Dosimetric Systems Developed in Brazil for the Radiation Processes Quality Control

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Abstract. In order to apply new technologies to the industrial processing of materials aiming economy, efficiency, speed and high quality, ionizing radiation has been used in medicine, archeology, chemistry, food preservation and other areas. For this reason, the dosimetry area looks for improve current dosimeters and develop new materials for application on quality control of these processes. In Brazil, the research in the dosimetry area occurs with great speed providing many different dosimetric systems. The chemical dosimetry is the most used technique in routine dosimetry, which requires fast and accurate responses. This technique involves determination of absorbed dose by measuring chemical changes radiation induced in the materials. Different dosimetric systems were developed at IPEN for application on radiation process quality and all of them present excellent results; the low cost of these materials allows a more effective dose control, therefore, a larger area or volume can be monitored.

1 Introduction

Accurate and precise dosimetry is essential to quality control in industrial and medical radiation processing. There are several materials that can be used as dosimeter, and, researchers around the world are constantly looking for materials to characterize them as dosimeters. Many routine dosimeters are commercially available, such as, *Gafchromic* MD-55 and HD-810 (ISP); *CTA FTR-125* (Fuji Film); *FWT 60.20* (Far West Technology); Perspex (Harwell) between others, and, its main specifications are shown in **Table 1** [1,2,4,8,9].

The dosimeters consist on thin plastic films colorless or dyed, named radiochromic films in reason of the involved effects in the direct color change by the absorption of energetic radiation without requiring latent chemical, optical, or thermal development or amplification. These color change can be measured by spectrophotometric techniques by change in the optical absorbance of the film for specific wavelengths and can be related with absorbed dose [2].

Radiochromic films offer excellent spacial resolution of dose variations and the films have been used to measure the isodose curves from irradiation sources. These polymeric films due its ruggedness, long shelf-life stability, ease of handling and convenient analysis by spectrophotometers are usually made available in large reproducible batches.

Table 1: Main specifications of commercial radiochromic dosimeters [1,2,4,8,9]

Material	*Film thickness*	*Dimension*	*Composition*	*Measuring Wavelength (nm)*	*Usable Dose Range (kGy)*
CTA FTR - 125	125 µm	Width:8 mm length: 100 m / reel	Cellulose triacetate; Triphenyl phosphate	280	5 - 300
Red 4034 Perspex	3 ± 0.55 mm	Width: 11 mm Length: 30 mm	Dyed polymethylme-thacrylate sheets	640	5 - 50
Gafchromic HD - 810	107 µm	8" x 10" sheet film	Single-sided active layer on polyester	615 675	0.01 – 0.4
Gafchromic MD - 55	-----	several	Double active layers laminated between polyester film substrate	615 675	0,002 – 0,1
FWT 60.20	0,05 mm	10 x 10 cm	Aminotriphenyl-methane dye on nylon base	510 605	0.01 – 1 0.8 - 150

Radiochromic film can also be used as a research tool, however, has many important limitations that must be considered when using it to determine the dose distribution of any experiment. Since ambient conditions may be different between calibration and practical use, variations of response with the surrounding conditions must be determined and corrected.

Radiochromic film should be calibrated using a large well-characterized uniform radiation field. The relationship between absorbed dose and film response can be plotted as a curve, often known as a calibration curve and determinate a minimum and maximum useful dose range.

However, for use in Brazil these dosimeters are imported with high cost and unfeasible to a routine control in processing facilities.

In reason of the found difficulties to use imported dosimeters, in the High Doses Dosimetry Laboratory of IPEN are being studied polymeric materials commercially available in Brazil and the obtained results are promising, since, a radiochromic dosimeter produced in Brazil similar to the Perspex-Harwell is now available for use in industrial facilities and other materials marketed nationally for different purposes are being characterized as dosimeter [5-7].

The analyzed materials in this work were: polycarbonate (*PC*), fluoropolymer (*PTFE*) and polymethylmetacrylate (*PMMA*); they are thermoplastic polymers, i.e., becomes pliable, plastic and melt when heated. The samples were provided by Policarbonatos do Brasil S.A, DuPont Brasil and TC Acrylics, respectively. In the **Table 2** are shown some physical characteristics of these polymers [3,5-7,10].

Table 2: Commercial polymers physical characteristics

Property	*Polycarbonate (PC)*	*Fluoropolymer (PTFE)*	*Polymethylmethacrilate (PMMA)*
Density (g/cm^3)	1.20	2.17	1.19
Maximum work temperature (^oC)	120	260	100
Glass transition temperature (^oC)	150	27	100

2. Experimental

The dosimeter consists of a piece of polymeric film of dimensions 3 x 1 cm^2 that was cut of the original sheets. The films require special handling to avoid errors associated with exposure to light and humidity. The polymethylmethacrylate films were sealed in labelled sachets made of aluminium foil/paper/polyethylene laminate and the others dosimeters were packing into dark and closed recipient. In the **Table 3** are presented the analyzed materials and its respective original dimensions.

Table 3: Analysed polymers available in the national market

Material	*Thickness*	*Dimensions*
Polycarbonate (PC)	3.0 mm	2 m x 1 m
Polymethylmethacrylate		
PMMA - Dyed Macrolex® Yellow 3G	2.4 mm	
PMMA - Dyed Macrolex® Yellow 4G	2.4 mm	
PMMA - Dyed Macrolex® Blue RR	2.5 mm	
PMMA - Dyed Macrolex® Green G	2.5 mm	2 m x 1 m
PMMA - Dyed Macrolex® Green 5B	2.4 mm	
PMMA - Dyed Macrolex® Red H	2.1 mm	
PMMA - Dyed Macrolex® Red G	2.4 mm	
PMMA - Dyed Macrolex® Red 5B	2.4 mm	
Fluoropolymer		
Homopolymer tetrafluoroethylene *PTFE*	200 µm	
Copolymer of PTFE with hexafluoropropylene *FEP 1000 C*	250 µm	290 mm x
Copolymer of PTFE with perfluoroalkoxy *PFA 500 CLP*	125 µm	210 mm

To ensure that irradiation is performed under conditions of electron equilibrium the dosimeters were placed between enough thicknesses of PMMA sheets.

The dosimeters were irradiated in a calibrated Gammacell 220 source. Optical absorption measurements were all recorded before irradiation and after irradiation using a Shimadzu UV-2101PC spectrophotometer set at selected wavelengths, which corresponded to maximum changes induced by radiation. Each data point represents an average of three measurements and the error bars are the standard deviation of the mean (1σ).

The ambient conditions effects such as light, humidity and temperature in the detectors response in function of the time exposition were evaluated.

3. Results and Discussions

The absorption spectrum is primarily determined by the atomic and molecular composition of the material, and is unique to that material. In the **Figure 1** are showed spectra of polymeric films that can be used to identify the material.

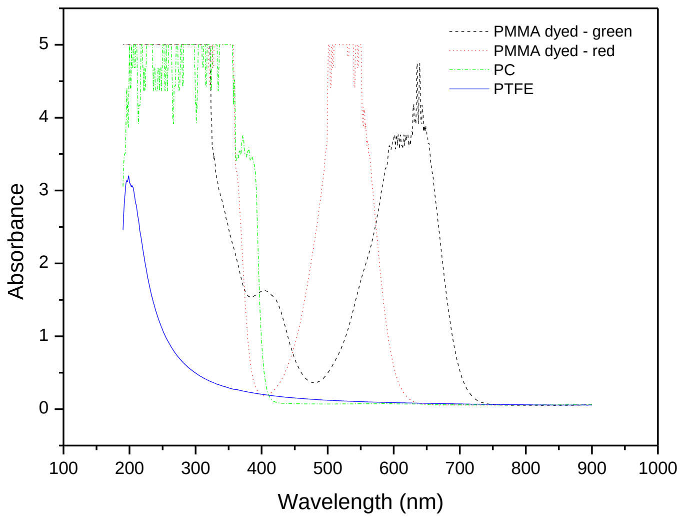


Fig. 1 : Polymeric films absorption spectra

Radiation induced changes in the films absorption spectra can be determined and related to the radiation absorbed dose. In the **Fig. 2** are showed absorption spectra of *PC* films between 300 and 600 nm irradiated with radiation absorbed doses between 1 and 150 kGy. The behavior of the studied films (*PMMA* and *PTFE*) is similar to the PC presented; there is a linear relation between absorbed dose and the film response.

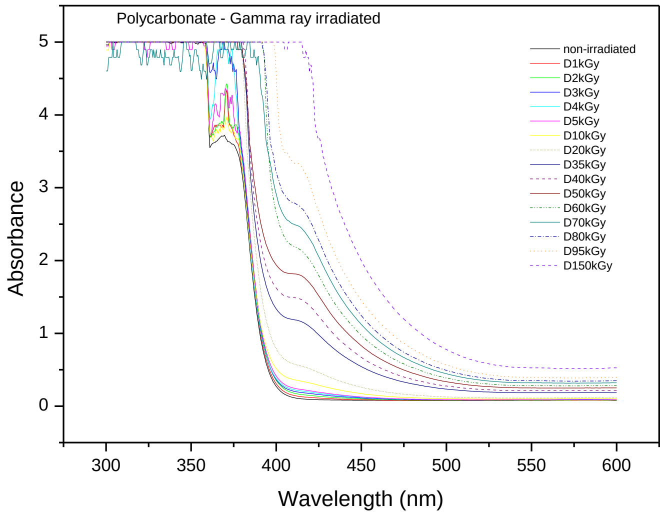
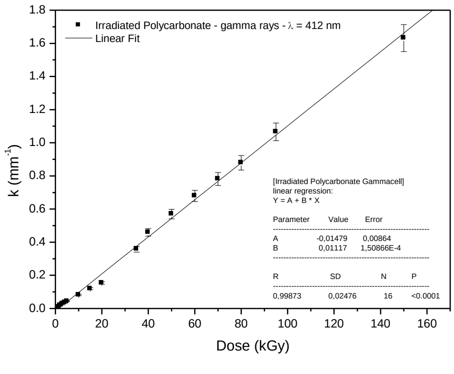
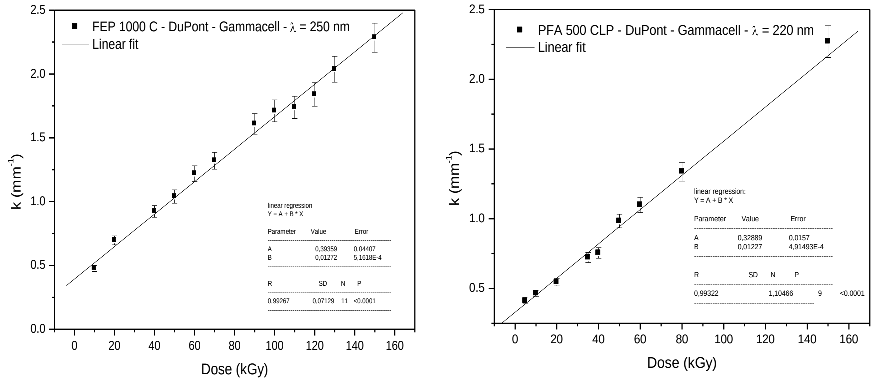


Fig. 2 : Absorption spectra of *PC* films non-irradiated and irradiated

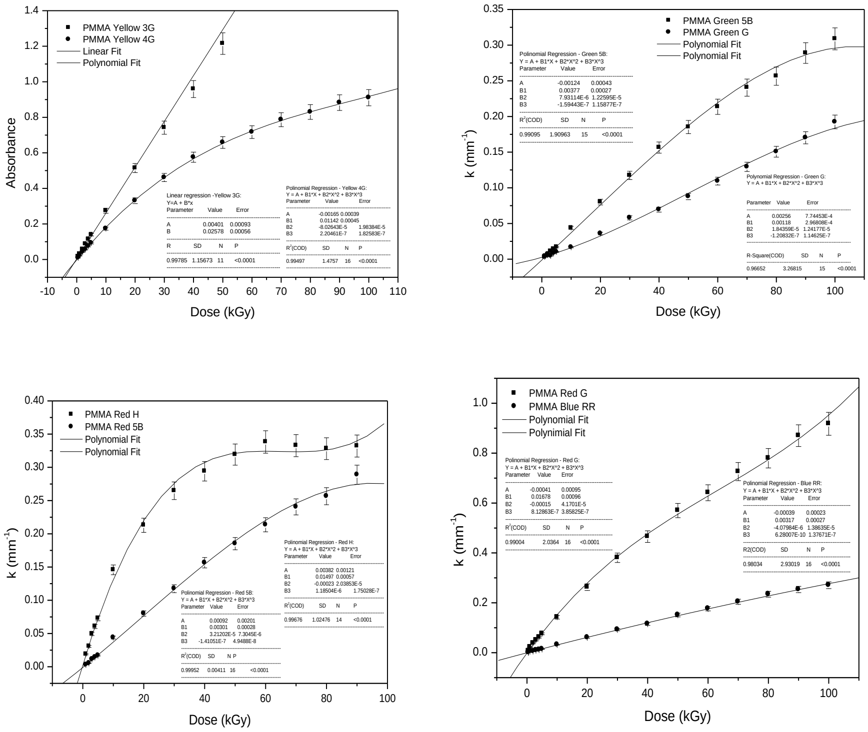
In the **Fig. 3** the relationship between absorbed dose and film response was plotted as a curve to (*a*) *PC*, (*b*) *PTFE* and (*c*) *PMMA* films; the minimum and maximum dose limits and the useful dose range in a specific wavelength were determined, **Table 4**.



(a)



(b)



(c)

Fig. 3: Dose – response of gamma irradiated of polymeric materials

Table 4: Useful dose range of the studied polymeric materials

Detector	*Wavelength (nm)*	*Minimun Dose (kGy)*	*Maximum Dose (kGy)*
Polycarbonate (PC)	412	4.5	150
Polymethylmethacrylate			
PMMA - Dyed Macrolex® Yellow 3G	300	<0.5	40
PMMA - Dyed Macrolex® Yellow 4G	353	5	80
PMMA - Dyed Macrolex® Blue RR	450	1	100
PMMA - Dyed Macrolex® Green G	528	1	100
PMMA - Dyed Macrolex® Green 5B	405	5	100
PMMA - Dyed Macrolex® Red H	620	5	50
PMMA - Dyed Macrolex® Red G	397	5	100
PMMA - Dyed Macrolex® Red 5B	415	5	100
Fluoropolymer			
FEP 1000 C	250	nd	150
PFA 500 CLP	220	nd	150

The results obtained when dosimeters are exposed in different ambient conditions showed that care must be taken for readout of radiochromic film. The PC response is more stable in low temperature. The detectors must be sealed in sachet to prevent risks and exposure to light and humidity when stored, and during the measures should avoid direct contact with ambient light.

4. Conclusion

This study revealed significant changes in optical response of several types of radiochromic film when exposed to gamma radiation.

The radiochromic films are used as a simple and inexpensive tool to accurately measure and to analyze the dose distributions. Other advantages of the radiochromic film include its high precision, large measurement range, dose-rate independence, ease of handling and no processing requirement.

This dosimetric systems are especially useful to measure absorbed dose distribution in routine monitoring.

Acknowledgemets

This work was supported by CAPES, the Brazilian government entity focused on human resource training. The authors are grateful for financial support of CAPES, CNPq and FAPESP.

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