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DOSIMETRIC CHARACTERIZATION OF DYED PMMA SOLID DOSIMETERS FOR GAMMA RADIATION

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ABSTRACT

The solid dosimeters of dyed or undyed polymethylmethacrylate (PMMA), in the plate form, are often used for routine monitoring in high-dose radiation processes. Ionizing radiation induces changes in the absorption spectrum of some polymers at characteristic wavelength; these changes can be related to absorbed dose. The dosimetric properties of dyed polymethylmethacrylate plates of commercial use were studied to evaluate the viability to use this material in radiation dosimetry. For dosimetric characterization PMMA samples were irradiated with ^{60}Co gamma radiation in the dose range between 0.5 and 100 kGy, using the facilities of the Centro de Tecnologia das Radiações of Ipen. For the samples preparation and spectrophotometric evaluations the facilities of the Centro de Metrologia das Radiações of Ipen were used. The samples (1 x 3 cm^2) were obtained from plates with original dimension of 120 x 60cm^2; the plates thickness varied between 2.1 and 2.5mm. The studied parameters were: batch homogeneity, ambient conditions sensibility and dose-response. The results were compared with the response of Red 4034 Perspex and Gammachrome YR dosimeters, developed by Harwell Dosimeters that show good performance in the quality control of the absorbed dose in the radiation processes. The evaluated samples present adequate properties to be used as control dosimeter in radiation process. They don't present significant variations with the ambient conditions and presents behavior similar to the comparative standards. Depending on the dyed used, the useful dose range can be between 5 and 100 kGy.

Keywords: Dosimetry, PMMA dosimeters, Gamma radiation, High doses.

1. INTRODUCTION

The use of PMMA sheets (1 x 3 cm) as dosimeter is widely known in the quality control of the radiation processes [1,2,4]. "Red 4034 Perspex" dosimeter (Harwell dosimeters) is worldwide used for routine determinations of the radiation absorbed doses. These dosimetric systems presents colour changes in its dye formulation when exposed to the ionizing radiation and is based on the measurement of specific optical absorbance at 640 nm. The high doses laboratory of Ipen studied the dosimetric properties of PMMA sheets produced in Brazil using dyes produced by Bayer, commercially known as Macrolex®: yellow 3G (class pyrazolone dyes); yellow 4G and red H (class azo dyes) and blue RR, green G, green 5B, red G and red 5B (class anthraquinone dyes) to be applied in routine quality control of industrial radiation processes. The influence of the environmental conditions, before and after irradiation such as temperature, light and relative humidity [5] was evaluated. The aim of this work was to characterize eight PMMA samples in order to verify if they can be used for dose control in industrial applications of ionizing radiation.

2. EXPERIMENTAL METHODS

2.1. Irradiation. The irradiations were carried out using a ^{60}Co Gammacell source installed at the Centro de Tecnologia das Radiações at IPEN-CNEN/SP. The dose range was between 0.5 and 100 kGy.

2.2. Analysis. For optical absorption measurement a Shimadzu UV-2101PC spectrophotometer was used. This device was connected to a PC with a special program that allows the automatic analysis of resulting data.

2.3. Ambient Influence. *Light*: The non-irradiated and irradiated PMMA samples were exposed for several days to the laboratory ambient light, which consists of fluorescent lamps and natural light. During several consecutives days the absorbance measures were made. *Humidity*: The different relative humidity conditions, between 0 and 100%, were obtained by means of saturated salt solutions that are very useful in producing known relative humidity. The PMMA samples were maintained during 24 h in specific conditions of relative humidity and then irradiated at same conditions. *Temperature*: The irradiated and non-irradiated samples were maintained during 1h at temperatures between 4^{o}C and 100^{o}C.

3. RESULTS AND DISCUTIONS

3.1. Absorption Spectrum: It is characteristic to the atom or molecule present in the substance, therefore, each dyed sample presents characteristic spectrum depending on the dye presents in its composition [3].

3.2. Light: *Non-irradiated samples***:** In the Fig. 1 and Fig. 2 are showed the relative responses obtained for non-irradiated PMMA samples exposed to ambient light. No significant influence was observed.

3.3. Irradiated Samples: Some materials are only photosensitive after irradiation, this way, it is necessary to determine how that factor can influence the performance of the dosimeter in order to avoid or to minimize this influence in the response. The PMMA samples were irradiated using the Gammacell source with doses of 10, 30 and 40 kGy and exposed to the laboratory ambient light. The samples presented variations in the response between 4% for standard Red Perspex and 20% for the yellow 4G, in that way, the effect of the incident light in the irradiated samples is significant, should be taken appropriate careful or to be considered for correction effect. To avoid the application of these corrections the samples should be maintained in a dark ambient and the measuring realized soon after the irradiation or in the maximum between 1 and 2 days.

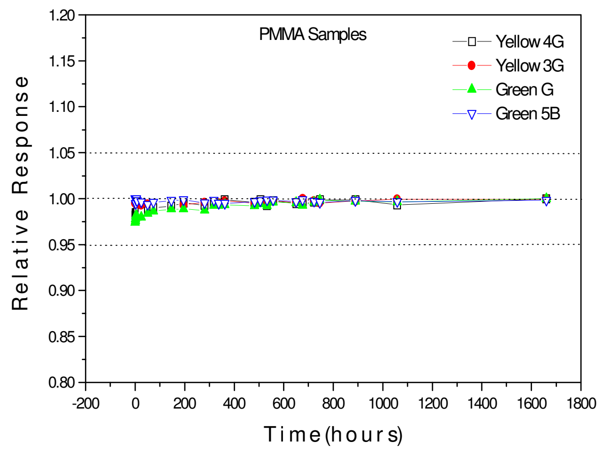


Figure 1. Relative response of the non-irradiated PMMA samples – dyed with yellow 4G, yellow 3G, green G and green 5B – exposed at ambient light.

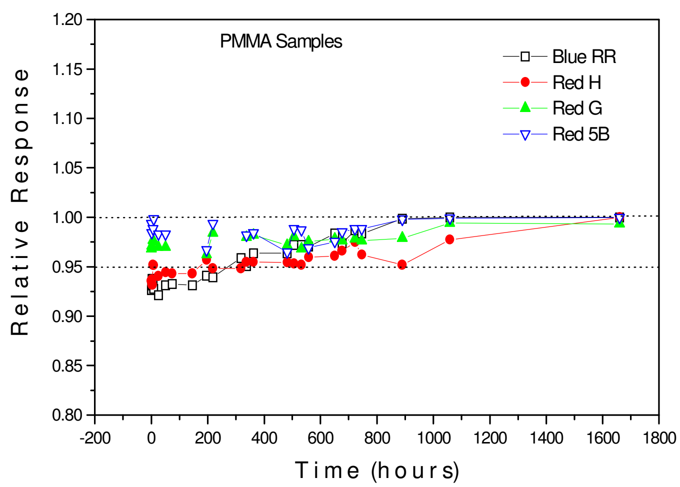


Figure 2. Relative response of the non-irradiated PMMA samples – dyed with blue RR, red H, red G and red 5B – exposed at ambient light.

3.4. Temperature: The non-irradiated and irradiated samples were exposed for one hour to temperatures of 4, 40, 80 and 100^{o}C, after stabilization, and than measures of absorbance of the non-exposed and exposed samples to the thermal treatment were realized. In the Fig. 3 and Fig. 4 are showed the relative responses obtained for non-irradiated and irradiated (20 kGy) PMMA samples, respectively.

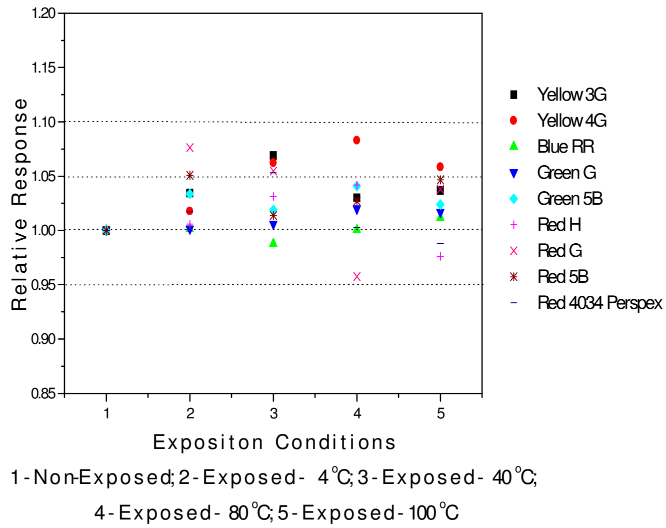


Figure 3. Response variation of the PMMA samples, non-irradiated, non-exposed and exposed the temperatures between 4 and 100°C.

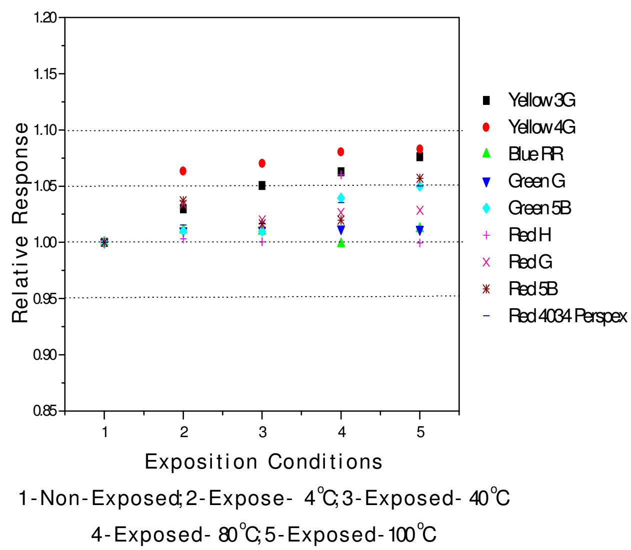
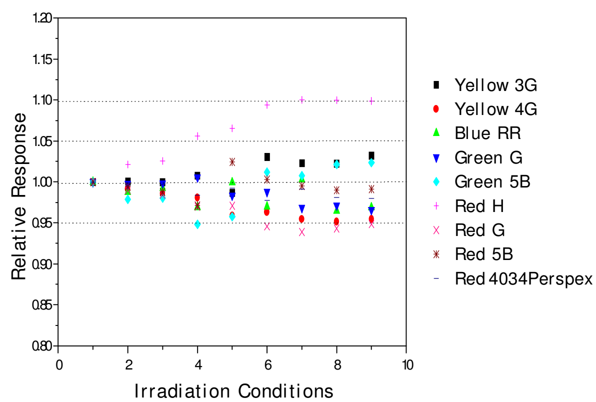


Figure 4. Response variation of the PMMA samples irradiated - dose 20kGy, non-exposed and exposed the temperatures between 4 and 100°C.

Using lead attenuators, the samples were irradiated with 20 kGy and with dose rates of 4.90 kGy/h (without attenuator); 2.45 kGy/h (with attenuator of 50%); 1.47 kGy/h (with attenuator of 70%) and with 0.49 kGy/h (with attenuator of 90%). The samples containing the yellow 4G, green G, green 5B, red H and red G dye presented behavior similar to the comparative standard Red 4034 Perspex (variation between 5-10%). For the samples containing the yellow 3G, blue RR and red 5B dye the variation arrived the values above 20%.

3.5. Humidity: The non-irradiated samples were exposed, for several hours, in atmosphere with relative humidity of 0%, 75.5%, 93.0% and 100.0%. The samples that contains the green dyed were the ones that presented smaller variation in the response (<2.5%), however, significant variation was not observed in the other samples, the largest value found was 5.0% for the red H and red G dyed, for the standards was found 5.0% for Red Perspex and 10.0% for Gammachrome YR. To determine the effect of R.H. on irradiated samples, the samples were exposed to variate R.H. conditions during 24 hours and, after the exposition were irradiated in the source Gammacell with dose of 20 kGy, in the same conditions of R.H.. The responses are showed in the fig. 5.



1- R.H. ambient; 2 - R.H. = 0%, 3 - after 24 hours;
4 - R.H. = 75.5%; 5 - after 24 hours; 6 - R.H. = 93%;
7 -after 24 hours; 8 - R.H. = 100%; 9 - after 24 hours

Figura 5. Effect of the relative humidity in the response of the irradiated PMMA samples - dose 20 kGy of ^{60}Co.

3.6. Dose-Response: The useful dose-response range was determined for each sample in the wavelength in which occurs the most intense variation of the optical response; the obtained values are presented in Tab. 1.

Table 1. **Dose-response useful range of the developed PMMA detector.**

Detector	Wavelength (nm)	Minimum Dose (kGy)	Maximum Dose (kGy)
Yellow 3G	300	< 0,5	40
Yellow 4G	353	5	80
Blue RR	450	10	100
Green G	528	10	100
Green 5B	405	5	100
Red H	620	5	50
Red G	397	5	100
Red 5B	415	5	100

4. CONCLUSIONS

The detectors developed are rugged, inexpensive and very useful material. They have easy method of analysis (spectrophotometry). The Brazilian market domain the technology for the PMMA sheets production with high quality and the raw materials are of easy acquisition.

All developed detectors presented behavior similar to the detectors considered as comparative standard (Red 4034 Perspex and Gammachrome YR), however, the detector that contain the red G and red 5B dye presented better characteristics than the detectors that contain other dyes.

The batch reproducibility was evaluated and was found to be better than 95% from batch to batch, represented by a sheet produced in the dimensions 60 x 120 cm^2.

The detectors didn't present significant variation of the response in function of the temperature conditions variating between 4 and 100^oC; relative humidity, between 0 and 100%, and ambient light of the laboratory, even so, this variation can be minimized if certain careful were taken during handle: the detectors should be sealed in pouches to avoid risks and the contact with the light and humidity of the atmosphere when stored, and during the measures the direct contact with the ambient light should be avoided.

The dose rate dependence in the range between 0.49 and 4.90kGy/h was approximately 20% for the detectors that contains the yellow 3G, blue RR and red 5B dyes.

The obtained results assure the viability of the PMMA detectors production with high quality and reduced prices. The red G and red 5B detector compared with the used standard were the ones that presented better performance, they can be used for a dose range between 5 and 100 kGy, although all the other ones can also be used in range of different doses.

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