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Dosimetric properties of various colored commercial glasses

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Abstract

Brazilian commercial glasses of various colors (bronze, brown and green) have been studied to evaluate their potential as radiation-sensitive materials in gamma high-dose dosimetry. Characteristics of their optical absorption responses (reproducibility, room temperature stability, and calibration curves) have been obtained using a spectrophotometer and a simple densitometer specially designed for glass samples. The glass spectra feature a decay at room temperature that has to be taken into consideration. The results show that the colored glasses can be used in dosimetry; the upper limit of the dose range depends on the glass type.

Keywords: Glass; High doses; Dosimeter; Spectrophotometry

1. Introduction

Advances in irradiation technologies made possible such commercial processes as sterilization, pasteurization, food preservation, and treatment of various materials (Farrar, 1999; McLaughlin et al., 1989).

Radiation processing at irradiation facilities requires a quality control. 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).

Various glasses have been studied for possible use as radiation dosimeters at doses up to 100 kGy (Debnath, 1995; Del Nery et al., 1994; Dogan and Tugrul, 2001; Randhawa and Virk, 2000; Teixeira et al., 1996; Zheng et al., 1988). From the viewpoint of this application, color centers appear to be very interesting entities. The dosimetric properties of the colorless window glass manufactured in Brazil have been studied using various evaluation techniques (Caldas and Quezada, 2002; Caldas and Teixeira, 2001; Quezada and Caldas, 1999; Rodrigues and Caldas, 2002). This type of glass has a smaller size, easier handling and a lower cost, but also the disadvantage of a post-irradiation decay at room temperature. This problem may be avoided by standardizing the time between the irradiations and measurements (Caldas and Teixeira, 2001; Quezada and Caldas, 1999; Rodrigues and Caldas, 2002) or by applying special post-irradiation treatments to the material (Caldas and Quezada, 2002).

In this work, main dosimetric characteristics of several colored Brazilian commercial glasses were studied to evaluate the potential of these glasses as high-dose dosimeters or as irradiation indicators, because of their extremely low cost and relatively easy characterization.

2. Materials and methods

Commercial glass samples of various colors (bronze, brown, and green), manufactured (float bath process at 1600°C) by Cebracê, Brazil, with dimensions of $10 \times 12 \times 3\,mm^3$ were tested as radiation detectors. The main difference between this kind of glass and the common glass is the high optical quality provided by the

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float manufacturing process. This technology provides uniform thickness of a homogeneous mass, free of optical distortions. The common glass manufactured in Brazil before 1970 by conventional processes generally featured deformation and undulations. Table 1 shows the results of a neutron activation analysis of the three types of glasses performed by the Radiochemistry Department of IPEN. In this case, standard samples of the color-forming elements were exposed to a thermal neutron flux of $10^{12}\,n\,cm^{-2}\,s^{-1}$ for 8 h in the IEA-R1 m research reactor of IPEN. After varying cooling time intervals, the element concentrations were determined. The concentrations of these elements in the colorless samples were only $645\,\mu g\,g^{-1}$ (Fe) and $0.28\,\mu g\,g^{-1}$(Co).

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. The color of the samples studied in this work is probably due to iron and cobalt (Mekki and Salim, 1999; Wilk and Schreiber, 1998). The irradiations were performed in air (room temperature) in the radiation field of a Gamma-Cell 220 (^{60}Co) system (dose rate $5.49\,kGy\,h^{-1}$) under electronic equilibrium conditions achieved by covering the samples with 6-mm-thick Lucite plates.

Thermal treatments (30 min at 300°C) were applied to the glass samples for recycling.

The changes in optical density were measured with a simple digital densitometer (M.R.A., Brazil) and an ultraviolet–visible double-beam scanning spectrophotometer (Shimadzu, model UV 2101PC).

Due to the thermal fading of the spectra of glass samples, all measurements in this work were taken exactly 1 h after the irradiations.

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	68000 ± 5000	65000 ± 6000	73000 ± 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

3. Results

The main dosimetric properties of the colored glasses studied in this work were reproducibility of the response, dependence of the response on dose, and thermal fading of the spectra. They were studied in order to explore the possibility of using this kind of materials in measuring doses up to 400 kGy.

Figs. 1–3 show the spectra of the colored glasses irradiated to various doses. In all the spectra of these colored glasses, a weak, narrow absorption peak can be seen at 380 nm next to the broad band at 420 nm, which is present in the spectra of colorless glass samples, too (Caldas and Teixeira, 2001).

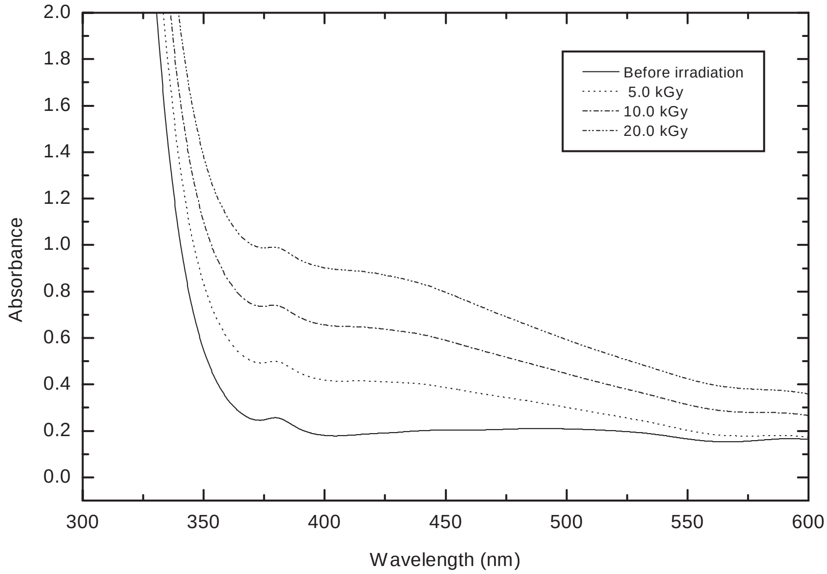

Fig. 1. Optical absorption spectra of a bronze glass irradiated to different absorbed doses (^{60}Co).

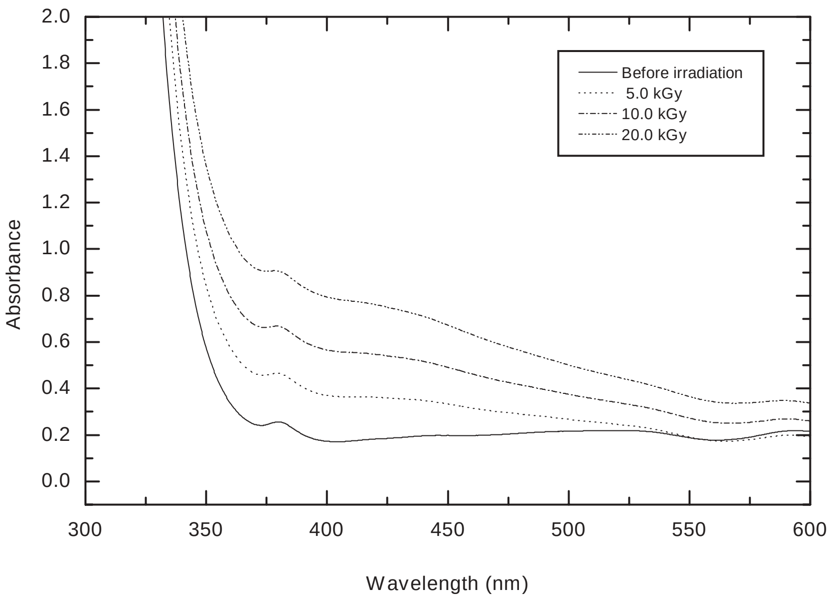

Fig. 2. Optical absorption spectra of a brown glass irradiated to different absorbed doses (^{60}Co).

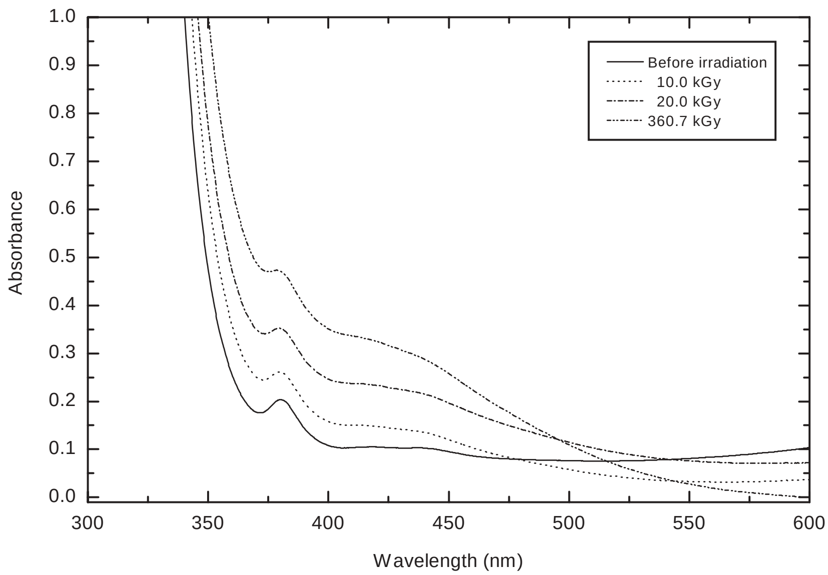

Fig. 3. Optical absorption spectra of a green glass irradiated to different absorbed doses (^{60}Co).

Due to the equipment limitations, the optical absorption was measured only in the range between 300 and 600 nm.

3.1. Reproducibility

Groups of eight samples of each type of the colored glass were repeatedly irradiated to 5 kGy ten times with the usual thermal treatments of 300°C for 30 min^{-1} for recycling. Measurements were made with the densitometer and the spectrophotometer. Table 2 lists the relative standard deviations obtained, which appear to be adequate for dosimetric purposes, and Fig. 4 shows the responses of the eight brown-glass samples during ten irradiation/annealing cycles.

3.2. Thermal fading

At room temperature, spectrum fading is noticeable for at least 30 days after irradiation for each type of glass. The spectrum decays in the whole observed range, but the effect in some regions is more significant than in the others. Figs. 5 and 6 show fading of the responses of the different types of glass over the period of 60 days after irradiation. For bronze, brown, and green glass, the response gets approximately constant after about 20, 25 and 30 days, respectively, when measured with the spectrophotometer, and after 12, 18 and 15 days, respectively, when measured with the densitometer. These fading characteristics are similar to those observed for colorless glass samples (Caldas and Teixeira, 2001).

Table 2
Reproducibility of the responses of colored glass samples irradiated to 5 kGy (^{60}Co)

Glass	Relative standard deviation (%)	
	Densitometer reading	Spectrophotometer reading (380 nm)
Bronze	2.5	1.7
Brown	2.6	1.9
Green	1.3	1.6

3.3. Dose response curves

The glass samples were irradiated to various doses in the range between 50 Gy and 400 kGy. Figs. 7 and 8 present the calibration curves for all the three types of samples, obtained with the densitometer and the spectrophotometer. Maximum relative standard

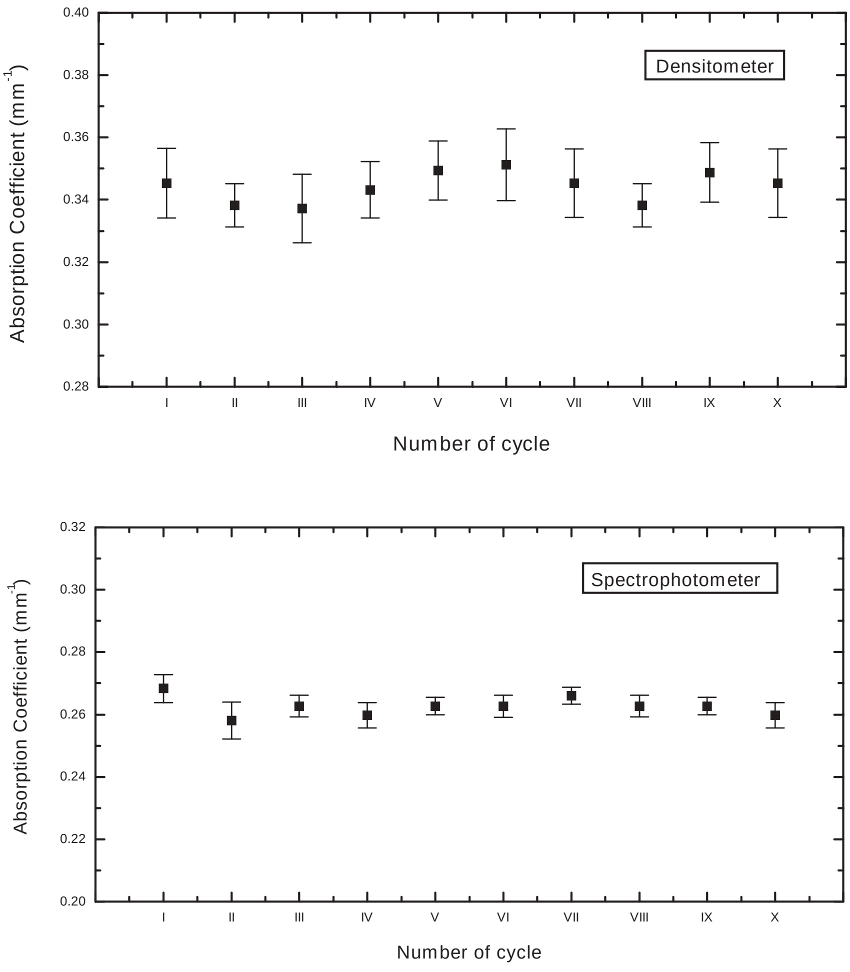

Fig. 4. Reproducibility of the spectra of brown glass samples repeatedly exposed to the ^{60}Co radiation (5 kGy) after annealing.

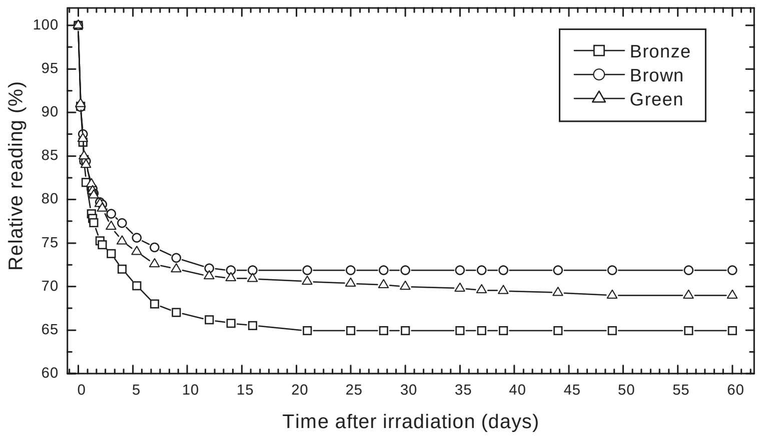

Fig. 5. Room-temperature fading of glass responses measured with the densitometer.

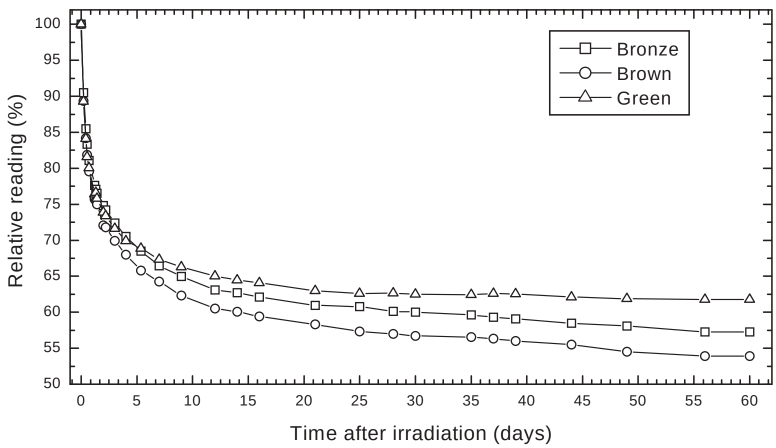

Fig. 6. Room-temperature fading of glass responses measured with the spectrophotometer.

deviations of the responses of replicate samples of 1.2% and 2.2% were observed for the brown glass samples using the densitometer and the spectrophotometer, respectively.

An increase in the response with dose of the degree convenient for high-dose dosimetry can be seen in all the cases. The responses of all the glasses reach saturation, but it occurs at different absorbed doses (Table 3), probably due to the difference in the instrument sensibility. In the case of the colorless glass, the saturation was observed at the absorbed doses of 40 kGy when measured with the densitometer and at 20 kGy, when measured with the spectrophotometer (Caldas and Teixeira, 2001).

Due to the thermal fading, which occurs even during irradiations and is different for sources with different dose rates, the results in this section are directly applicable only to the specific irradiation facility. Each user has to construct his/her own calibration curve, as for any dosimetric system.

3.4. Yes/No irradiation indicators

All three kinds of colored glass samples may be used as the "Yes/No" irradiation indicators. Visual observation of their color provides immediate confirmation of irradiation.

4. Conclusions

The basic advantages of commercial glasses are their chemical inertness, insolubility, rigidity, small size, and very low cost. This kind of materials is interesting for radiation dosimetry. The results obtained in this work show that colored glasses present adequate dosimetric

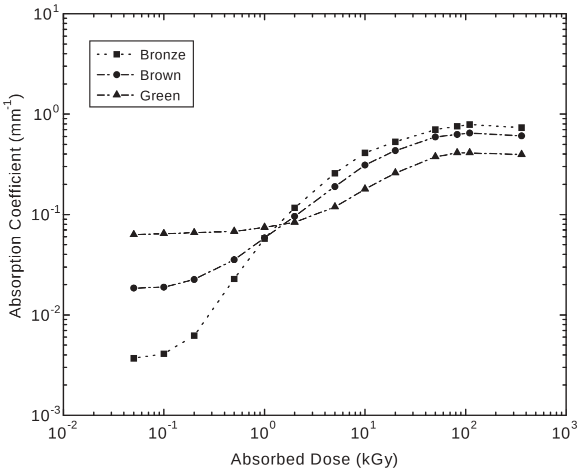

Fig. 7. Calibration curves for colored glass samples constructed with the densitometer. ^{60}Co, 5.49 kGy h^{-1}, measurements taken 1 h after irradiation. Relative standard deviations of replicate measurements were 2.0%, 2.2% and 1.5% for the bronze, brown and green glass samples, respectively.

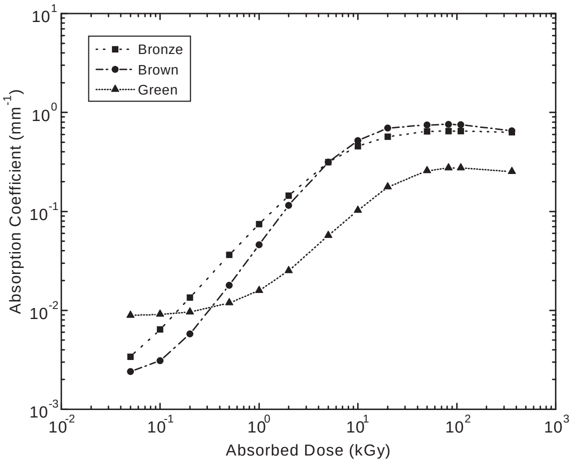

Fig. 8. Calibration curves for colored glass samples constructed with the spectrophotometer. ^{60}Co, 5.49 kGy h^{-1}, measurements taken 1 h after irradiation. Relative standard deviations of replicate measurements were 1.0%, 1.2% and 0.9% for the bronze, brown and green glass samples, respectively.

Table 3
Doses of the response saturation for colored glass samples

Glass type	Absorbed dose (kGy)	
	Densitometer reading	Spectrophotometer reading (380 nm)
Bronze	100	20
Brown	80	15
Green	80	80

properties for doses up to 100 kGy, provided that their thermal fading is taken into account. They may be used for dosimetry in the main radiation processes of disinfection (10–100 Gy), water purification (1–10 kGy), pasteurization (1–10 kGy), and sterilization (10–100 kGy). Because fading is temperature dependent and sources with different dose rates heat irradiated sample to different temperatures, the exact data reported in this paper are specific for the particular source utilized in this work.

Moreover, colored glasses can be used as irradiation indicators, with great advantages as compared with the more sophisticated ones.

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