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Descalvado Sand for High-Dose Dosimetry

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Abstract

Brazilian beach sand has already shown usefulness for high-dose dosimetry using the electronic paramagnetic resonance (EPR) and thermoluminescence (TL) techniques. In this work sand samples from Descalvado were studied in relation to their main dosimetric properties. The EPR signal grows significantly in function of absorbed dose for g of 2.000 and 1.996. All studied sand samples can be used as EPR dosimeters for different applications in medical, agricultural and industrial areas.

Keywords: electronic paramagnetic resonance; sand; radiation dosimetry.

1. Introduction

Glass samples have revealed a potential use as radiation Sand samples were investigated with the purpose to verify the possibility of their use in dosimetric procedures of irradiation (high-doses). Advances in irradiation technologies made possible commercial processes as sterilization, pasteurization, food preservation, and treatment of various materials (McLaughlin et al., 1989; Farrar, 1999). Radiation processing at irradiation facilities requires a quality control program. The verification of absorbed doses is an essential procedure of such a control. Several kinds of dosimeters have been proposed, tested, and are presently in use for this purpose (McLaughlin et al., 1989). Propositions of dosimetric material easily found in the nature, as sand or commercial products as glass, were already studied (Vaijapurkar et al., 1993; Vaijapurkar et al., 1998; Quezada and Caldas, 1999; Caldas and Teixeira, 2002; Rodrigues and Caldas, 2002; Caldas et al., 2004).

The main component of sand is quartz (SiO_2), and its EPR properties received a great attention in literature; Griscom (1990) published a review paper of this important insulating material. Marfunin (1979) and Ikeya (1993) cited the main paramagnetic defects in quartz.

In this work sand samples from Descalvado, an inland city of São Paulo State, Brazil, was studied. Descalvado is the city that produces most of the sand used in the Brazilian glass industry. These sand samples contain high pureness and controlled concentrations of heavy minerals presenting steady physical and chemical characteristics, in compliance with the requirements in the area for the manufacture of glasses, silicates and ceramics. The industrial quartzous sand samples are produced by special equipment that confers steady physical characteristics to the end items, surpassing the very demanding specifications of the casting market. Their main dosimetric properties as response reproducibility, batch uniformity and calibration curves were investigated in order to trace a comparative study with the results of Brazilian beach

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sand (Teixeira and Caldas, 2004; Teixeira et al., 2005). The studied sand samples can be utilized as EPR dosimeters for different applications in medical, agricultural and industrial areas.

2. Materials and Methods

Sand samples used in the present work proceed from a Descalvado natural reserve, São Paulo, Brazil. Two types of sand are manufactured there: one type for the glass industry and another type for the casting market, presented in different granulometries. These sand samples were called in this work DSG (Descalvado sand for glass industry) and DSC (Descalvado sand for casting), respectively.

Sand was bolted, and grains were obtained between 0.180 mm and 0.075 mm diameter. The sand samples were washed with a cloridric acid solution 1N (1 molar); after that, distilled water was used to remove the HCl and the organic impurities (Vaijapurkar and Bhatnagar, 1993). The wet sand samples were dried using an electric oven, Formitex, at 150ºC/50 min.

Magnetic particles (mainly iron) were removed from sand samples using a magnetic separator (S.G. Frantz Com. Ind., Isodynamic, model L-1).

The samples were packed in aluminum foils and in black plastic bags for the irradiations, following the facility procedure. The irradiations were performed in air (room temperature) using a Gamma-Cell 220 system (^{60}Co, dose rate of 3.67 kGy) of the Center of Radiation Technology, IPEN. The irradiations were made at ambient temperature, and the samples were fixed between 3 mm thick polymethyl methacrylate plates (Lucite), to guarantee the occurrence of electronic equilibrium during the irradiations.

Thermal treatments of 500°C/1h were applied to the glass samples for reutilization. The electronic paramagnetic resonance (EPR) measurements were carried out using a Bruker EMX spectrometer with a rectangular cavity (ER4102 ST), at room temperature, with microwave frequency of 9.76 GHz (X-band), microwave power of 0.202 mW, and with frequency and field modulation amplitude of 100 kHz and 0.1mT, respectively. This EPR spectrometer belongs to the Multi-User Group of the Institute of Physics, University of São Paulo.

The sand samples were inserted in the equipment resonant cavity using a pure quartz tube with an average mass of (150 ± 1) mg. These samples present a thermal fading of their EPR spectra of about 8% after 24 hours post-irradiation (Caldas et al, 2006). Due to this thermal fading, all measurements in this work were taken exactly one hour after the irradiations.

3. Results and discussion

3.1. EPR spectra

Some dosimetric properties were studied in this work for the verification of the possibility of utilization of sand samples for high-dose dosimetry. The EPR spectra obtained of the DSG (for glass) and DSC (for casting) sand samples, irradiated with different absorbed doses of 0.1 kGy, 1 kGy and 5 kGy are shown in Figures 1 and 2, respectively.

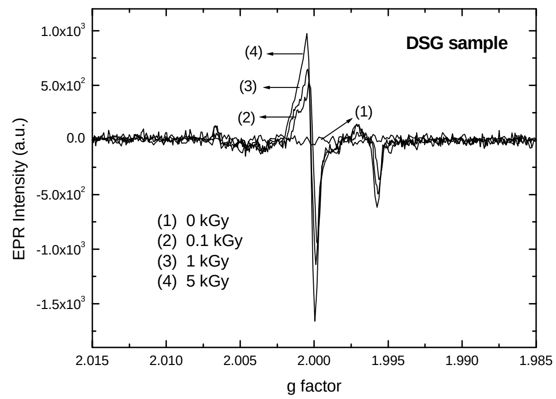

Fig 1. EPR spectra of the DSG sand samples irradiated to different absorbed doses (^{60}Co).

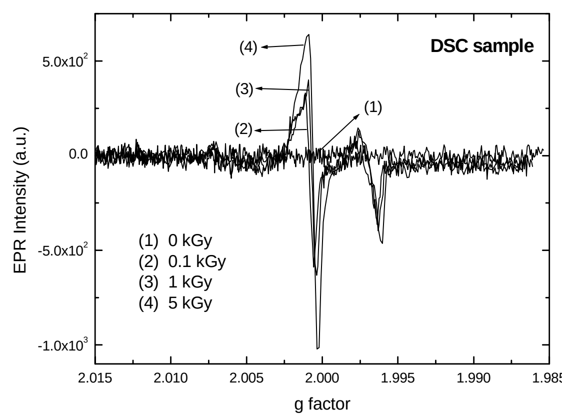

Fig 2. EPR spectra of the DSC sand samples irradiated to different absorbed doses (^{60}Co).

The g factor was obtained using the EPR spectrum of Mn^{2+} from a standard MgO:Mn sample. The third and fourth lines of the six lines associated with Mn^{2+} appear at g = 2.033 and 1.181, respectively (Ikeya, 1993). The EPR spectra of DSG and DSC samples are shown in Figure 3, using the Mn^{2+} line as reference.

The EPR spectra of DSG and DSC samples present two g-factors at 2.000 and 1.996. These signals are formed in quartz grains present mainly in sand: 97%-99%. These EPR signals were observed by Teixeira et al. (2005) in some Brazilian beach sand samples after irradiation. The signal at g = 2.000 corresponds to the counterfeit $E`_1$ center, according to Toyoda and Schwarcz (1997). The counterfeit $E`_1$ center is an electron

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trapped by an oxygen vacancy in the [SiO_3] tetrahedron of quartz grains. However, this center is less stable than the original E`$_1$ center. The signal at g = 1.996 was not identified because it was less interesting from the dosimetric point of view

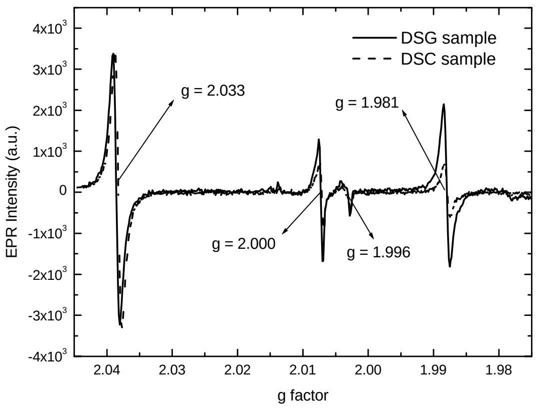

Fig 3. EPR spectra of the DSG and DSC sand samples using Mn^{2+} as reference, (^{60}Co, 5 kGy).

3.2. Reproducibility

Groups of five sand samples (DSG and DSC) were submitted five times to the same procedure of thermal treatment at 500 ºC/1h (defined for the reutilization), and irradiation (5 kGy), in order to study the response reproducibility. The maximum standard deviations obtained were approximately 4.1% for the DSG sand sample, and 4.9% for the DSC sand sample. The Ponta Negra Brazilian beach sand samples (Teixeira et al., 2005) presented 6.1% for the maximum standard deviation.

3.3. Dose Response

The sand samples (DSG and DSC) were irradiated to various doses in the range between 50 Gy and 50 kGy. Figure 4 presents the calibration curves for the materials. Sublinear behaviors were obtained in both cases. The maximum standard deviations obtained of these measurements were 2% and 3% of DSG and DSC sand samples, respectively.

In comparison with the calibration curve of Ponta Negra Brazilian beach sand samples (Teixeira et al., 2005), the DSG and DSC samples presented a greater region of linearity. This region starts at 50 Gy and can be extended up to 50 kGy. Although the EPR spectra intensity of the Brazilian beach sand samples were more intense for high doses, these spectra present a clear saturation effect about 10 kGy.

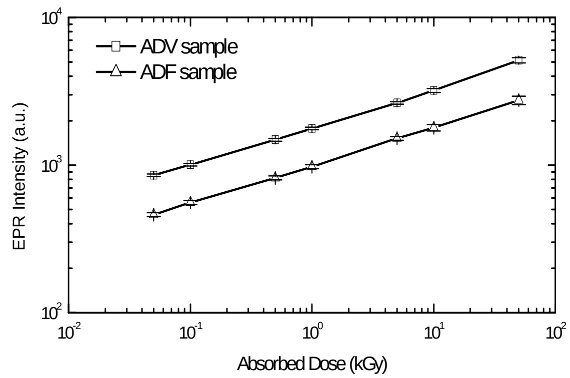

Fig 4. Calibration curves of the EPR signal at g = 2.000 for DSG and DSC sand samples (^{60}Co).

4. Conclusions

The calibration curves obtained in this work show that the Descalvado sand samples may be applied to high-dose dosimetry. The EPR signal grows significantly in function of the absorbed dose, for the g-factor at 2.000. Descalvado sand samples for glass industry present higher radiation sensitivity than that of the sand samples for casting. These samples present some advantages in relation the Brazilian beach sand samples, as a better reproducibility and linear dose response in a greater dose interval up to 50 kGy.

The basic advantage of sand samples is their very low cost. Sand samples may be applied to dosimetry in the main radiation processes of seed stimulation, mutation breeding, industrial radiography, and insect population control, pasteurization and water purification.

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