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Thermal treatments to minimize fading effects of colored glass radiation detectors

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Abstract

The use of colored glasses (bronze, brown and green) for high-dose dosimetry in routine procedures and as gamma radiation detectors has been investigated in this study. Different dosimetric techniques were employed using a densitometer, a spectrophotometer, a thermoluminescent reader and an electron paramagnetic resonance system. However, these kinds of samples show a strong post-irradiation thermal decay at room temperature, which is a problem for high-dose dosimetry purposes. This effect may be avoided by always taking measurements of the glass samples after the same post-irradiation time, for example 1 h. In this work, different thermal treatments have been applied to the glass radiation detectors. The influence of post-irradiation thermal treatments on the glass response fading was studied using different kinds of glass samples (bronze, brown and green). This process destroys the unstable color centers of the glass samples that are responsible for the initial strong response decay; after that the response becomes stable at room temperature. The different kinds of glasses show the possibility of their use for high doses of industrial, medical and agricultural applications, with the advantages of very low cost and easy handling.
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1. Introduction

Applications of high doses of radiation are of interest for food preservation, sterilisation of pharmaceutical products and treatments of several materials [1,2].

At the Calibration Laboratory of IPEN, Brazil, glass samples have been studied in relation to their main dosimetric properties: reproducibility, batch uniformity, detection range and dose response [3–8]. These kinds of glasses (bronze, brown and green) presented suitable characteristics as dosimeters for doses from 5 kGy up to 100 kGy, depending on the evaluation technique. Special glasses have been studied as possible radiation dosimeters at doses up to 100 kGy [9–12]. The applications of glass radiation detection systems were tested in a flower irradiation process [3] and at a large irradiator [6], where they provided adequate results and showed their usefulness for high-dose dosimetry.

However, they showed the disadvantage of an initial fast thermal decay in the first 24 h after irradiation. This effect can be avoided by taking measurements always at the same time interval after each irradiation, or using special thermal treatments after the glass irradiation [13,14]. Caldas and Quezada [14] suggested a post-irradiation thermal treatment at 130 °C for 10 min in the case of transparent window glass. At this temperature (130 °C), the glass response presents a deep decline, and later it stabilizes.

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In this work, different post-irradiation thermal treatments were studied to determine the temperature, which destroys the color centers that decay quickly, and allows other color centers to be used for dosimetric procedures.

2. Materials and methods

The samples of commercial glasses (bronze, brown and green), were produced by Cebracê, Brazil, by the "float" process at 1600 °C. This procedure provides uniform thickness of a homogeneous mass, free of optical distortions.

In this work the optical absorption (OA), thermoluminescence (TL) and electron paramagnetic resonance (EPR) techniques were utilized, because they are very good techniques for the characterization of dosimetric materials.

The glass samples were cut into the dimensions of $10 \times 12 \times 3\ mm^3$ to allow measurements of optical density. For the TL and EPR techniques, the glass samples were cut into pieces of $4 \times 7 \times 3\ mm^3$ (0.210 g).

An analysis of the three types of glasses was obtained using the neutron activation technique at the Radiochemistry Department of IPEN, presented in Table 1. In the mixture used for fusion at Cebracê, the bronze color was achieved by adding 24 ppm Se, 0.38% Fe and 34 ppm Co; in the case of the brown samples, 16 ppm Se, 0.44% Fe and 68 ppm Co was sufficient. The green color was obtained by adding 0.53% Fe only.

Table 1
Results of neutron activation analysis of colored glass samples (the intervals correspond to 1σ)

Element	Concentration ($\mu g\ g^{-1}$)		
	Bronze glass	Brown glass	Green glass
Ca	$68{,}000 \pm 5000$	$65{,}000 \pm 6000$	$73{,}000 \pm 5000$
Na	9.75 ± 0.04	9.86 ± 0.04	9.61 ± 0.04
Rb	24 ± 4	28 ± 6	24 ± 5
Fe	2409 ± 256	2980 ± 317	3368 ± 358
Co	29 ± 3	54 ± 6	0.43 ± 0.05

All irradiations were performed in air (room temperature) in the radiation field of a Gamma-Cell 220 (^{60}Co) system (dose rate of 4.48 kGy/h) under electronic equilibrium conditions achieved by covering the samples with 3 mm-thick Lucite plates.

Thermal treatments at 400 °C for 30 min were applied to the glass samples for reutilization. The evaluation of glass samples was performed by using a simple densitometer M.R.A., Brazil, a Shimadzu UV–VIS scanning spectrophotometer (double-beam), model UV 2101PC and a Harshaw

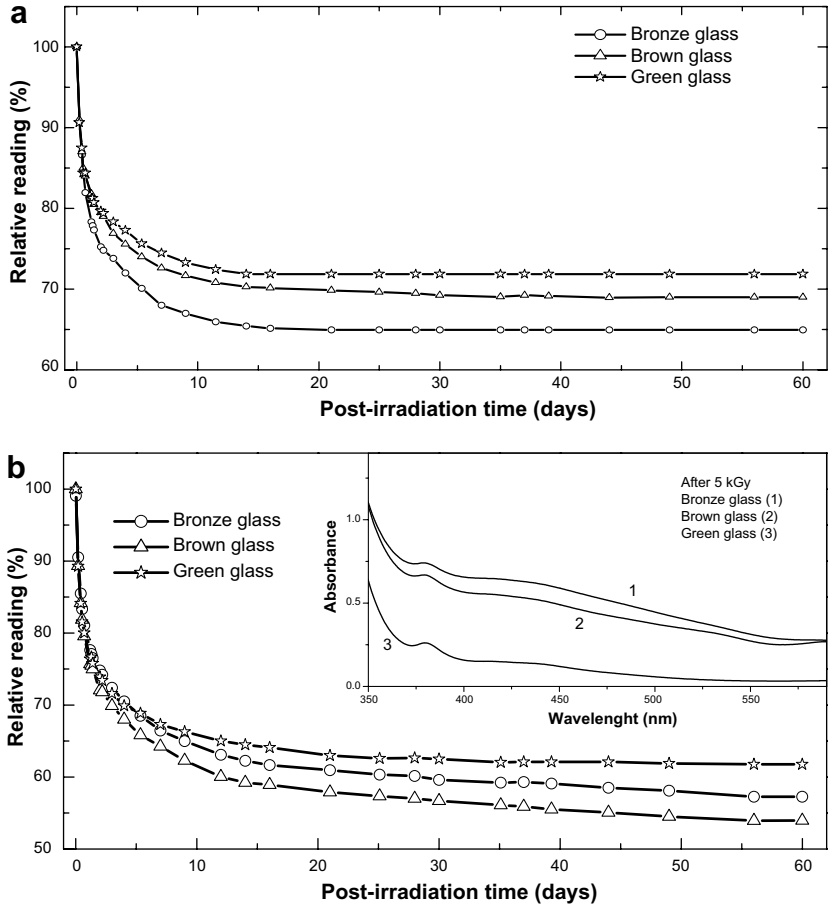

Fig. 1. Thermal fading at room temperature up to 60 days of glass samples (bronze, brown and green), after an irradiation of 5 kGy (^{60}Co). (a) Densitometer and (b) spectrophotometer.

Chem. Co. thermoluminescence reader, model 2000 A/B (heating rate of 10 °C/s). The EPR measurements were carried out using a BRUKER EMX spectrometer with a rectangular cavity (ER4102 ST), at room temperature, with a microwave frequency of 9.75 GHz (band X), microwave power of 20 mW, and with frequency and field modulation amplitude of 100 kHz and 0.1 mT, respectively. The magnetic field was varied between 100 and 400 mT. This EPR spectrometer belongs to the multi-users group of the Institute of Physics-University of São Paulo, Brazil. To insert the glass samples into the equipment resonant cavity, the use of a pure quartz rod, flattened in one of the extremities, was necessary; the samples were fixed with silicone paste. Due to the thermal fading of the glass spectra, all measurements in this work were taken exactly 1 h after the irradiations.

3. Results

The glass samples were irradiated with 5 kGy of gamma radiation. Their optical density response (Fig. 1(a) and (b)), TL response (Fig. 2(a)) and EPR spectra (Fig. 2(b)) were recorded up to 60 days after irradiation in order to verify their decay at room temperature.

The glass response showed, after the first 24 h post-irradiation time in the case of all four evaluation techniques, a reduction of about 20% for bronze glass, 22% for brown glass and 19% for green glass (Figs. 1 and 2). Afterwards, the decay rate slowed, tending to a constant value after about 15, 20 and 12 days, using all techniques, for bronze, brown and green glass samples, respectively (Figs. 1 and 2).

Fig. 1(b) shows the spectra of the colored glass irradiated to 5 kGy. In all of the spectra two absorption bands with maximum at 380 and 420 nm can be seen. However, the irradiation induced only the broad band at 420 nm, which was studied in this work. Fig. 2(a) shows the TL glow curves of the colored glass samples. The curves represent main TL peaks at 135, 150 and 145 °C, for the bronze, brown and green glass samples, respectively. The EPR spectra of colored glass samples after irradiation are presented in Fig. 2(b). The observed signal at spin g-factor equal 2.01 in these EPR spectra corresponds to pairs of exchange coupled Fe^{3+} ions, in the interstitial positions of the lattice, as described by Teixeira et al. [8].

The influence of post-irradiation thermal treatments on the glass samples response fading was studied after an irradiation of 5 kGy. These glass samples were treated for 15 min at different temperatures, and the results are

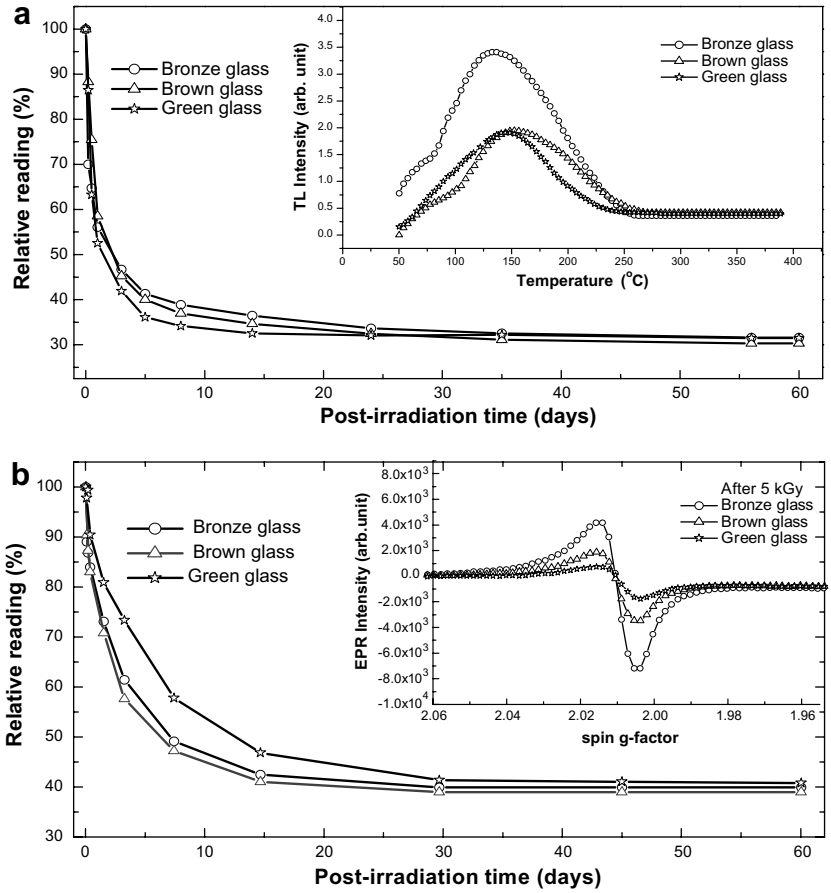

Fig. 2. Thermal fading at room temperature up to 60 days of glass samples (bronze, brown and green), after an irradiation of 5 kGy (^{60}Co). (a) TL response and (b) EPR intensity.

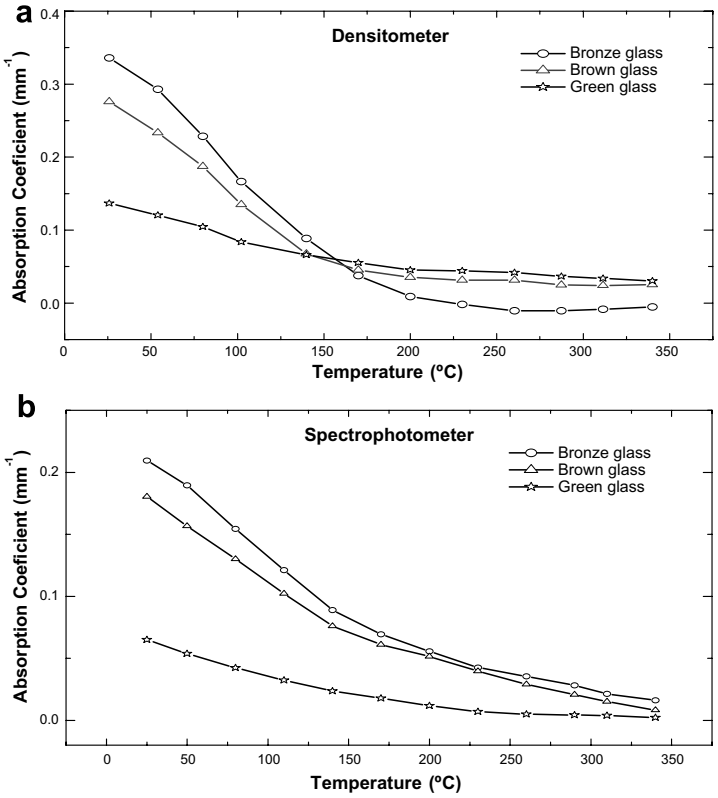

Fig. 3. Thermal treatment for 15 min during different temperatures after an irradiation of 5 kGy (^{60}Co). The measurements were taken by using a densitometer (a) and spectrophotometer (b).

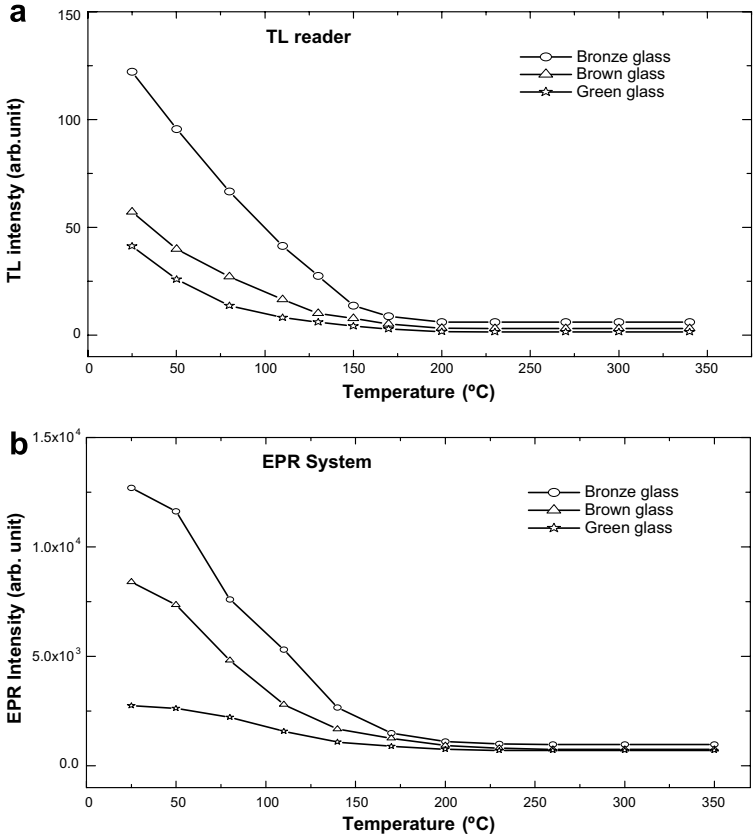

Fig. 4. Thermal treatment for 15 min during different temperatures after an irradiation of 5 kGy (^{60}Co). The measurements were taken by using a TL reader (a) and an EPR system (b).

presented in Figs. 3 and 4, for measurements taken by the densitometer, the spectrophotometer, the TL reader and EPR system. The thermal treatments were carried out with the purpose of determining the temperature, which destroys the signals induced by irradiation.

The post-irradiation thermal treatment of the glass samples showed that the absorbance, the TL peak and EPR signal decay with the temperature in very similar ways and the heat treatments after 200 °C can quench all signals. This suggests that the color centers responsible for the absorbance at 420 nm are the same centers responsible for the TL peak and EPR spectrum.

4. Conclusions

For a particular level of irradiation investigated in this work bronze glass samples presents better results than the other samples, for the first 24 h after irradiation, because it is more sensitive to gamma radiation for all techniques investigated in this work. For dosimetric procedures, the TL technique seems to be less favourable, due to its fading at room temperature.

Dosimeters of commercial glasses continue to be studied, because of their potential use as high-dose dosimeters. These materials present good reproducibility, and they can be reused or discarded, because of their extremely low cost and relatively easy characterization.

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