ELECTRON DOSE RADIATION RESPONSE OF DYED PMMA DETECTORS DEVELOPED AT IPEN

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Running title: Electron dosimetry using PMMA detectors

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ABSTRACT

Dyed polymethylmethacrylate (PMMA) detectors using yellow, red, blue and green coloring compounds, commercially available in Brazil, were originally developed and characterized using the optical absorption (OA) technique for gamma radiation, with the aim of at obtaining a sensitive, useful, practical and cheap dosimeter for use in the quality control of industrial gamma radiation processing. In this work these detectors were evaluated for electron OA response, for use in the quality control of electron accelerator radiation processing. The studied parameters were: the absorption spectra, dose rate dependence between 2.66 and 45.22 kGy/s; dose response between 1.2 and 110 kGy; and energy dependence of response between 0.8 and 1.5 MeV electron energy.

INTRODUCTION

Radiation processing is a rapidly growing industry involving the improvement of several materials by ionizing radiation (electron beam; X-rays; gamma rays) [1,2].

Polymethylmethacrylate (PMMA) dosimetry systems are commonly applied in industrial radiation processing [3]. PMMA is a very useful material which is cheap and easy to acquire. It is available in different forms and colors, and has been studied as a dosimeter material. The PMMA detector provides a means of directly estimating the absorbed dose, since under the influence of ionizing radiation, chemical reactions take place in the material, creating and/or enhancing absorption bands in the visible and/or ultraviolet regions of the spectrum. The absorbed dose is determined by using a measured calibration curve obtained by the irradiation of a set of detectors to known absorbed doses.

Dyed PMMA detectors were produced at the Higher Doses Laboratory of IPEN using dyes produced by Bayer, commercially known as Macrolex®: yellow 3G (class pyrazolene 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 used in routine quality control of industrial radiation processes. They were previously characterized using the OA technique for their ^{60}Co gamma response. The results were compared to the commercially available Red 4034 Perspex and Gammachrome YR detectors, with the intention to introduce them into the quality control system of the gamma irradiation process carried out at IPEN. The PMMA detectors developed here presented good results, compared to the commercial materials [4].

In this work the OA response of the PMMA detectors was evaluated for electron beams. The samples were irradiated with electron beams of different energies, which are used in the radiation processing of materials such as polymers, resins, food, paints and inks [5].

The objective of the present work is to investigate the efficacy of the new PMMA detectors, produced in Brazil, for electron beams and their use in the quality control of radiation processing carried out at the Radiation Technology Center of IPEN.

EXPERIMENTAL

Materials - The PMMA plates (120 x 60 cm^2 - 2 to 2.5 mm thickness) produced using the Bayer Macrolex® dyes, yellow 3G, yellow 4G, green G, green 5B, red H, red G and red 5B were cut into strips of 10 mm width and 30 mm length, and sealed in sachets of aluminium / paper / polyethylene. The commercial Red 4034 Perspex dosimeters were used for comparison of the OA response with the new PMMA detectors.

Irradiations - The irradiations were carried out at the JOB-188 Dynamitron Inc. Electron Accelerator installed at the Radiation Technology Center CTR/IPEN-CNEN/SP. The accelerator settings were: energies of 0.8, 1.25 and 1.5 MeV and currents of 0.6, 5.1 and 10.2 mA.

Measurements - The absorbances, before (A_o) and after (A) irradiation, were measured using a spectrophotometer (Shimadzu UV-2101PC). The detector thickness (t) was measured after the spectrophotometric measurement.

Each data point represents an average of 3 measurements and the error bars are the standard deviation of the mean (1σ).

RESULTS

Calibration curve - The OA dose response curves of the detectors produced with yellow 3G, yellow 4G, blue RR, green G, green 5B, red H, red G and red 5B, measured at 300 nm, 353 nm, 450 nm, 528 nm, 405 nm, 620 nm, 397 nm and 415 nm, respectively, were obtained by irradiating the samples with 1.25 MeV electrons, current 0.6 mA and absorbed doses between 1.2 and 110 kGy. The results are presented in Fig. 1 (a - h), respectively. The wavelengths of yellow 3G, yellow 4G, blue RR, green G and red 5B PMMA dosimeters were taken from transmittance spectra and green 5B, red H and red G PMMA detectors readout wavelengths were taken from absorbance spectra. The selected wavelengths exhibited higher sensitivity as a function of the dose and better stability as a function of environmental conditions.

Dose - rate dependence – To verify the electron dose-rate dependence of the OA response, the samples were irradiated with 1.25 MeV electrons at doses rates of 2.66, 22.61 and 45.22 kGy/s, varying the current between 0.6 and 10.2 mA. The relative response of detectors was determined in terms of the absorbance per unit thickness normalized to its value at the lowest dose-rate. The responses of the PMMA detectors yellow 4G, green G and green 5B, and red H, red 5B and blue RR were independent of dose rate to within ± 10%, while the red G detector showed a decrease in response of approximately 15%, and the yellow 3G detector showed 20% increase in response, the dose rate was increased.

Energy dependence for electron beams – The electron energy dependence of the OA response was measured using samples of 2.4 mm thickness. The samples were irradiated with 0.8, 1.25 and 1.5 MeV electron beams operated at 0.6 mA current. The results are shown in Fig. 2 (a) and (b). The observed energy dependence of the OA response is due to insufficient electron range, and can be reduced by accounting for the thickness of the detector relative to the electron range. For measurements using un-dyed PMMA detectors with thicknesses between 1.2 and 5.6 mm for electron energies of 0.8, 1.25, 1.5 MeV, no energy dependence was observed when the thickness was less than the electron range, as shown in Fig. 3. The relative response of the detectors was expressed in terms of the absorbance per unit thickness normalized to its value for the lowest electron energy.

Batch reproducibility – The batch reproducibility was studied and was found to be within 5% from batch to batch, each batch representing a sheet of 120 x 60 cm^2 dimensions.

CONCLUSIONS

The use of dyed PMMA detectors for electron beam dosimetry is cheap and the absorbance analysis is very simple.

The results obtained show the viability of using these newly developed detectors for dose evaluation in electron radiation processing. The detectors are easy to prepare, manipulate and analyze.

The useful dose range of the eight dyed PMMA detectors developed is large and interesting for dose evaluation in electron radiation processing, and compares favorably to that of the commercially available Red 4034 Perspex detector.

The yellow 4G, green G and red 5B detectors were shown to be the most promising, considering their response characteristics and dose range, although the others detectors can also be used for different dose ranges.

All types of dyed PMMA detectors demonstrated high sensitivity and reproducibility. They do not present energy dependence when thicknesses equal to or smaller than the range of the electrons are used. These data also show that the dyed detectors present promising characteristics and can be useful for electron dosimetry.

ACKNOWLEDGMENTS

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Figure Captions

Fig. 1 – Optical absorption dose-response of dyed PMMA detectors irradiated with 1.25 MeV electrons.

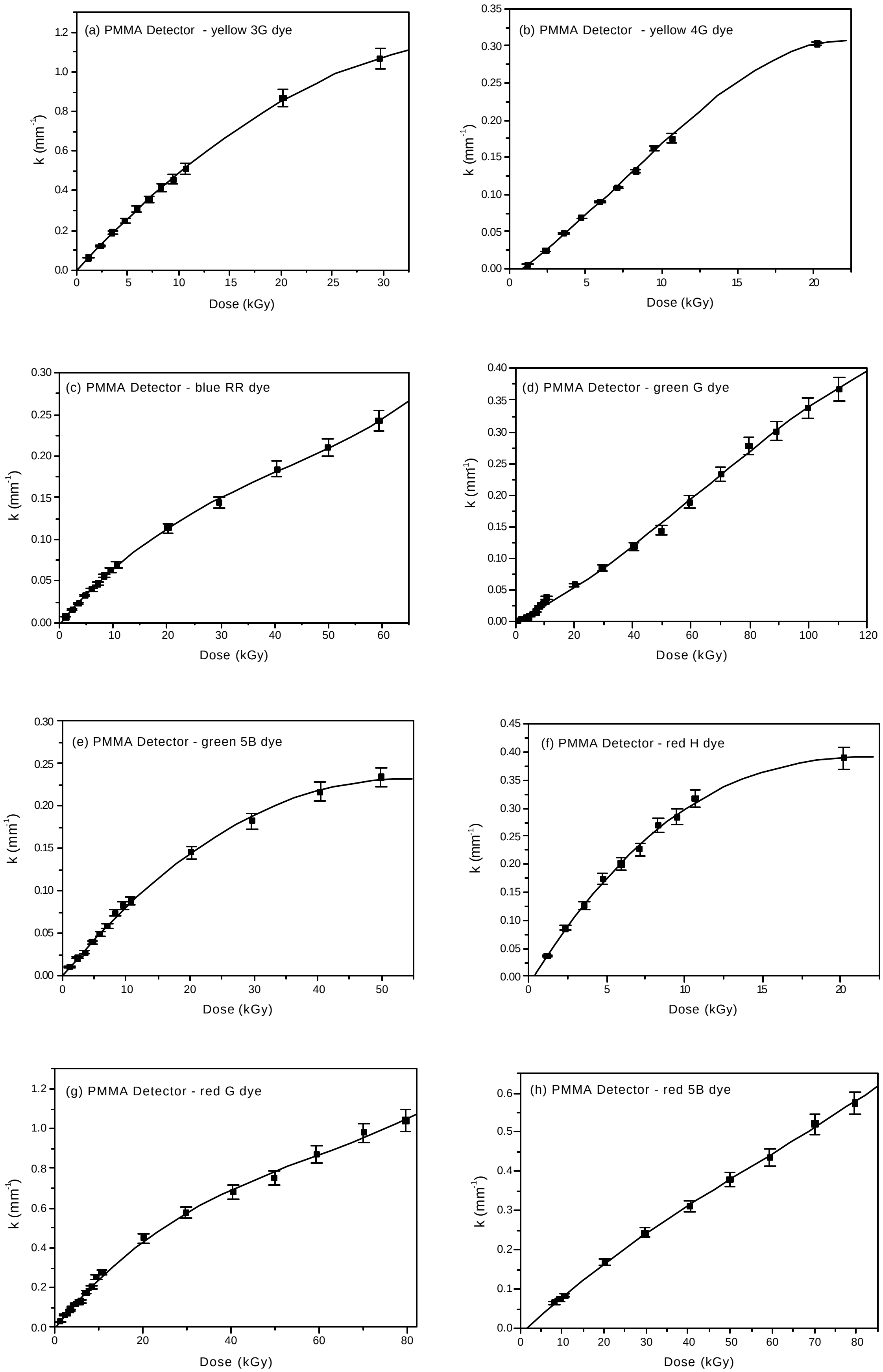
(a) yellow 3G λ=300 nm.
(b) yellow 4G λ=353 nm.
(c) blue RR λ=450 nm.
(d) green G λ=528 nm.
(e) green 5B λ=405 nm
(f) red H λ=620 nm.
(g) red G λ=397 nm.
(h) red 5B λ=415 nm.

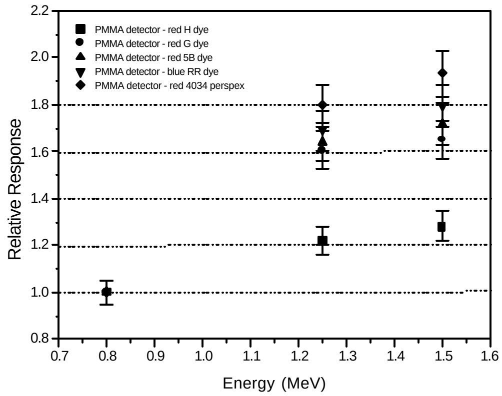
Fig. 2 – Optical absorption energy dependence of response of dyed PMMA detectors of 2.4 mm thickness for electron beam irradiations.

(a) red H (λ=620 nm); red G (λ=397 nm); red 5B (λ=415 nm), blue RR (λ=450 nm) and red 4034 perspex (λ=640 nm).

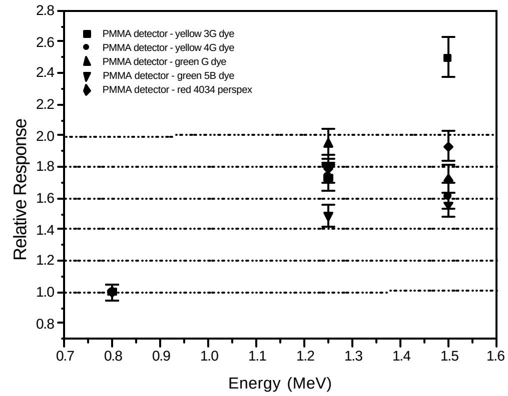
(b) yellow 3G (λ=300 nm); yellow 4G (λ=353 nm); green G (λ=528 nm), green 5B (λ= 405 nm) and red 4034 perspex (λ=640 nm).

Fig. 3 – Optical absorption energy dependence response as a function of thickness of un-dyed PMMA detectors with electron beam energy.

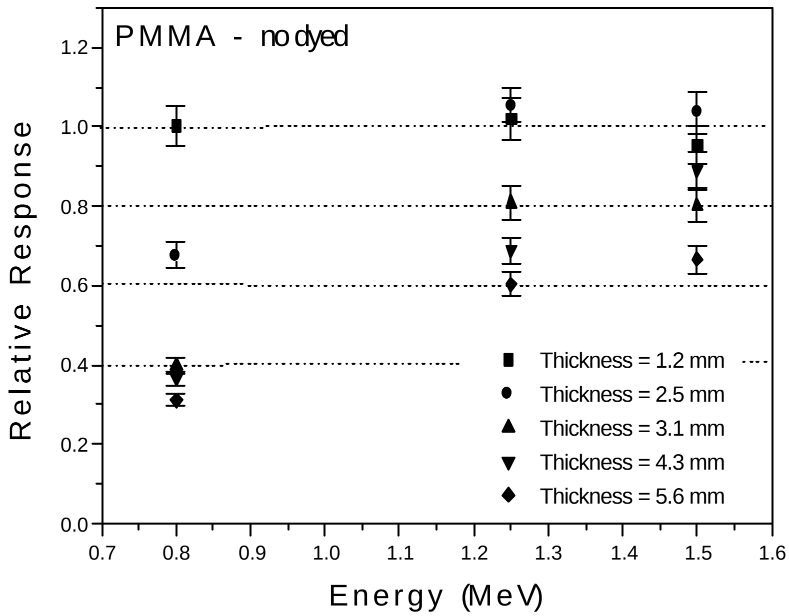

(a) PMMA Detector - yellow 3G dye
k (mm-1)
Dose (kGy)
(b) PMMA Detector - yellow 4G dye
k (mm-1)
Dose (kGy)
(c) PMMA Detector - blue RR dye
k (mm-1)
Dose (kGy)
(d) PMMA Detector - green G dye
k (mm-1)
Dose (kGy)
(e) PMMA Detector - green 5B dye
k (mm-1)
Dose (kGy)
(f) PMMA Detector - red H dye
k (mm-1)
Dose (kGy)
(g) PMMA Detector - red G dye
k (mm-1)
Dose (kGy)
(h) PMMA Detector - red 5B dye
k (mm-1)
Dose (kGy)


PMMA detector - red H dye
PMMA detector - red G dye
PMMA detector - red 5B dye
PMMA detector - blue RR dye
PMMA detector - red 4034 perspex
Relative Response
Energy (MeV)

(a)


PMMA detector - yellow 3G dye
PMMA detector - yellow 4G dye
PMMA detector - green G dye
PMMA detector - green 5B dye
PMMA detector - red 4034 perspex
Relative Response
Energy (MeV)

(b)


PMMA - no dyed
Relative Response
Energy (MeV)
Thickness = 1.2 mm
Thickness = 2.5 mm
Thickness = 3.1 mm
Thickness = 4.3 mm
Thickness = 5.6 mm
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6