INTERNATIONAL SPECIALTY PRODUCTS

A BUSINESS UNIT of ISP

GAFCHROMIC® EBT2

SELF-DEVELOPING FILM FOR RADIOTHERAPY DOSIMETRY

February 19, 2009

1361 Alps Road Wayne • NJ 07470 • 973- 628-3831/-3531

Revision 1

INDEX

1.0 INTRODUCTION

GAFCHROMIC® EBT2 dosimetry film has been developed specifically to address the needs of the medical physicist and dosimetrist working in the radiotherapy environment. Like its predecessors, EBT2 film is self-developing, but with several improvements in ISP radiochromic film technology. Some of these improved features include:

- EBT2 contains a yellow "marker" dye; a feature that minimizes response differences caused by coating anomalies.
- Formulated to be energy independent from 50 keV into the MeV range
- More tolerant of light exposure
- Less prone to damaged edges when cut

2.0 CONFIGURATION AND STRUCTURE OF GAFCHROMIC® EBT

GAFCHROMIC® EBT2 is made by combining a clear, polyester over-laminate with the active film coating. The substrate of the active film is clear 700 gauge (175 micron) polyester. The substrate is coated with an active layer film, nominally 30 microns thickness, over which a topcoat, nominally 5 microns, is applied. The over-laminate, 200 gauge (50 micron) polyester with approximately 25 microns of pressure-sensitive adhesive, is bonded to the coated side of the active film. The configuration of EBT2 is shown in Figure 1.

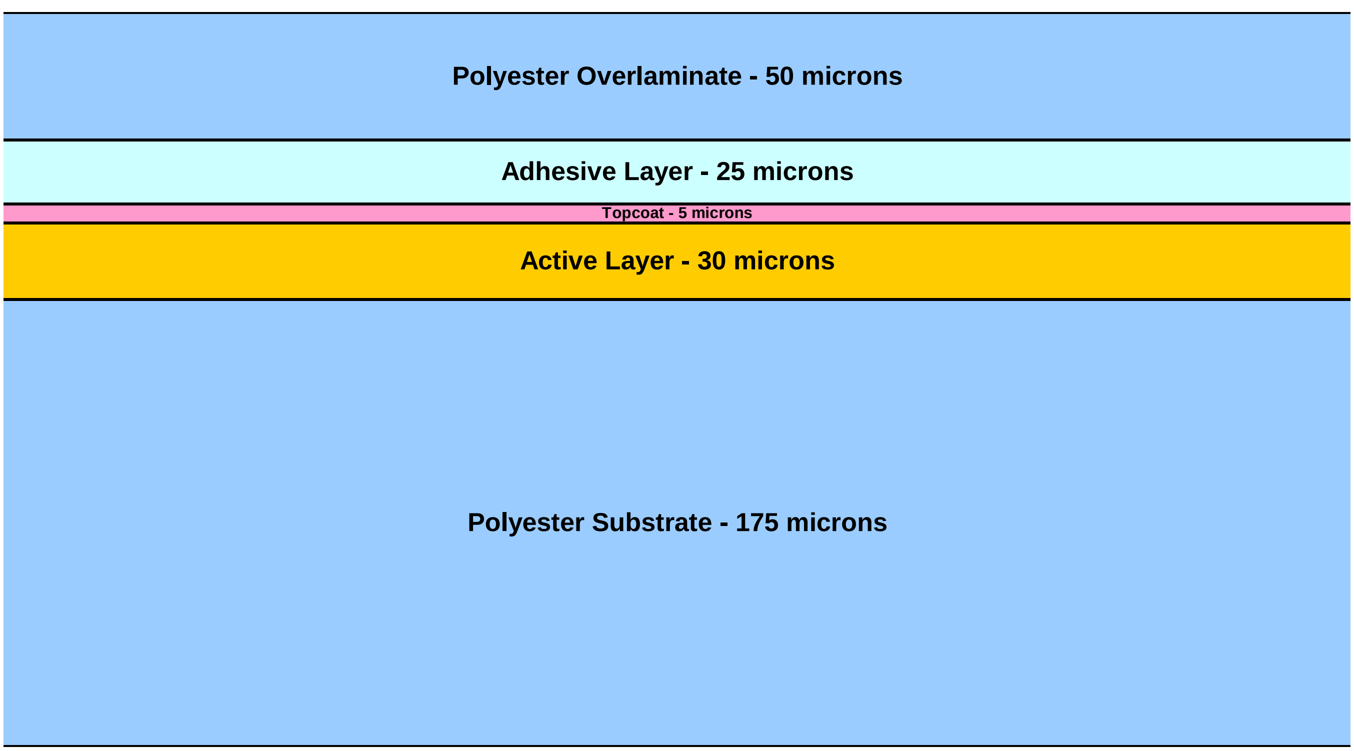

Figure 1: Configuration of GAFCHROMIC® EBT2 Dosimetry Film

The over-laminate protects the active layer/topcoat from mechanical damage as well as from the effects of water and other liquids. Like the previous EBT film, the new version can be immersed in water for short periods (see Section 3.1.1) with the water only penetrating 1-2 mm and affecting film performance only along the edges.

The active layer contains the same radiation-sensitive component used in the earlier EBT version. However, the binder in the active layer and the topcoat has been changed from a natural polymer, gelatin, to a synthetic polymer. This change is beneficial in several ways. For example, the use of a synthetic polymer provides a high degree of surety of the atomic composition of the active layer. It also makes it less likely that a change in trace contaminants originating from the source of the natural polymer leads to performance issues. These factors are important in controlling properties like energy dependence that are known to be sensitive to the presence of elements with high atomic numbers. The synthetic polymer also makes it possible to apply the active material as a single layer coating.

The most obvious difference between EBT2 and its predecessor is the yellow color of the film. This arises from the presence of a dye incorporated in the active layer. The principal purpose of this dye, referred to as a marker dye, is to establish a reference against which the response of the film can be measured; resulting in a net response that is independent of small differences in the thickness of the active layer. In Section 3.4.2.1 it is described how the dye response can be measured and used to correct for subtle differences in the thickness of the active layer.

The EBT2 film product is identified by a lot number inscribed on the outside of the product box. The expiration date, 30 months from the date of manufacture, is also printed on the box.

EBT2 dosimetry film is a Class 1 Medical Device (equivalent to radiographic x-ray film) and is manufactured under a cGMP quality system.

3.0 GAFCHROMIC® EBT2 DOSIMETRY FILM CHARACTERISTICS

This high sensitivity radiochromic film has been designed for the measurement of absorbed dose of high-energy photons used in IMRT. The film has been designed for use with doses of up to approximately 800 cGy with the marker dye used to make the film response independent of small thickness differences. The film can be used to measure higher doses up to at least 50 Gy without utilizing the marker dye feature. The usefulness of the marker dye feature has not been fully validated at doses >8 Gy.

EBT2 film has been designed also to have a photon response that is nearly energy independent from about 50 keV into the MV range. This has been accomplished by the careful adjustment of the atomic composition of the film. ISP believes that the responses of EBT2 to 100 keV and 6 MV photons are within 10%. The level of performance is still under study, and since it has not been fully validated, users are advised to conduct their own tests.

3.1 STORAGE AND HANDLING

GAFCHROMIC® EBT2 film has been designed to be handled in interior room light. The incorporation of the yellow marker dye is beneficial in this regards because it makes the new film about 10X less sensitive to room light than the original EBT product. This makes the EBT2 film considerably more forgiving if it is inadvertently left out for 24 hours. Nevertheless, to assure the highest level of performance it is good practice to keep exposed and unexposed film in the dark when not in use. Exposure to sunlight should be avoided since the film may darken rapidly.

The expiration date of the EBT2 film assumes that the film is stored in the dark at room ambient temperature (20º-25ºC) away from radiation sources. However, as with conventional radiographic films, the best practice would be to store the film at, or below, refrigerator temperature (2º-8ºC). The shelf-life of the film is 2.5 years when stored at room ambient temperature. Brief exposures (e.g. <1 min.) to temperatures up to 70ºC, or more prolonged exposure (e.g. <1 day) at temperatures of 50ºC should not affect the performance of EBT2 film.

Unlike the original EBT film the EBT2 product is not interleaved with a tissue paper. The new film is laminated with a solvent-free pressure sensitive adhesive, replacing the aqueous-based adhesive used in the earlier product. At the time the product is packaged the moisture content of the EBT2 film is substantially lower than the old EBT film, and the interleaving paper is unnecessary.

3.1.1 Water Immersion

The active layer in EBT2 film is protected by two polyester substrates. Since diffusion of water through polyester is extremely slow, it is possible to immerse the film in water without causing permanent damage. Because the edges of the film are not sealed, water can penetrate the active layer. However, the diffusion is slow enough that the film can be immersed for a few hours, and only the active layer within a few mm of the exposed edges should be affected. The areas affected are visible because they become an opaque, milky-white as water is slowly absorbed. It is advised not to attempt dosimetry in the areas where water had diffused. Figure 2, below, shows the rate at which water penetrates the film as judged by the milky-white appearance at the edges.

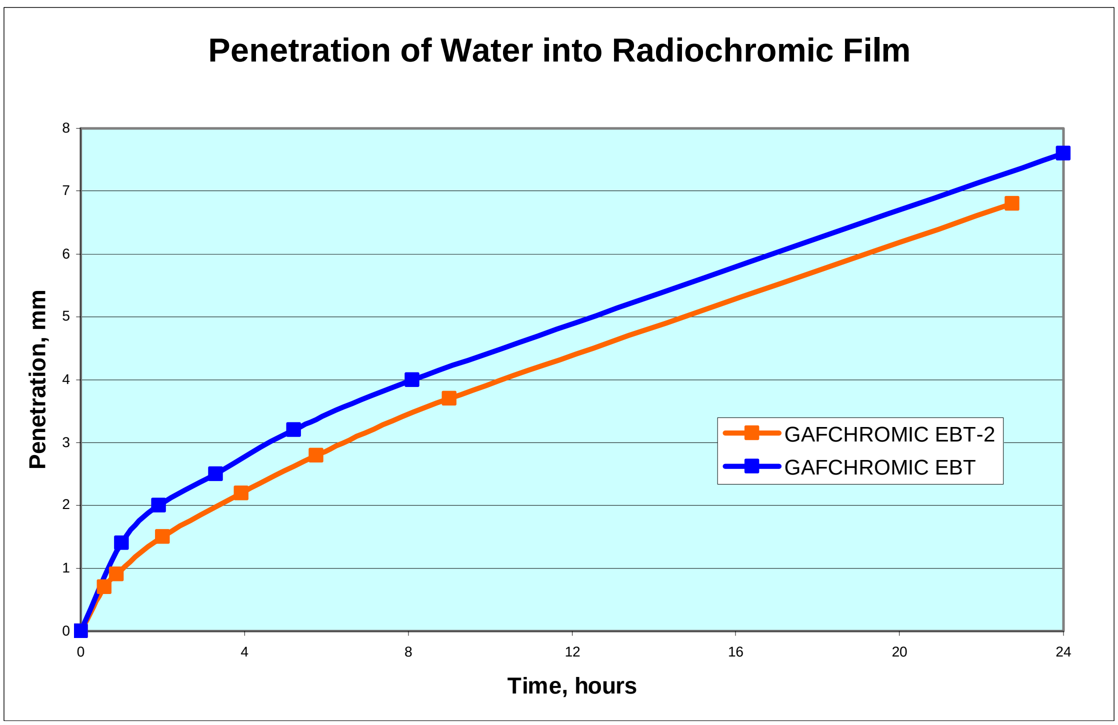

Figure 2: Penetration of Water into the Edges of EBT and EBT2 Films

3.1.2 Cutting Film

GAFCHROMIC® EBT2 dosimetry film can be easily cut to required shape and size. It is preferable to use scissors or a guillotine cutter, but with care good results can also be obtained by using a scalpel or a sharp knife. The use of the over-laminate with pressure sensitive adhesive has made the EBT2 film considerably less prone to de-lamination at the cut edges than the original EBT film.

If film is cut it is advisable to mark the pieces to indicate their orientation with respect to the original sheet as discussed in Section 3.4.2.3.

3.1.3 Marking Film

Since the outer layers are polyester, the film can be marked with a pen without damaging the active layer. If the marks interfere with scanning, or other measurement, they can be removed with a soft rag, or tissue, moistened with an appropriate solvent, e.g. alcohol, acetone. Most solvents should not damage the polyester. If in doubt, test a corner of the film with the solvent to observe whether it causes harm.

3.2 FILM CONSTRUCTION

GAFCHROMIC® EBT2 is made by laminating an active film coating to a clear over-laminate film with a pressure sensitive adhesive. The active layer, nominally 30 microns, is coated on a 175 micron, clear polyester substrate, and over-coated with a surface layer, or topcoat, nominally 5 microns thick. The over-laminate consists of a 50 micron clear polyester substrate with an acrylate-based, pressure sensitive adhesive of 25 micron nominal thickness.

3.3 ACTIVE COMPONENT

The active component in GAFCHROMIC® EBT2 is the same as that in previous GAFCHROMIC® Dosimetry Films including EBT, RTQA, XRQA, and XR-RV2 films. Details of the atomic composition of the layers in EBT2 film are contained in the Table 1 Section 5.0. Note that the composition in this table is given in terms of atom %, not weight %.

3.4 MEASUREMENT

GAFCHROMIC® EBT2 dosimetry film can be measured with transmission densitometers, film scanners or spectrophotometers. When the active component is exposed to radiation, it reacts to form a blue colored polymer with absorption maxima at about 636 nm and 585 nm. However, to the human eye, the exposed film appears green owing to the presence of the yellow marker dye in the active layer. Figure 3 shows the absorbance spectrum of the active component of EBT2 film after exposure to radiation. Following exposure, peak absorption of the active component is at about 636 nm, with a secondary peak at about 585 nm. Consequently the response, upon irradiation, of dosimetry films containing this active component is enhanced by measurement with red light.

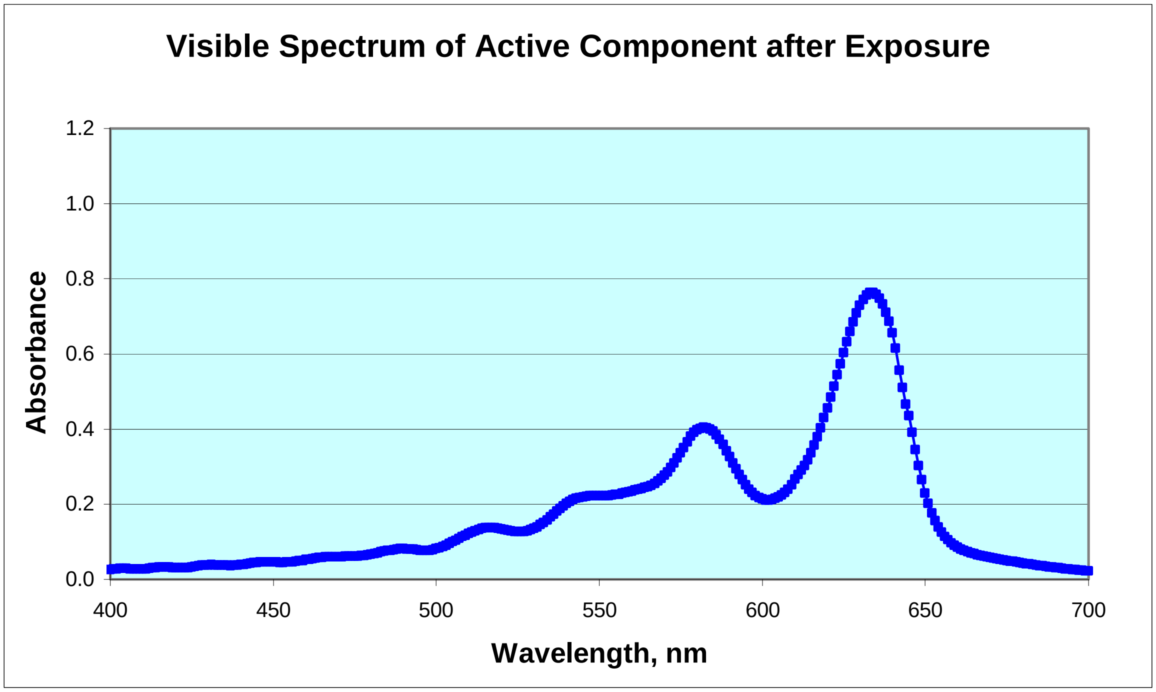

Figure 3: Absorption Spectra of the Active Component in EBT2 Film After Irradiation

Figure 4 depicts the absorption spectra of GAFCHROMIC® EBT2 film before and after irradiation. Before irradiation the active component produces little response as evidenced by the low absorbance at 636 nm. The prominent feature in the spectrum of the unexposed film is the absorbance peak at approximately 420 nm resulting from the presence of the yellow marker dye.

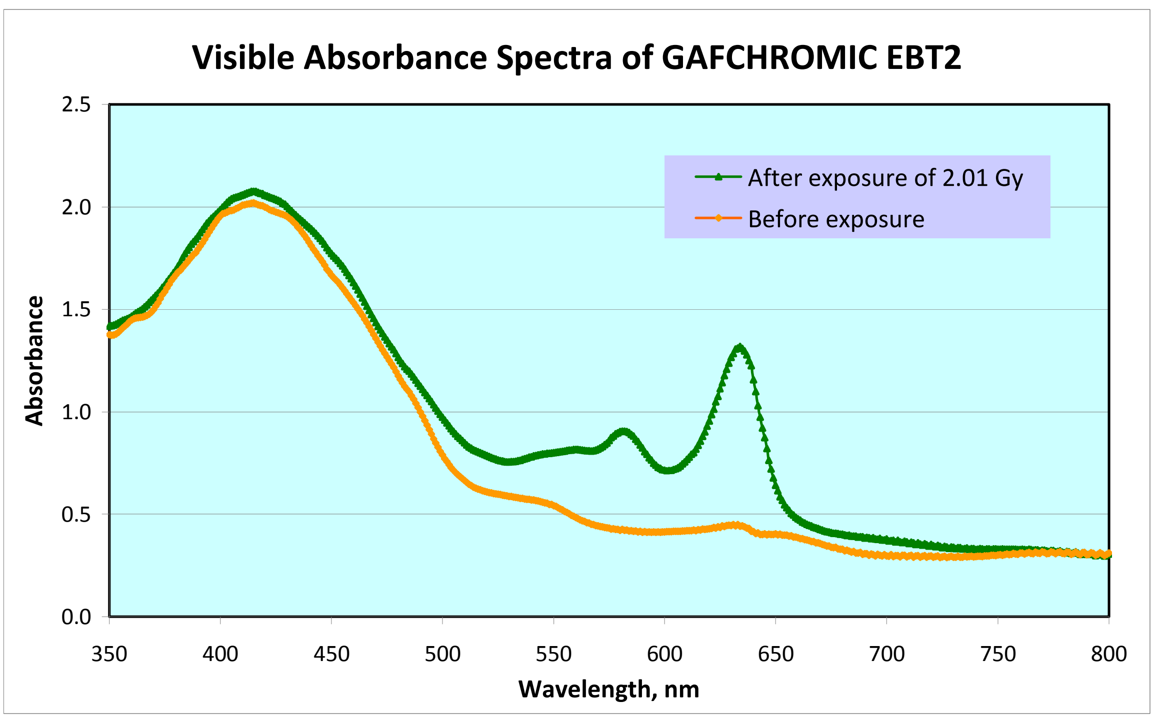

Figure 4: Absorption Spectra of EBT2 Film Before and After Irradiation

Figure 5 shows absorption spectra of a coating containing only the marker dye and the binder. The strong absorption maximum at about 420 nm is due to the marker dye. The absorbance at wavelengths greater than about 510 nm is due to the polyester substrate and binder. At the wavelengths >550 nm where the active component in the film produces its strongest response the marker dye has no contribution to the absorbance. It is also evident from Figure 5 that the spectrum of the marker dye/binder is the same before and after exposure to a dose of 50 Gy. This demonstrates that the marker dye and binder are unaffected by radiation exposure at doses up to at least this level.

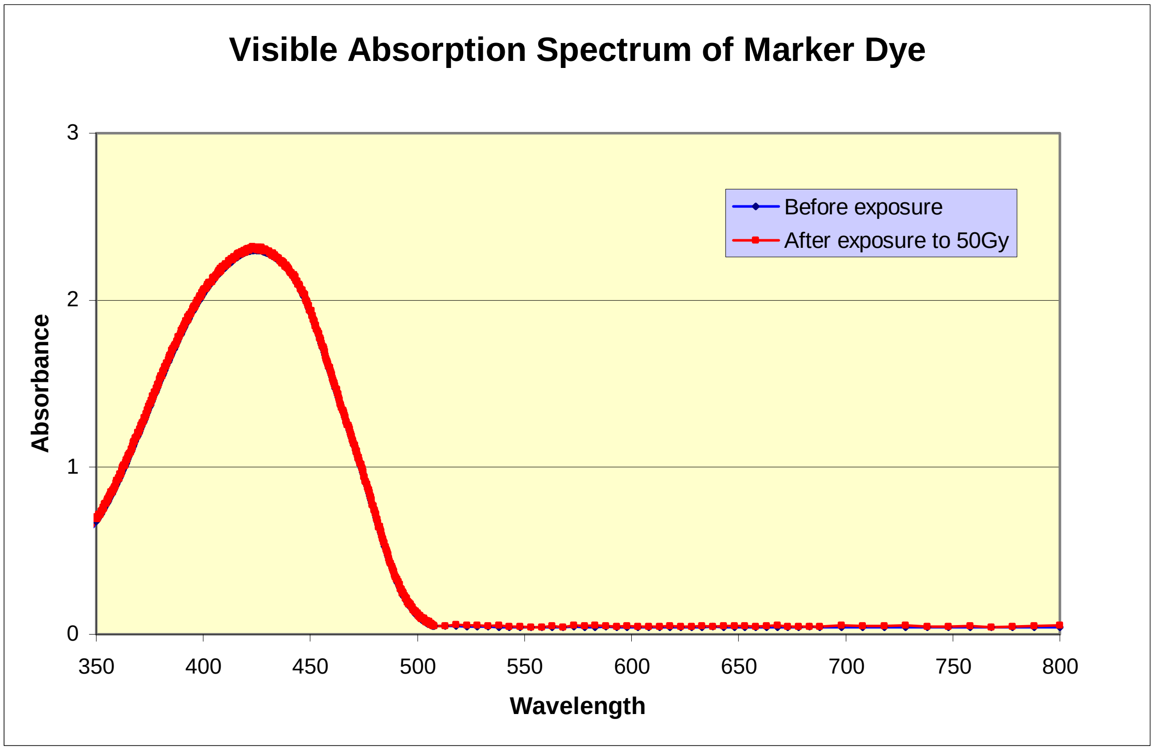

Figure 5: Absorption Spectra of the Marker Dye and Binder Before and After Irradiation

With reference to Figure 4, the most obvious change in the spectrum of EBT2 film after irradiation is the appearance of absorbance maxima at about 636 nm and 585 nm. These absorbance peaks are due to the active component and the formation of a dye polymer. The absorbance peak at about 420 nm due to the marker dye remains after exposure, but the peak absorbance is slightly increased. This increase is due to the contribution from the active component after irradiation. The secondary absorbance peak at 585 nm has a tail on the low wavelength side that extends down below 400 nm and into the ultraviolet.

3.4.1 Densitometry

Transmission densitometers measuring the visible density are commonly employed in measuring film and are suitable for measuring EBT2 film. However, the response could be significantly increased by using a red filter while making densitometer measurements. A narrow band pass filter with central wavelength at about 636 nm would be ideal. is ideal. *NOTE: If you would like to use such a filter we are pleased to recommend one upon request.*

3.4.2 Scanning

EBT2 film can be read with a film scanner or digitizer. The best response is obtained if the film is scanned in transmission, and the spectral response of the scanner is matched to the absorbance of the film. An example of this is the Vidar DosimetryPRO Advantage (Red) scanner with the red LED light source. The LEDs in this scanner have maximum emission at a wavelength close to 630 nm, and thus well matched to the spectral maximum in EBT2 film. Other examples are ***rgb*** color scanners, e.g. Epson, Microtek, Canon, HP designed to scan color films in the red, green, and blue bands of the visible spectrum. Once an ***rgb*** scan has been obtained the user can extract the information from the red color channel where the active component in EBT2 film produces its maximum response. When purchasing a flatbed scanner be sure that it scans in transmission mode. With some scanners, e.g. Epson Expression 10000XL Graphic Arts, it is necessary to purchase a transparency adapter to obtain transmissions scans.

HeNe laser scanners (Lumisys, Array, Molecular Dynamics) can provide the highest response with EBT2 film because the laser has a wavelength of about 633 nm, nearly at peak absorbance. However, the coherent light of the laser scanners can produce artifacts caused by the interaction of polarized light with the film. If you are considering using a laser scanner please contact us for our recommendations.

3.4.2.1 Use of Marker Dye Response to Compensate for Differences in Coating Thickness

GAFCHROMIC® EBT2 dosimetry film contains a yellow marker dye. When an ***rgb*** color scanner is used to digitize the EBT2 film, the marker dye makes it possible to obtain a response signal that is proportional to thickness, and thereby to compensate for small non-uniformities in the film. Because the dye is yellow, it produces a strong signal in the blue color channel, but no signal in the red color channel. Since the marker dye has no response in the red channel it does not interfere with the signal produced by exposure of the active component. However, the active component does produce a small response in the blue color channel, and this must be accounted for before the response from the marker dye can be used to compensate for thickness differences.

The use of the marker dye takes advantage of an inherent feature of an ***rgb*** scanner, that is, its ability to acquire scan measurement simultaneously in three color channels. Not only does this save the necessity of separate scans for each channel, but it also ensures that the response values from all the color channels are in close spatial registration.

ISP plans to offer a new version of FilmQA software to automate the application of the marker dye, to enable the user to apply thickness difference corrections in a straightforward manner after acquiring ***rgb*** scan images of calibration film(s) and measurement film(s). The procedure is similar to the following in which the calculations are to be automated within the upcoming software.

1. Scan all films in ***rgb*** mode on a color scanner. It is assumed that there is one, or more, calibration films plus at least one “measurement film”, i.e. a film on which you would like to make dose measurement.

2. Split out the red and blue color channels for all images

3. Convert the red and blue images from raw scanner values to “density” values to create images in density space - $I_{\text{red, density}}$ and $I_{\text{blue, density}}$

$$\text{Density value} = -\log10(\text{scanner value}/65535)$$

4. Calculate images $I_{red:blue,\ density}$ that are the ratio of red density : blue density

$$I_{red:blue,\ density} = I_{red,\ density} / I_{blue,\ density}$$

5. Measure the images $I_{red,\ density}$ and $I_{red:blue,\ density}$ of the calibration films to get responses in the red color channel and the ratio of the red:blue channels

6. Plot the red channel density vs. the ratio of the ratio of red:blue channel density and fit to a function (a 2^{nd} or 3^{rd} order polynomial works well)

$$\text{Red channel density} = f(\text{red:blue channel density})$$

7. For each image in red:blue channel density space (calibration film and measurement film images) use the function in Step 6 to convert the red:blue channel density image, $I_{red:blue,\ density}$, into a corrected red channel density image, $I_{red,\ density,\ corrected}$

8. Re-measure the Corrected Red Image(s) for the calibration films (or recalculate the values), plot the corrected red density values vs. dose and fit to a function:

$$\text{Dose value} = f(\text{Value}_{red,\ density,\ corrected})$$

9. Use the function in Step 8 to convert the corrected red channel images, $I_{red,\ density,\ corrected}$, of the measurement films, from density values to dose values.

10. FilmQA™ software can be used to analyze the measurement images against treatment plans

3.4.2.2 Film Position on Scanner

When measuring film on most scanners, the response of the scanner is not perfectly flat over of the scan field. The differences may be up to about 2% in magnitude, and are greatest within 2-3 cm of the lateral edges of the scan field, i.e. the edges in the direction orthogonal to the scan direction. For best field flatness, it is recommended that films should be positioned in the center of the available scan area, away from the edges. It is easy to position films at the center of the scan field of a flatbed scanner, but for Vidar scanners it is helpful to set up a stop on the left side of the film feed area so that films can be fed squarely into the center of the scanner.

The field flatness of an individual scanner is consistent, and can be characterized and compensated for by obtaining a scan image of an unexposed film. The mean response value of this image is measured, and the responses of each pixel in the image are normalized to the mean value. The image to be corrected should be the same size as the normalized image, and the films should be centered at the same location of the scanner. The normalized image can then be used to correct other images for field flatness.

3.4.2.3 Film Orientation on Scanner

Vidar, Epson, and Microtek scanners are all examples of CCD scanners in which there is an extended light source, and the sensor has a linear array of detectors. When EBT2 film is digitized on this type of scanner the response is sensitive to the orientation of the film on the scanner. This can be seen in Figure 6 which shows the measured response of EBT2 dose-calibration films scanned in transmission in orthogonal directions on an Epson Expression 10000XL Photo scanner with transparency adapter. The response difference is the result of anisotropic light scattering (the anisotropic light scattering can be seen by observing the light transmitted by the film from a narrow source of illumination such as a recessed light fixture). The active component in EBT2 film is in the form of needle-like particles about 1-2 μm in diameter and 15-25 μm in length. Since the particles tend to align with their long axes parallel to the coating direction they scatter light differently in orthogonal directions.

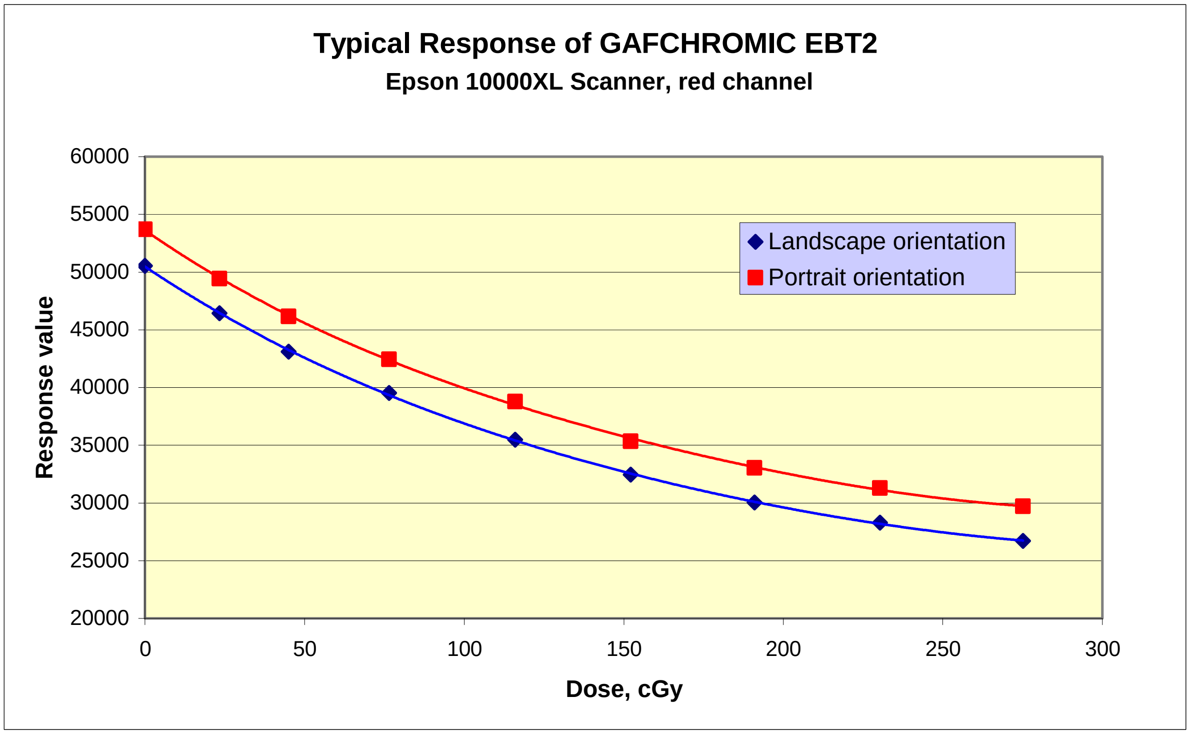

Figure 6: Response of GAFCHROMIC® EBT2 Film on a Scanner

For this reason it is critical to **always scan EBT2 films in the same orientation on Vidar, Epson, Microtek, and other CCD scanners.** Users often cut sheets of EBT2 into smaller pieces for exposure and scanning. If this is done it is essential to mark the film pieces in some way to indicate their orientation with respect to the original sheet. This way it can be certain that each cut piece is oriented in the same way on the scanner.

We recommend that scanning in landscape mode (short dimension of the film parallel to the long dimension of the scan bed) be adopted as standard practice.

4.0 PERFORMANCE DATA

The data presented in this section is provided for informative and/or guidance purposes, and is not meant to be definitive. We believe that the data is representative of all lots of EBT2 film, but users are responsible for calibrating EBT2 film response and verifying all aspects of film performance.

4.1 SENSITOMETRIC RESPONSE

4.1.1 Scanner Measurement

Figure 7 shows the response of EBT2 film to doses up to about 3 Gy as measured in transmission in the red color channel of an Epson Expression 10000XL Photo scanner and compared to its predecessor, GAFCHROMIC® EBT. The responses are virtually identical. The yellow marker dye has no absorbance in the red portion of the spectrum and therefore has no effect at all on the film response in the red color channel.

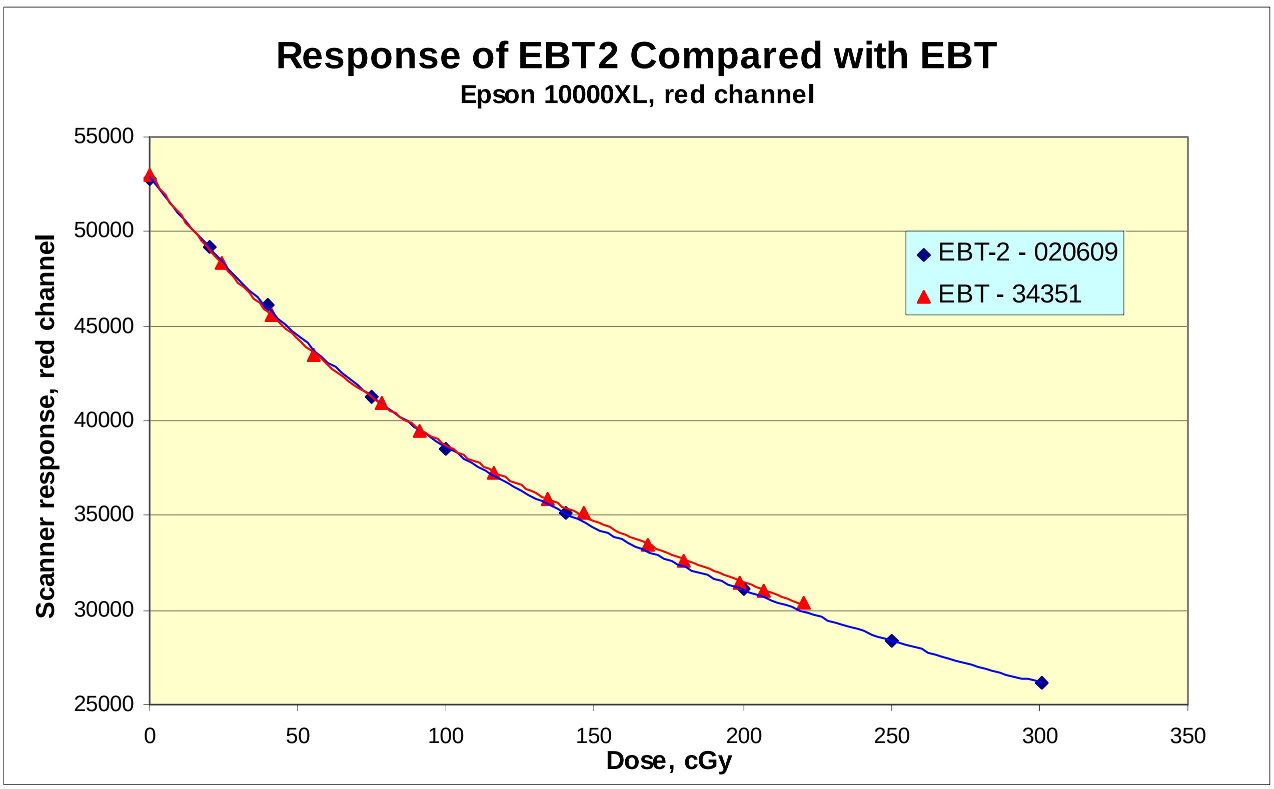

Figure 7: Responses of GAFCHROMIC® EBT2 and EBT to Doses up to 3Gy

Figure 8 shows the response of EBT2 film to high doses between 5 Gy and 40 Gy. The responses, measured in transmission on an Epson Expression 10000XL Photo flatbed scanner, were converted from raw scanner values to density values using the relationship:

$$\text{Density} = -\log_{10}(\text{Raw response value}/65535)$$

Responses were measured for all three color channels. The data in Figure 8 show that EBT2 can be used to make measurements up to doses of 40 Gy. In principal any of the color channels could be used for measurements. However, it would be preferable to use the color channel that has the greatest response gradient, i.e. the highest change in response per unit change in dose. Using this criterion it is clear that for doses >10 Gy the response gradient is greatest in the green color channel. At doses in the range 5-10 Gy the response gradients are similar in the red and green channels. The response in the blue channel has a substantially lower response gradient because of the influenced of the marker dye. This makes the blue color channel less suitable for making dose measurements.

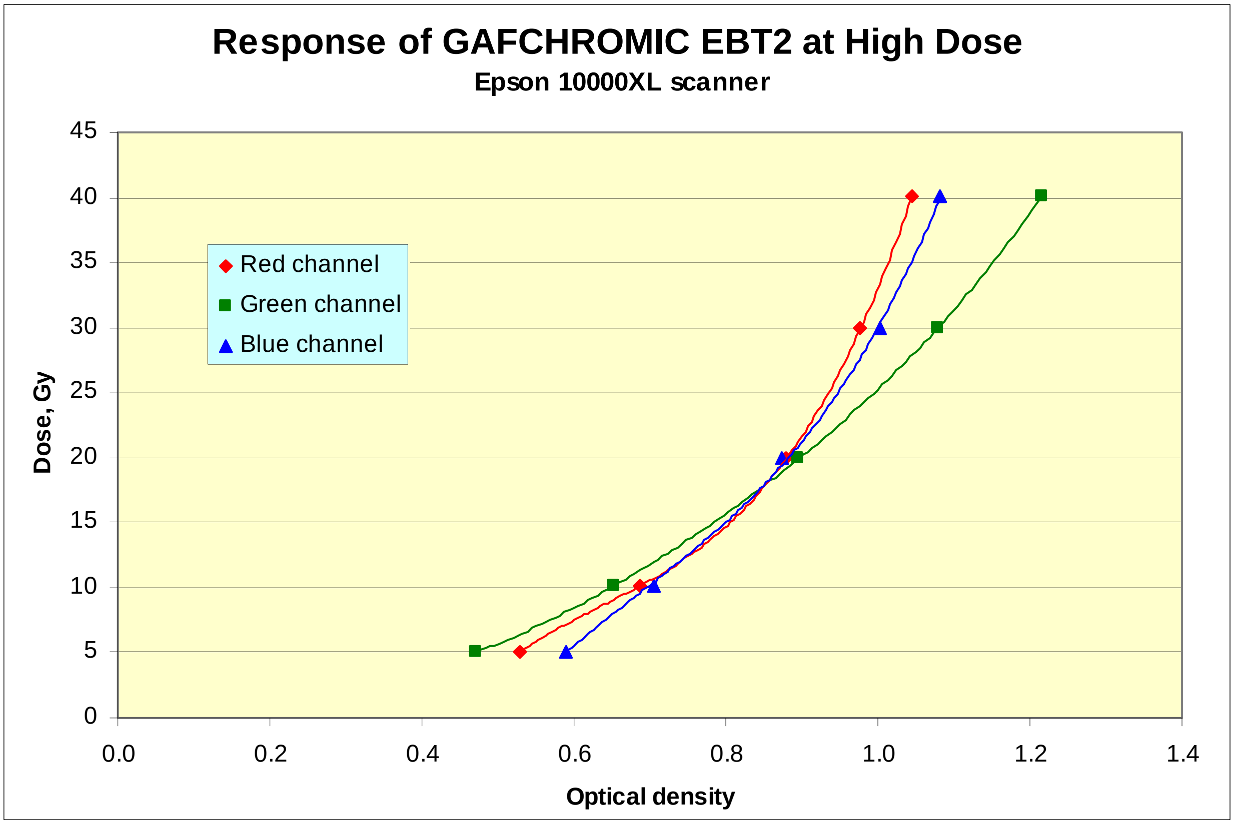

Figure 8: Response of GAFCHROMIC® EBT2 to Doses between 5Gy and 40Gy

5.0 ENERGY DEPENDENCE AND EFFECTIVE ATOMIC NUMBER

Table 1 contains details of the configuration and atomic composition of the first production batch of GAFCHROMIC® EBT2 dosimetry film with Lot Number containing the designation F020609. Note that the composition is given in atom %, not weight %. The effective atomic number of EBT2 Lot # F020609 has been calculated according to McCullough and Holmes, *Med. Phys*., 12:237-242, 1985. The Z_{eff} is 6.84.

Layer	Thickness*** microns	Approximate density g/cm2	COMPOSITION (ATOM%)									
			H	Li	C	N	O	Na	S	Cl	K	Br
Polyester film base*	50	1.35	36.4%	0.0%	45.5%	0.0%	18.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Adhesive*	25	1.2	57.1%	0.0%	33.3%	0.0%	9.5%	0.0%	0.0%	0.0%	0.0%	0.0%
Surface layer (assumes 7.5% moisture)**	5	1.2	56.9%	0.9%	25.7%	0.0%	15.6%	0.0%	0.0%	0.9%	0.0%	0.0%
Active layer (assumes 7.5% moisture)**	30	1.2	58.3%	0.8%	29.6%	0.1%	10.7%	0.0%	0.0%	0.3%	0.1%	0.1%
Polyester film base*	175	1.35	36.4%	0.0%	45.5%	0.0%	18.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Overall Composition			40.85%	0.10%	42.37%	0.01%	16.59%	0.00%	0.00%	0.04%	0.01%	0.01%

* The composition of these layers is a good faith estimate based on the manufacturer's identification of the constituents. The composition should not be used as a specification.
** The composition of these layers is a good faith estimate based on the proportion of the chemical constituents. The composition should not be used as a specification.
*** The thicknesses are approximate and are not specifications.

Table 1: Atomic Composition of GAFCHROMIC® EBT2 Dosimetry Film Lot # F020609

Radiochromic films such as GAFCHROMIC® HD-810 and MD-55 contain only carbon, hydrogen, nitrogen, and oxygen and have approximately 25% lower response to kV than MV radiation. GAFCHROMIC® EBT2 contains minor amounts of sulfur, chlorine, potassium, and bromine. In designing EBT2, trace components with moderate Z values are added to boost photoelectric absorption of keV photons. Consequently EBT2 film should exhibit better energy dependency than earlier radiochromic films. The energy dependence of EBT2, Lot# F020609, was assessed by measuring the dose response of the film with 6 MV x-rays and two kilovoltage x-ray beams. The results shown in Figure 9 indicate that under these exposure conditions the EBT2 film has a low energy dependency, showing about a 10% difference between 6 MV and keV photons.

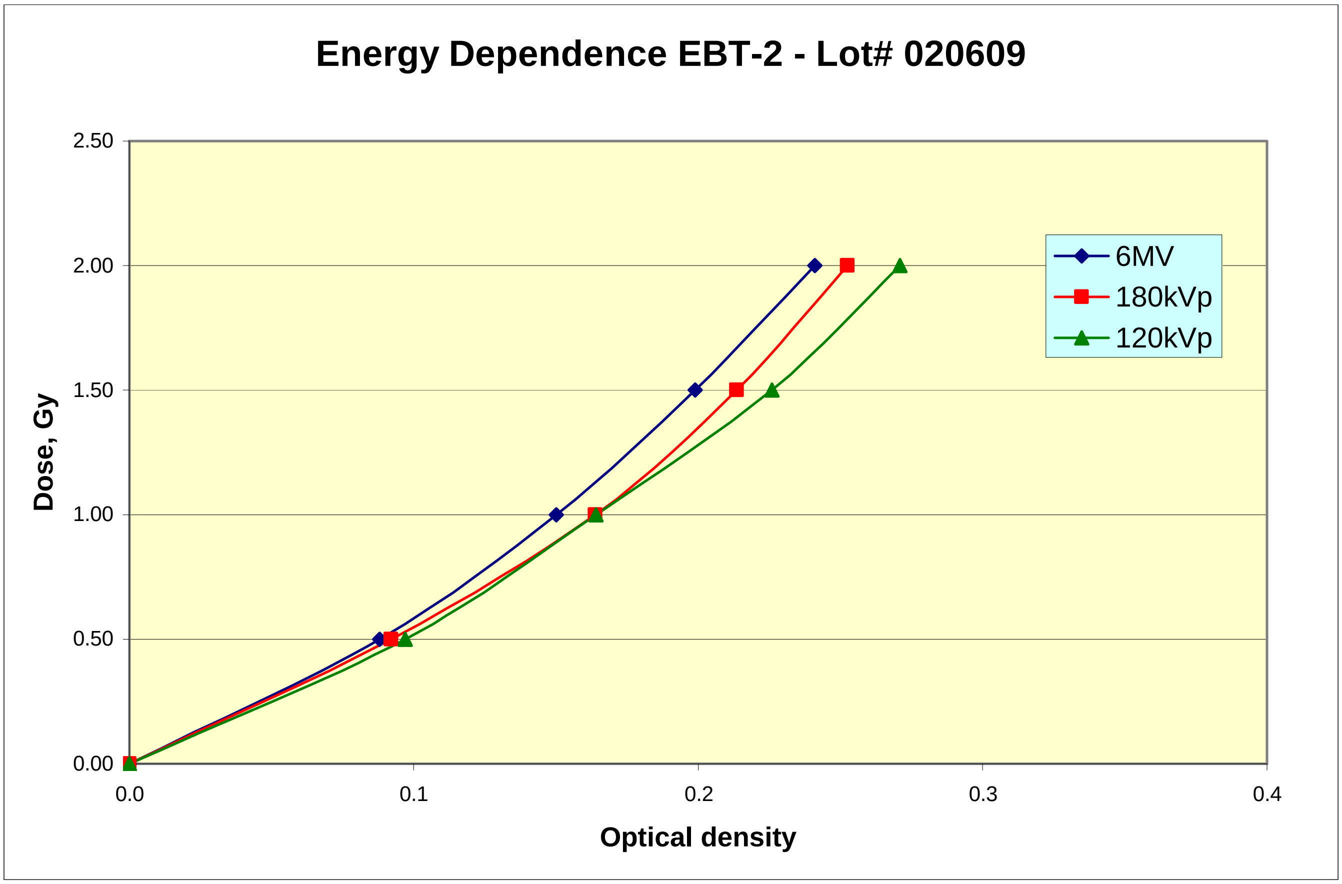

Figure 9: Energy Dependence of GAFCHROMIC® EBT2 Dosimetry Film Lot# 020609

ISP's goal is to further reduce the energy dependence of EBT2 film. To assist in this goal ISP welcomes input of performance data from all users. Using such assessments, the atomic composition of future lots of EBT2 film may be adjusted to minimize energy dependence between about 50keV photon energy and the MV range. Any adjustments made to the composition of future lots are to be published on our web site, www.gafchromic.com

6.0 POST-EXPOSURE DENSITY GROWTH

The post-exposure density growth of GAFCHROMIC® EBT2 dosimetry film has been investigated. In common with all previously available GAFCHROMIC® dosimetry films, the density of EBT2 increases with time following exposure. The data in Figure 10 illustrate the growth of EBT2 films after exposure to 0.5 Gy, 1 Gy, 1.5 Gy, and 2.5 Gy. In all cases the changes are proportional to log(time after exposure).

If EBT2 film is being used for absolute dosimetry it is important to recognize the effects of post-exposure changes and adopt a working procedure to measure all films, including calibration films, at the same time after exposure. Since the effects of post-exposure changes are proportional to log(time) it would be preferable not to measure or scan films immediately after exposure because errors in the time of measurement could have a significant effect on dose accuracy. To keep such errors small, it is suggested to wait 1-2 hours after exposure before measuring or scanning EBT2 films. If it is feasible to wait and scan films after about 24 hours, a delay of even two or three hours should have an insignificant impact on accuracy.

If an independent means for measuring absolute dose is available, and the EBT2 film is being used for relative dosimetry, then the effects of post-exposure changes in the film can be ignored. Because all post-exposure changes are in proportion regardless of dose, the films can be measured or scanned at any time after exposure.

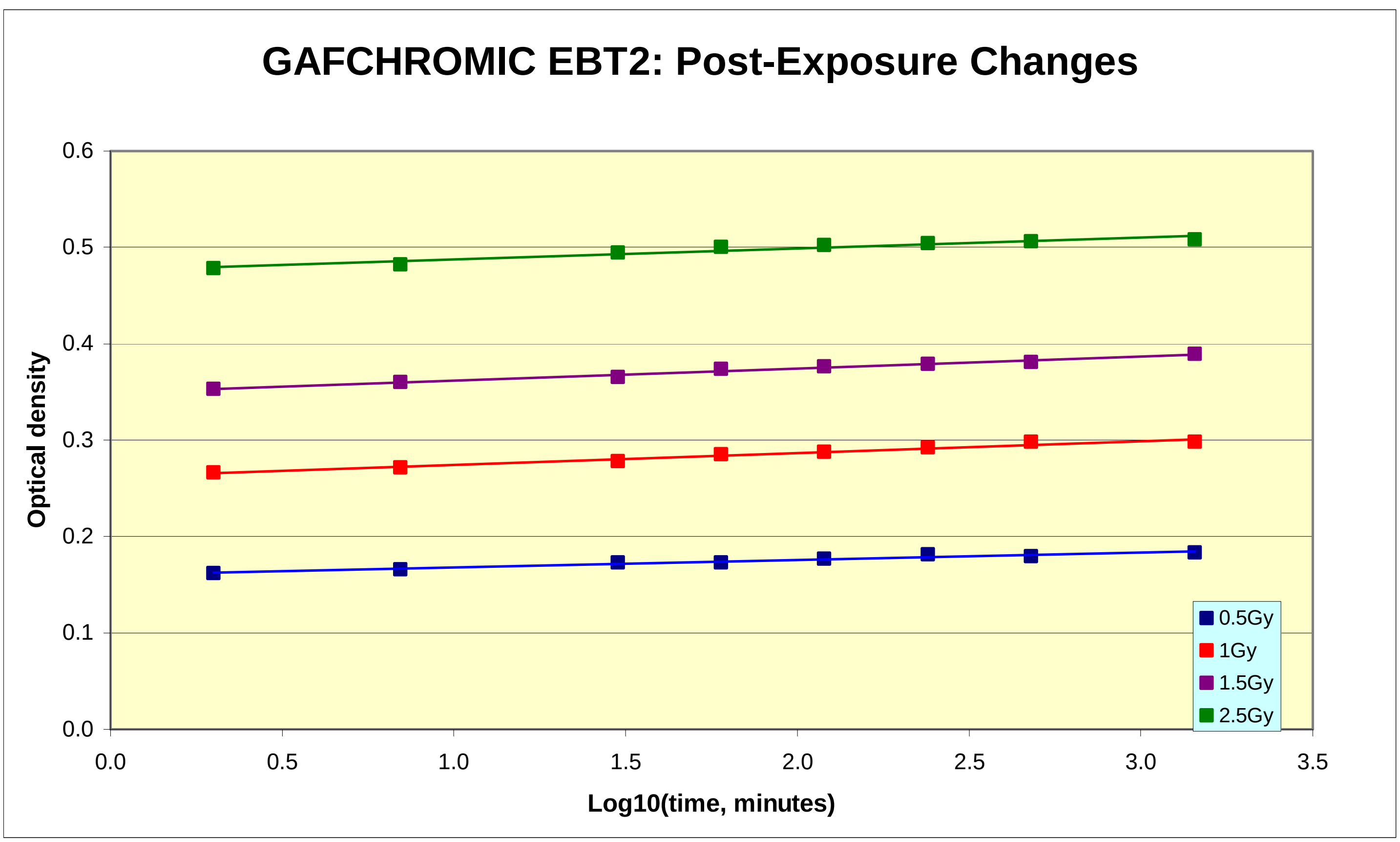

Figure 10: Post-Exposure Changes in GAFCHROMIC® EBT2

7.0 WHITE LIGHT SENSITIVITY

Although the active component in GAFCHROMIC® dosimetry films is not particularly sensitive to visible light it is comparatively more sensitive to the shorter, blue wavelengths. The interior environments are usually illuminated with cool white fluorescent light bulbs. These sources produce balanced proportions of blue, green, and red light. In measuring the white light sensitivity of GAFCHROMIC® dosimetry film, the performance is evaluated under exposure to the light from cool white fluorescent sources.

The active layer of EBT2 film contains a yellow marker dye. Since this dye strongly absorbs blue light it can be expected to reduce the effect of light exposure on the active component of the film. Therefore GAFCHROMIC® EBT2 film should be significantly less sensitive to the effects of light exposure than its predecessor. However, because EBT2 film is not totally insensitive to light it is good practice to minimize this exposure by placing films, exposed or unexposed, back into the box, immediately after use. Establishing this good habit of minimizing exposure of EBT2 film to light helps optimize the performance of your dosimetry system.

The intensity of the illumination on working surfaces, e.g. desktops and laboratory benches, was measured in a representative number of offices and laboratories. It was found that the light intensity ranged from about 600 lux to 1000 lux. For the purpose of the evaluation it has been assumed that “standard” indoor illumination intensity is 800 lux.

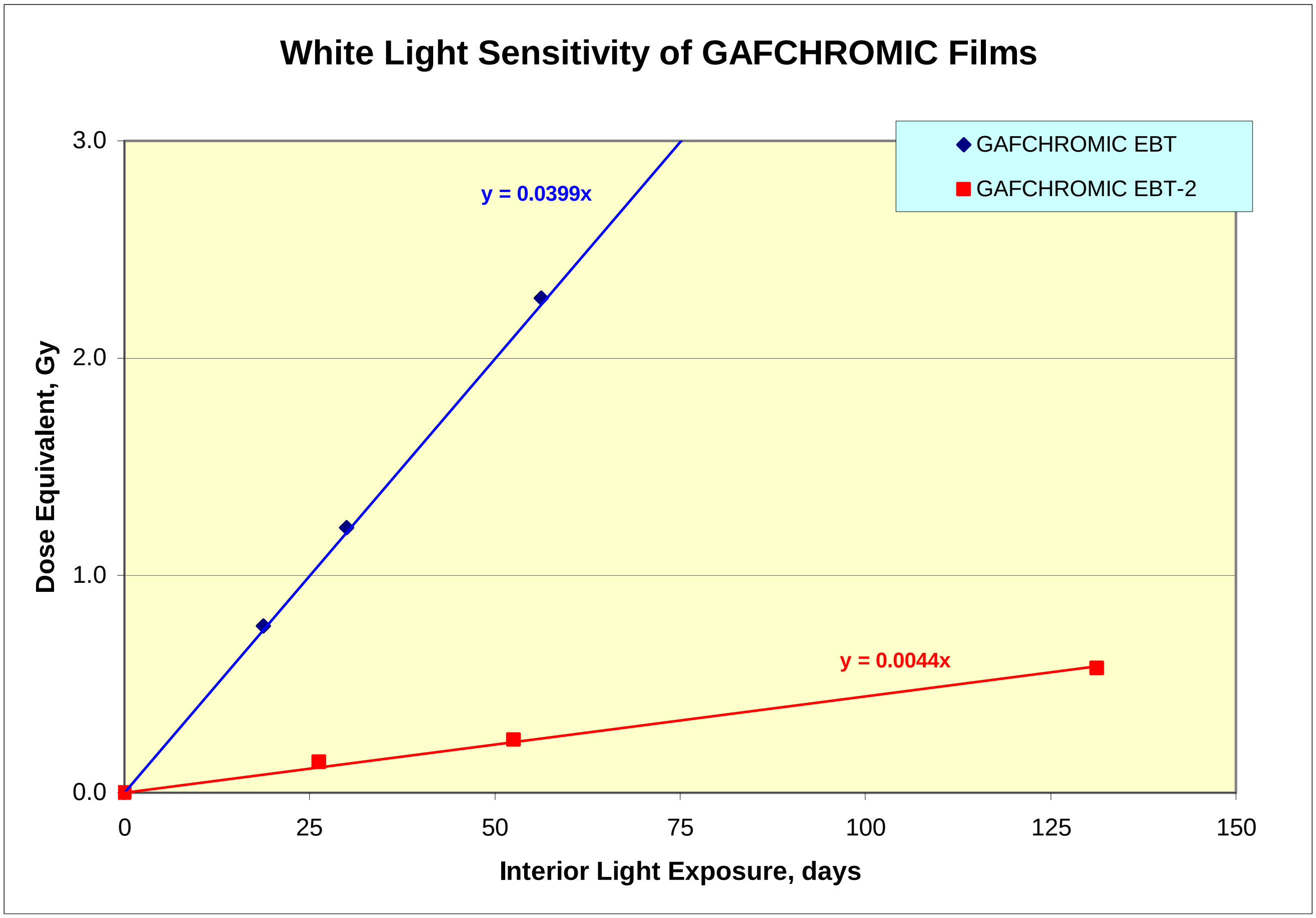

Figure 11: White light sensitivity of GAFCHROMIC® EBT and EBT2

The white light sensitivities of GAFCHROMIC® EBT2 and EBT films are graphically represented in Figure 11. When film is exposed to white light it darkens as if exposed by x-rays. To bring meaning to the film performance, the graphical data show the relationship between light exposure of the film, i.e. the number of days of continuous exposure to "standard" illumination, vs. the dose-equivalent response, i.e. the radiation dose required to darken the film to the same extent as the light exposure. Both EBT2 and EBT films show a linear relationship between light exposure and dose-equivalent response, but EBT2 is nearly 10X less sensitive to cool white fluorescent light than EBT. Using the slope of the linear fit, it is calculated that it would take about 2.5 days continuous light exposure of EBT film in the "standard" environment to have the same effect as a radiation exposure of 10cGy. However, for EBT2 film, it would take >22 days exposure to reach the same point.