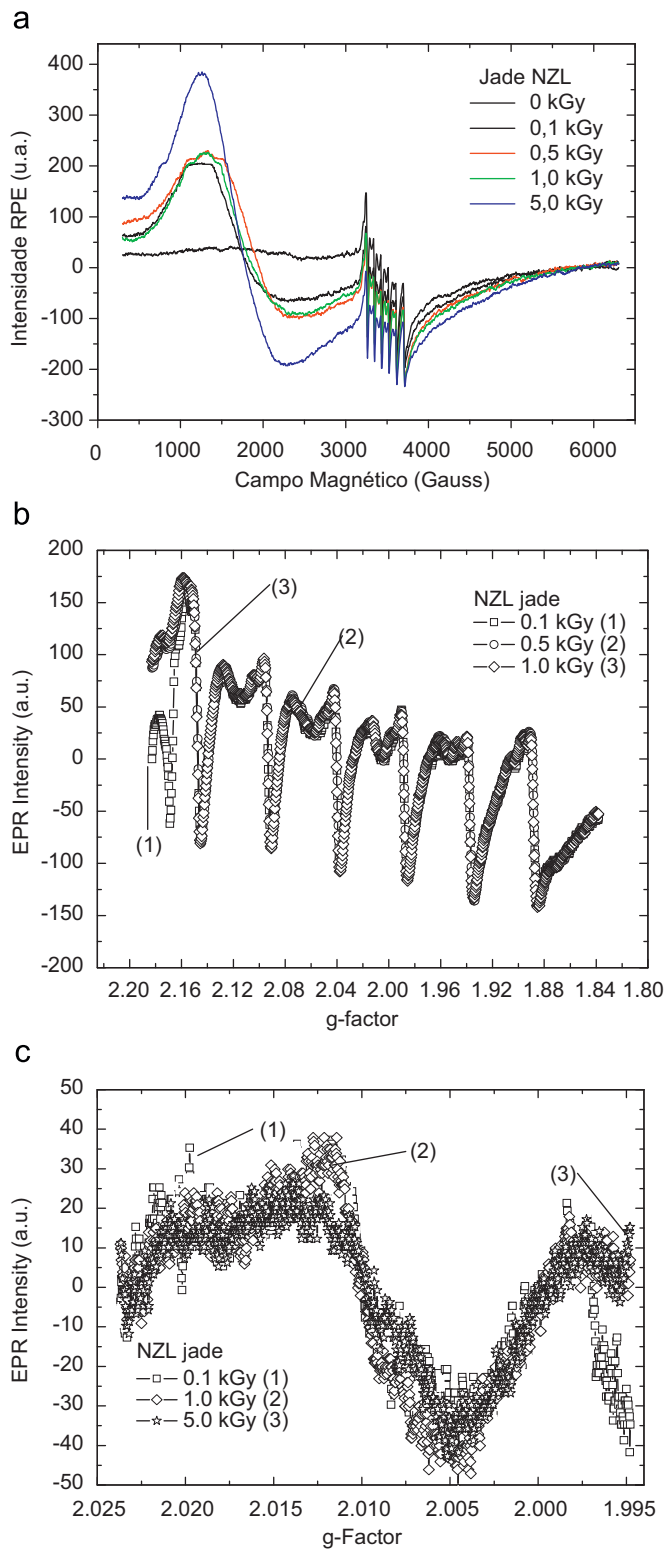


Fig. 3. EPR spectra in different intervals of measurement of jade NZL irradiated with various absorbed doses (^{60}Co).

of g-factor between 2.20 and 1.90. This fact can be seen in the EPR spectra presented in Figs. 2a, b, 3a, b, 4a and b. The EPR spectrum of USA jade presents a signal that increases with the absorbed dose (g-factors around 2.00), as can be seen in Fig. 4c.

The EPR spectra of the NZL and USA jade samples (Figs. 3a and 4a) present also a sign whose g-factor is approximately 4.3, which

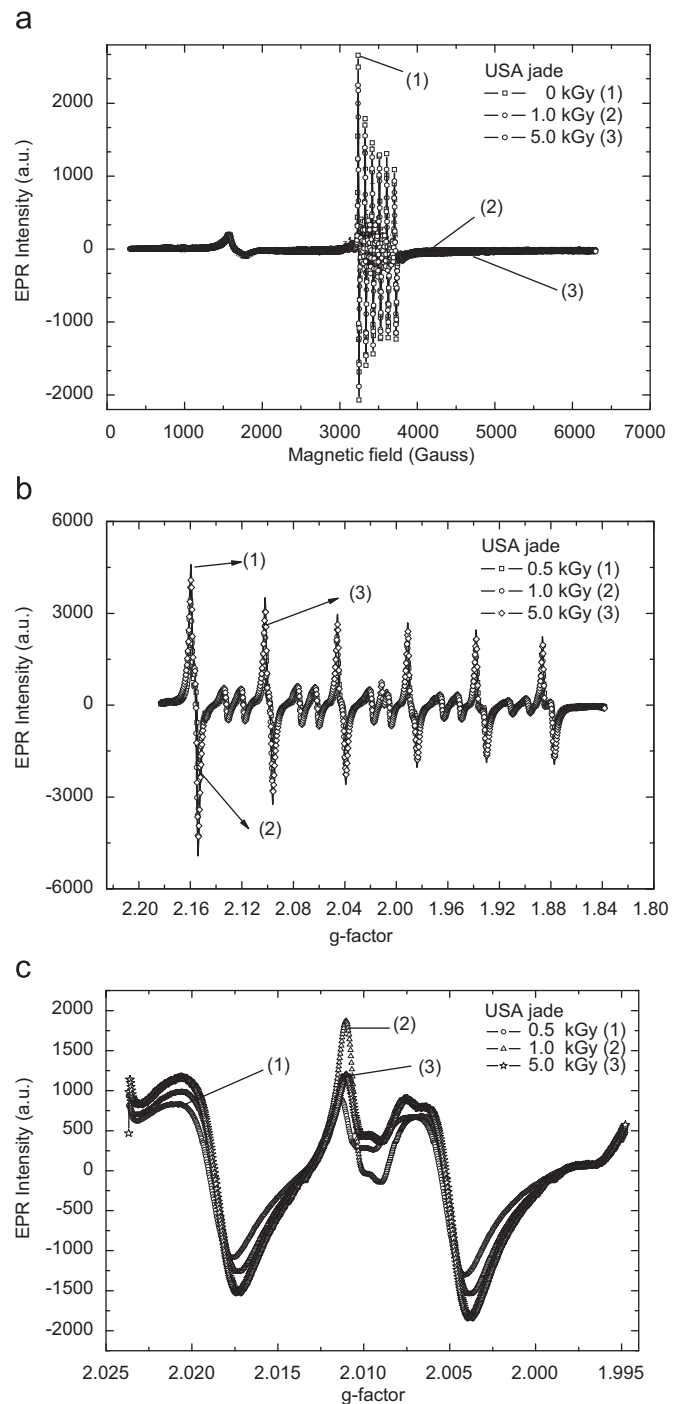


Fig. 4. EPR spectra in different intervals of measurement of jade USA irradiated with various absorbed doses (^{60}Co).

corresponds to the substitutional Fe^{3+} of the Si^{4+} in tetrahedron SiO_4 . This tetrahedron is distorted due to the presence of a monovalent cation in its neighborhood, to offset the imbalance caused by the electrostatic difference between the valence of the ions Fe^{3+} and Si^{4+} (Marfunin, 1979).

Figs. 2 and 3 show the EPR spectra of AUS and NZL jade samples, irradiated to various doses (^{60}Co); they present EPR signals that does not vary with the absorbed dose. The USA jade samples showed the characteristic CO_2^- signals at $g=2.0025$ and 2.0009 (Fig. 5). In this case, the EPR intensities present an increase

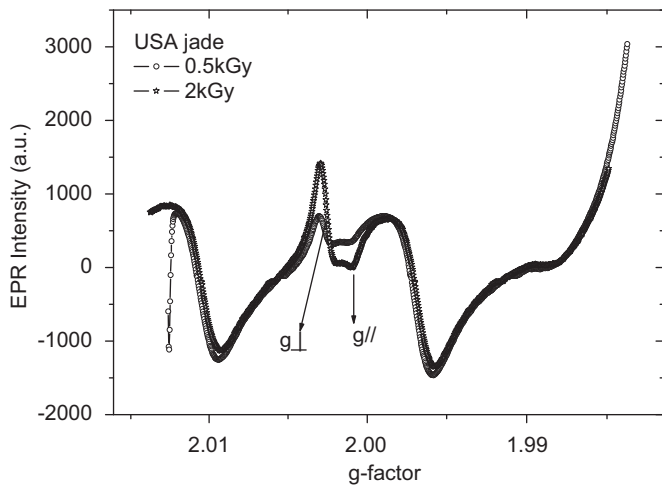


Fig. 5. g -factor for the center CO^{2-} observed in the USA jade sample: $g_{\perp}=2.0025$ e $g_{\parallel}=2.0009$.

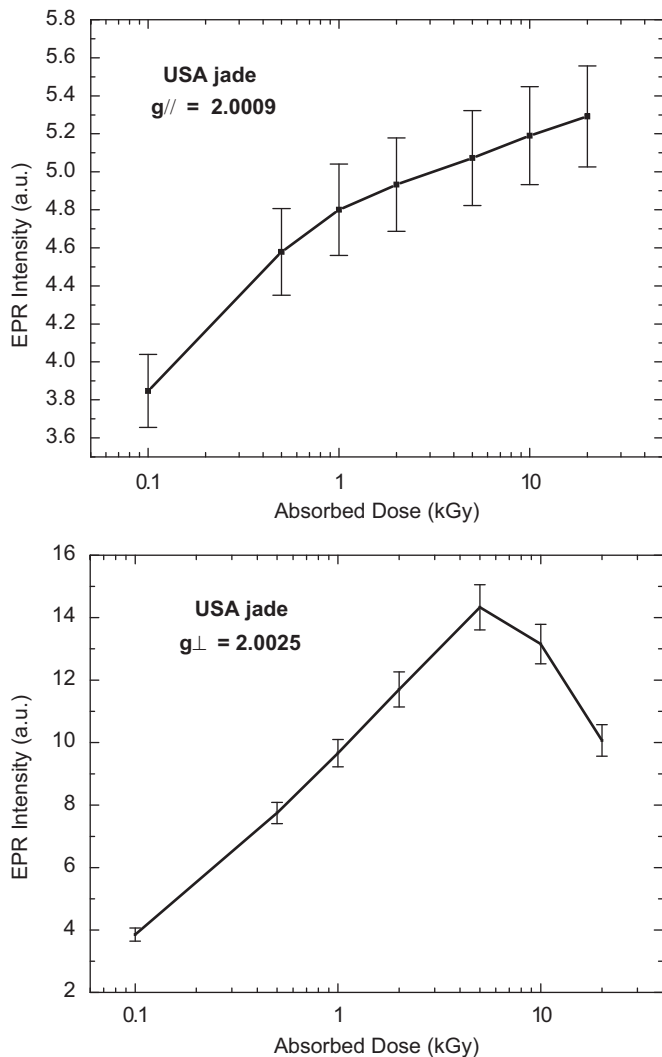


Fig. 6. Calibration curves of the EPR response of the USA jade sample (^{60}Co), g -factors: 2.0025 and 2.0009.

with the absorbed dose; they may be attributed to electron centers.

Fig. 6 shows the dose–response curve of USA jade samples for g_{\perp} and g_{\parallel} -factors. In the case of g_{\perp} -factor, a sublinear behavior can be observed between 0.1 and 5 kGy, and then the signal decreases until 20 kGy. In the case of the g_{\parallel} -factor, the response curve presents a sublinear behavior in the all tested range of 0.1–20 kGy.

4. Conclusion

The EPR spectra of the USA jade samples present signals that increase with the absorbed dose (g -factors around 2.00) between 100 Gy and 5 kGy. They can be attributed to electron centers. The results obtained indicate the possibility of use of these jade samples as radiation detectors for gamma high-doses, using the EPR technique.

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