

# Reflection spectrometry analysis of irradiated GAFCHROMIC XR type R radiochromic films

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## Abstract

The absorption spectra of the GAFCHROMIC<sup>®</sup> XR type R radiochromic film measured with reflectance spectroscopy have been investigated in order to analyze the dosimetry characteristics of the film. Like the XR type T film, this film features two peaks in its absorption spectrum, approximately at 676 and 618 nm, whose intensities increase with increasing absorbed dose. When the main absorption peak at 676 nm is used, the XR GAFCHROMIC type R film is approximately 1.4 times more sensitive to radiation doses in the 0–5 Gy range than the XR type T film. The major difference of the films of this type from the original GAFCHROMIC film products is the opaque backing material, which permits only reflected, but not transmitted, light measurements as a means of analysis. A yellow dye is used as the opaque backing to enhance the visible color change for qualitative assessment of the delivered dose. The XR type R radiochromic film in combination with reflection spectroscopy can provide accurate assessment of doses.

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## 1. Introduction

GAFCHROMIC<sup>®</sup> radiochromic film (manufactured by International Specialty Products—ISP—Wayne, NJ, USA) has been extensively used over the past few years in industrial and therapeutic applications (Butson et al., 2003; Vuong et al., 2003; Meigooni et al., 1996; Devic et al., 2004). ISP has recently developed radiochromic films suitable for lower energy X-rays, which are used in diagnostic X-ray machines, computer tomography, and superficial/orthovoltage therapy. An example of such

films is GAFCHROMIC XR type R (Thomas et al., 2003). This film has found a niche in diagnostic cardiology procedures, where an estimate of radiation exposure is required during fluoroscopic procedures (Giles and Murphy, 2002). This advancement was primarily due to a change in the sensitive emulsion constituents, which resulted in higher dose sensitivities, and a modification of the film construction, which made possible reflective assessments of absorbed doses. A basic qualitative analysis can be performed visually by comparing the film color with colors on dose charts. However, in order to assess the dose more accurately, one needs to scan the film with a reflective scanning spectrometer, which measures the absorption at a chosen wavelength or band. In this paper, we describe the dependence of the absorption spectra of the

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GAFCHROMIC XR type R film measured with a highly accurate reflectance spectrophotometer on the absorbed dose.

## 2. Materials and methods

GAFCHROMIC XR type R radiochromic film (Batch No. J0123XRR) was used. The films were irradiated in a  $30 \times 30 \times 30$  cm solid water phantom (Constantinou et al., 1982). The irradiations were performed with a Pantak Therapax 300DXT orthovoltage machine, and doses between 0 and 8 Gy were given using a 100 kVp X-ray beam with a 3.1 mm Al added filtration (HVL = 3.5 mm Al, mean energy  $\sim 50$  keV) according to the IAEA protocol (IAEA, 1987). The films were perpendicular to the central axis of the beam at a distance of 30 cm from the focal spot of the X-ray tube. The radiochromic films were handled with the precautions outlined in the recommendations of TG-55 (Niroomand-Rad, 1998). The films were stored and processed at  $22 \pm 2^\circ\text{C}$ , which reduced temperature-dependent variations of their absorption spectra (Meigooni et al., 1996).

A GAFCHROMIC Type R film is comprised of two substrates, one of which is transparent and the other is opaque (white). The transparent polyester substrate contains a yellow dye. One of the purposes of the yellow dye is to enhance the visual contrast of the chromatic changes that occur when the film is exposed to radiation. The other purpose is to protect the active layer from UV and blue light and, thereby, make the film even more tolerant of handling in the light. The opacity of the white substrate in the Type R media is provided by a baryta filling. The polyester film substrates are approximately  $97 \mu\text{m}$  thick. GAFCHROMIC XR dosimetry media employ the same active component as is used in the

MD-55 films, but include a proprietary high atomic number ( $Z$ ) material in addition. The thickness of the active layer in the type R film is approximately  $15 \mu\text{m}$ .

The absorption spectra were measured with an Avantes AvaSpec-2048 reflectance photo spectrometer (Avantes, Eerbeek, Netherlands). It is a fiber optic spectrometer with a 300 lines/mm grating. The operational range is 327–1100 nm, and the instrument has a FWHM resolution of 2.4 nm. Measurements can be made in a scope mode (see below), absorbance mode, or transmission mode. The scope mode refers to a raw, reflected light intensity reading. The transmission mode relates to the “transmittance” at pixel  $n$  utilizing a dark current and reference spectrum and is given by

$$T_n = 100I/I_0,$$

where  $I$  is the net intensity of the sample film and  $I_0$  is the net intensity of the reference film. The absorbance mode relates to the absorption of light within the film with the absorbance at pixel  $n$  given by

$$A_n = -\log(T_n).$$

The reference spectrum is the reflectance spectrum of an “unirradiated” film. Subtracting this spectrum from the spectrum of the film after irradiation provides net absorption as a function of wavelength (nm).

## 3. Results and discussion

Fig. 1 shows the net absorption spectra for GAFCHROMIC XR type R films in the ultraviolet, visible and low infrared (350–1100 nm) regions. The results are given for films irradiated to doses from 0 to 500 cGy with the 100 kVp X-ray beam. As can be seen from the reflectance measurements, the spectra feature the same pronounced peaks located approximately at 676 and 618 nm as the spectra of MD-55-2 films that we

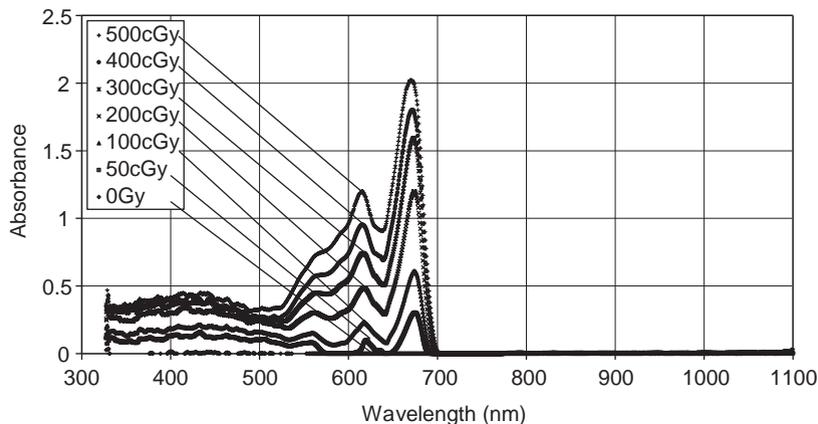


Fig. 1. Visible reflectance absorption spectra of a GAFCHROMIC XR type R radiochromic film exposed to 100 kVp X-rays.

published before (Butson et al., 2003). Similar spectra of the MD-55-2 GAFCHROMIC films, but with less pronounced absorption peaks, have been seen, also with reflectance spectroscopy, by Fusi et al. (2004). They have published percentage reflectance values over the visible wavelengths, but the peaks that they have observed are flattened. This may be a result of a larger FWHM used for the analysis, which should have caused a bigger averaging. The main visible difference between the results by Fusi et al. for the MD-55-2 film and our data for the XR type R film is the effect of the opaque yellow backing substrate for the XR type R film, which produces a larger reflectance and a visible enhancement of the color change in reflectance measurements. Another major difference is the much higher sensitivity of the XR type R film as compared with the MD-55-2 and XR type T films. The average net absorption per unit of absorbed dose for the former is approximately 0.4 AU/Gy in the 0–5 Gy region, whereas the corresponding characteristic for the XR type T film at 676 nm, the same X-ray spectrum and beam energy is only 0.3 AU/Gy (Butson et al., 2003). It is acknowledged that these numbers will depend on the wavelength of the analysis and the bandwidth of the readout light source. Nevertheless, theoretically, XR type R films could be up to twice as sensitive in the reflection mode as the XR type T films in the transmission mode, because the length of the optical path in reflectance measurements is effectively doubled. When the main absorption peak is used, the dose response function is best fitted by a second-order polynomial. For other wavelengths, alternative functions with varying degrees of non-linearity are more appropriate.

#### 4. Conclusion

GAFCHROMIC XR type R reflective radiochromic film has been developed for use specifically in diagnostic and therapeutic applications, such as fluoroscopic procedures and superficial therapy, which use low-energy, kilovoltage, X-rays. The change of its reflective color with absorbed dose makes it suitable for accurate dose measurements. A reflective analysis of this film produces an absorption spectrum similar to the spectra obtained in transmission measurements of other GAFCHROMIC film varieties. However, the sensitivity of

dose measurements with the XR type R films in the reflection mode is higher.

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