

## DOSIMETRY WITH RADIOCHROMIC MATERIALS IN ACCELERATED ELECTRONS FIELDS – HIGH DOSE PROCESSES

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### ABSTRACT

Radiation dosimetry, i.e., the measurement of the dose, is fundamental in all irradiation processes, being recommended for laboratories and industrial scale irradiation plants for routine control, so that any irradiation can be in agreement with the established patterns in the process of dose measurement. This work is dedicated to the study of some of the main dosimetric characteristics of radiochromic films as FWT-60.20 (colored nylon), HD-810 (colored plastic) and Sunna (colorless plastic). The possibility of applying these materials in routine dosimetry in an electron accelerator, whose energy varies from 0,8MeV to 1,5MeV and the current from 0,3mA to 15mA was verified. The experiments were concluded in a JOB 188 - Dynamitron Inc. accelerator installed at the Radiation Technology Center, IPEN-CNEN/SP. Analyzed topics involve the best wavelength for optical reading, calibration curves, and influence of the environmental conditions as well the evaluation of film response to different electrons energies. The results were considered positive since the films can be applied for absorbed doses determination in routine irradiations processes in this type of electron accelerator.

Keywords: dosimetry, radiochromic films, accelerated electrons

### I. INTRODUCTION

Electron beam (EB) facilities are of great importance in many fields of materials processing in industrial scale. This technology is steadily growing in Brazil and is applied for different purposes: research and development as well as for commercial services. Some of the applications of EB facilities compete with other technologies using a non-radiative media for materials bulk changes.

The facilities of high-power electron beams are designed to obtain effects that somehow introduce special characteristics as cross-linking in insulating for threads and electric cables, sterilization and disinfection of medical products and nutritious goods and other procedures linked to research and development.

The dosimetry allows the control of the irradiation processes and it makes possible to determine, precisely and accurately, the dose when products or raw materials are irradiated before their use in several areas of human life.

Radiochromic films have been used as dosimeters since the 1960s and can easily be acquired abroad. In the next decades the industry produced these materials with more advantages because of some coloring additives such as leukometoxid triphenilmethanes, that enlarged the interval of radiation detection, and pararosaniline that gives a dose sensibility below 1kGy. In this last case, the films

can be used mainly in irradiations of materials that are under research or biological compounds. In general the irradiations could be required for a wide range of doses.

The dose distribution in the product depth is improved by choice of the appropriate energy of the EB. This requires the thickness of the product to be less than the range of electron penetration or by giving two-sided irradiation when the product is thick. The difficulty of calculating the absorbed dose with accuracy depends on the electron energy, EB and the geometry of the sample. When electrons of initial energy  $E$  pass through the titanium (Ti) window and are scattered in the air gap, they lose part of their energy. Consequently the energy of incident electrons impinging on the first layer of the products is quite lower. It was observed elsewhere that by increasing the energy, the electrons are less influenced by multiple scattering deflections as normally occurs in the low energy interval, for different air gaps [1].

The aim of this work was to characterize three radiochromic films in order to verify if they can be used in dose control for materials that undergo EB irradiation.

## II. EXPERIMENTAL

**Electron accelerator.** The irradiations were carried out at the JOB-188-Dynamitron Inc. accelerator installed at the Radiation Technology Center in IPEN-CNEN/SP.

**EB parameters.** The accelerator generates monoenergetic electrons by means of a rectified transformer type manufactured by Radiation Dynamics Inc. The EB has a normal incidence on a medium placed on the conveyor.

The energy of the electrons can be varied between 0,5MeV and 1,5Mev and the current between 0,01mA and 25mA. The beam can be scanned in such a way as to cover the maximum irradiation area of 2.5cm by 112cm. The distance between the Ti window and the conveyor is about 21cm but there exist a refrigeration device installed near the window that reduces free space to 12cm. The conveyor traveled back and forth under the irradiation window perpendicular to the direction of the scanned EB, as can be seen in Fig.1.

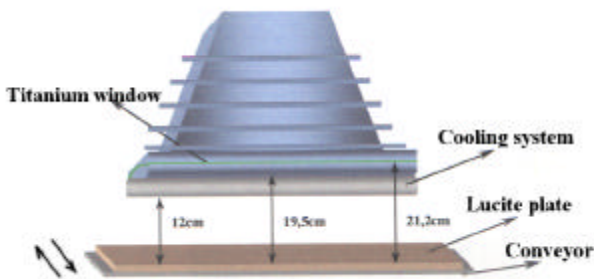


Figure 1. Electron accelerator irradiation parameters [2].

The accelerator energy was fixed at 1.5MeV, the current at 3mA and the EB scanning width at 100cm. Conveyor velocity was fixed at  $3.36\text{m}\cdot\text{min}^{-1}$ . In tests where the response of films to lower electron energies was evaluated, it was fixed at 0.8MeV and 1.2MeV for the same current and width.

The substrate used to support the films was a Lucite® plate that can absorb all the electrons that eventually passed through the materials. This substrate avoids the backscattering effect that subsequently could give rise to higher electron interaction with the irradiated materials giving rise to higher dose values.

**Films.** Three types of radiochromic films were used: FWT-60.20 (colored nylon), HD-810 (colored plastic) and Sunna (colorless plastic).

**FWT-60-20.** The Far West Technology Inc. produces this colored nylon and recommends it for doses between 0.01kGy and 150kGy. The film has an average thickness of 0.05mm, density of  $1.4\text{g}\cdot\text{cm}^{-3}$  and nominal precision of 3%. The absorbance should be read at  $\lambda = 605\text{nm}$  for doses between 0.01kGy and 1kGy and  $\lambda = 510\text{nm}$  for doses between 0.8 and 150kGy.

**HD-810.** The producer is the ISP Technologies Inc. and the film comes in sheets of 20cmx25cm with 0.11mm thickness. The recommended doses interval ranges from 0.1kGy to 50kGy. Optical absorption values should be obtained at  $\lambda = 400\text{nm}$  for doses from 1kGy to 50kGy,  $\lambda = 500\text{nm}$  from 0.1kGy to 5kGy and  $\lambda = 580\text{nm}$  from 0.01kGy to 1kGy.

**SUNNA.** This radiochromic film was put into the market in 1999 by Sunna Systems Corporation and is recommended for doses between 10kGy and 100kGy. Its average thickness is 0.25mm and the optical absorption should be taken at a wavelength between 240nm and 250nm.

**Spectrophotometer.** For optical absorption measurement, in the visible region of the spectrum, a Shimadzu UV1601 spectrophotometer was used. This device was connected to a PC with a special program that allows the automatic analysis of resulting data.

**Samples preparation.** The films that come in sheet forms were cut into strips 0.8cm width and 4cm long. Each film was identified and its initial optical absorption  $A_0$  was determined. After the irradiation, the absorption was measured at a determined wavelength resulting in a value A. Afterwards the thickness x was measured (in mm or cm). Each value of the results presented in this paper represents a medium value for three samples.

The doses at each point of the conveyor were determined by means of a graphite calorimeter [3]. The calibration curve was constructed by using dose (kGy) vs. optical absorption coefficient ( $\alpha$ ). The optical absorption coefficient  $\alpha$  can be represented by the correlation:

$$\alpha = (A - A_0) / x$$

Where:  $A_0$  = optical absorption before the irradiation; A = optical absorption after the irradiation; and x = thickness (in mm or cm).

**Ambient influence.** There were made two types of experiences: one to observe if the films are sensitive to the laboratory daylight and fluorescent lamps and the other to observe its sensitivity to temperatures above  $30^\circ\text{C}$ .

After the experiment of exposure to ambient light it was observed that the FWT 60.20 radiochromic film is very sensitive and that it should be manipulated preferably in darker areas of the laboratory without fluorescent light. Consequently it must be wrapped in a thin aluminium foil to avoid light exposure during the irradiation.

Temperature influence was also tested since when high doses are required a long time irradiation is performed and it was observed that even a good ventilation of the irradiation camera exist, for each 10kGy the temperature rise about  $3^\circ\text{C}$  in the neighborhood of the samples position on the conveyor. Therefore among the three films only Sunna should be manipulated with care in such conditions.

Dose detection lower limit. Using 20 non-irradiated films for which the medium absorption coefficient was measured the dose detection lower limit and the standard deviation ( $\sigma$ ) were obtained. The value was calculated throughout the expression:

$$\bar{a} \pm 3\sigma$$

### III. RESULTS

The films lower limits of detectable dose are: 1.277kGy for FWT-60.20; 1,433kGy for HD-810 and 0,048kGy for Sunna film.

Since usually the doses more requested are above the inferior limit of detection, the calibration curves were built in function of this information. The calibration curve can be divided into two or three parts depending on the film type to maintain the linearity.

Fig. 2 shows the calibrations curve for FWT-60.20 in the dose interval from 6kGy to 100kGy. This behavior continues up to 150kGy.

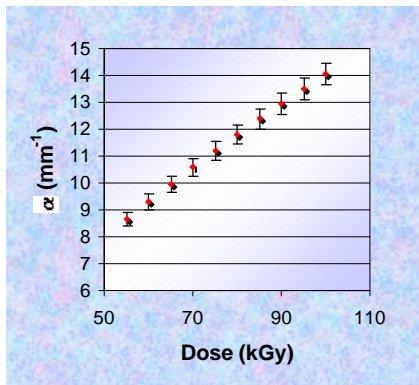


Figure 2. Calibration curve for FWT-60.20 irradiated with accelerated electrons ( $E=1.2\text{MeV}$ ,  $I=3\text{mA}$ ,  $V=3.36\text{m}\cdot\text{min}^{-1}$ ,  $W=100\text{cm}$ ) in the dose interval 6kGy and 150kGy [2].

Fig. 3 shows the characteristic calibrations curve of the HD-810 film for the dose interval 6kGy to 49kGy. It is recommended that the curve be represented into two dose intervals: one from 6kGy to 25kGy and the other from 25kGy to 50kGy. This results in linear curves.

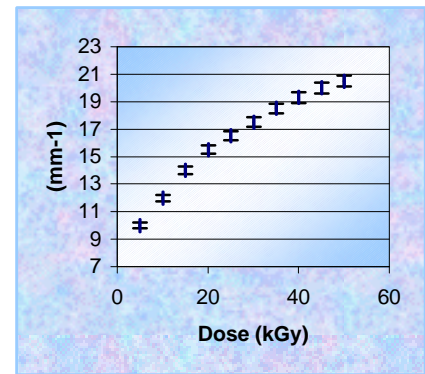


Figure 3. Calibration curve for HD-810 irradiated with accelerated electrons ( $E=1.2\text{MeV}$ ,  $I=3\text{mA}$ ,  $V=3.36\text{m}\cdot\text{min}^{-1}$ ,  $W=100\text{cm}$ ) in the dose interval 6kGy and 150kGy [2].

Fig 4 represents the characteristic calibration curve for electron irradiation of Sunna film for the dose interval 6kGy to 97kGy.

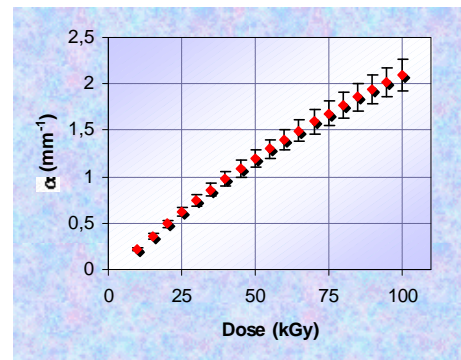


Figure 4. Calibration curve of Sunna film irradiated with accelerated electrons ( $E=1.2\text{MeV}$ ,  $I=3\text{mA}$ ,  $V=3.36\text{m}\cdot\text{min}^{-1}$ ,  $W=100\text{cm}$ ) in the dose interval 6kGy to 100kGy [2].

Temperature and ambient light influences are show in TABLE 1.

TABLE 1. Temperature and Ambient Light Influence on Optical Absorption.

	FWT-60.20	HD-810	Sunna
Temperature (60min in 50°C)	0,1%	>50%	None
Light (Daylight and fluorescent lamps)	Intense	None	3%

The calibration curves of the studied films for lower electrons energies have a fluctuation of about 8,0% for the FWT-60.20, 7,5% for the HD-810 and 3-4% for Sunna film.

#### IV. DISCUSSION AND CONCLUSIONS

Some precautions, as the correct choice of the film type for the requested dose interval, material on which the film will be attached, width of the electron beam etc, are very important for the absorbed dose calculation since the calibration curve can be modified due to those items.

The calibration curves need to be built for each situation especially when the parameters of the accelerator are changed. For instance, a variation of 2% and 6% in the dose value happens when, maintaining other parameters as energy, current and conveyor velocity, the width of the beam is modified from 60cm to 100cm or 120cm respectively.

When Sunna film was irradiated in the accelerator it was observed that the wavelength for optical reading could not be that recommended by the manufacturer. The suggested value can be used only when the film undergoes gamma irradiation.

The material over which the film lies is very important because materials different from Lucite<sup>®</sup>, wood or glass, cause the electron backscattering and could result in super-estimated dose values.

When films are irradiated in different heights, between the conveyor and the titanium window, it is not observed any significant dose value fluctuation. The fluctuation must remain under the nominal precision of the film.

It should never be forgotten that a light shielding material, as a very thin aluminium foil, to avoid dose value increasing must cover the FWT-60.20 film.

According to the results, all the three radiochromic films can be used for dosimetric purposes in electron beams irradiation processes of the same energy and current intervals such as these that can be obtained with the JOB-188 accelerator.

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