SCIENTIFIC NOTE

Dose and absorption spectra response of EBT2 Gafchromic film to high energy x-rays

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Abstract

With new advancements in radiochromic film designs and sensitivity to suit different niche applications, EBT2 is the latest offering for the megavoltage radiotherapy market. New construction specifications including different physical construction and the use of a yellow coloured dye has provided the next generation radiochromic film for therapy applications. The film utilises the same active chemical for radiation measurement as its predecessor, EBT Gafchromic. Measurements have been performed using photo spectrometers to analyse the absorption spectra properties of this new EBT2 Gafchromic, radiochromic film. Results have shown that whilst the physical coloration or absorption spectra of the film, which turns yellow to green as compared to EBT film, (clear to blue) is significantly different due to the added yellow dye, the net change in absorption spectra properties for EBT2 are similar to the original EBT film. Absorption peaks are still located at 636nm and 585nm positions. A net optical density change of 0.590 ± 0.020 (2SD) for a 1 Gy radiation absorbed dose using 6 MV x-rays when measured at the 636nm absorption peak was found. This is compared to 0.602 ± 0.025 (2SD) for the original EBT film (2005 Batch) and 0.557 ± 0.027 (2009 Batch) at the same absorption peak. The yellow dye and the new coating material produce a significantly different visible absorption spectra results for the EBT2 film compared to EBT at wavelengths especially below approximately 550nm. At wavelengths above 550nm differences in absolute OD are seen however, when dose analysis is performed at wavelengths above 550nm using net optical density changes, no significant variations are seen. If comparing results of the late production EBT to new production EBT2 film, net optical density variations of approximately 10 % to 15 % are seen. As all new film batches should be calibrated for sensitivity upon arrival this should not be of concern.

Key words radiochromic film, gafchromic XR-QA, radiation dosimetry, absorption spectra

Introduction

International Specialty Products (ISP) Gafchromic, is likely the most widely used radiochromic film for assessment of radiation dose in medical applications. Other film types like, B3 Windose[1] (GEX Corporation, Centennial, Colorado, USA), Radiachromic[2,3] (FWT technologies, Goleta CA, USA) or Radiation Imaging Film / SIRAD's[4,5] (JPLabs, Middlesex, NJ, USA) are used more for industrial and radiation safety purposes where in general larger radiation exposures are measured. In recent years, ISP has provided the medical physics community with a series of film type dosimeters which have found niche uses in therapeutic and diagnostic radiology. Historically these have included MD-55 and HS film[6-12], ISP's films designed specifically for radiotherapy applications where large doses (up to 30 Gy) are required, XR-R films[13-15] for high dose diagnostic imaging applications through to films such as XRQA[16-17] which is designed for low dose assessment at kilovoltage x-ray energies. Probably the most used film for radiation dosimetry in therapy applications has been Gafchromic EBT film[18-24]. Its properties have included lowest energy dependence of any film type dosimeter, radiation sensitivity matched to therapy applications (1-2Gy), flexibility and easy analysis with a common desktop scanner. ISP has now introduced a new updated version of the EBT film called EBT2[25]. This film type has under gone a few physical design changes, whereby the substrate and over-laminate materials have changed and the film now includes a yellow dye incorporated into its radiation sensitive layer. The manufacturers have performed these changes for a few reasons. They include, minimizing coating anomalies, reduction in UV sensitivity and the new film should be less prone to damage when cut. Whilst the new EBT film is said to have the same active ingredients forradiation dosimetry, the fact that the substrates and a

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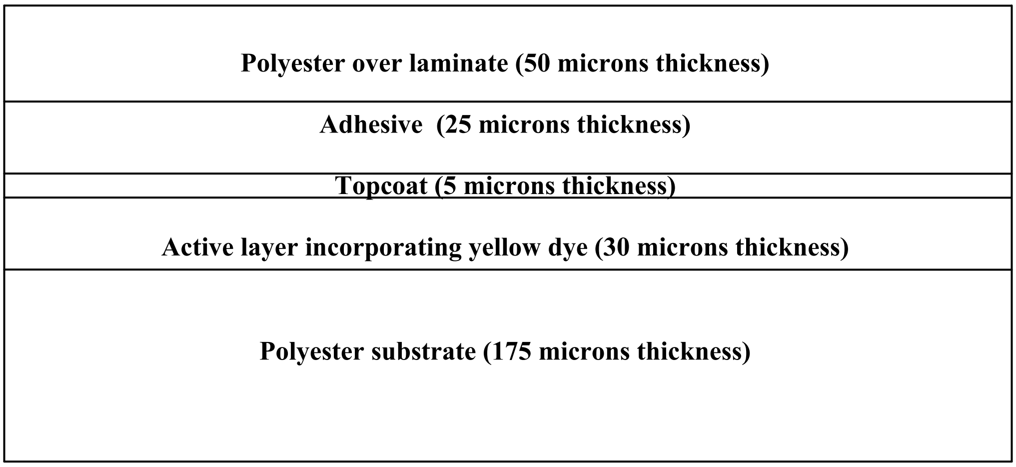

Figure 1. *Cross section of the new EBT2 Gafchromic film. The new film incorporates redesigned substrate and over laminate compared to the older EBT. Also, a yellow dye is incorporated into the active layer.*

colour dye has been added will affect the visible absorption properties of the film and may influence radiation dosimetry. This paper looks at the absorption spectra of the new EBT2 film and compares it to the original EBT film for dose assessment properties.

Materials and methods

Gafchromic EBT2, radiochromic film (Lot No. F02060902B) has been utilized for the measurement of absorption spectra changes caused by ionising radiation. These results have been compared to EBT Gafchromic (Lot No. 37122-04I and Lot no. 47277-06I) for comparison. The new EBT2 film has changed in physical design from EBT film. A schematic of the new film cross section is given in figure 1 as per manufacturer's specifications. The most significant changes in the design are the inclusion of the yellow dye into the films active component layer which acts as a "band pass filter" and the changed thickness of the substrate (50 microns for EBT2 compared to 97 microns for EBT) and over-laminate material (175 microns for EBT2 compared to 97 microns for EBT). Both the yellow dye and the new thicknesses are expected to alter the visible absorption spectra properties of the EBT2 film compared to EBT.

For dose delivery, the films were positioned in a solid water[26] phantom of dimensions 30cm x 30cm x 30cm. A Varian 2100 EX linear accelerator was used to deliver various absorbed doses up to 500 cGy at 6 MV x-ray energy. Irradiations were performed at the position of Dmax which is located at a depth of 1.5 cm. The phantom size used provided ample backscatter material for full scatter conditions.

The absorption spectra results were measured using a Shimadzu UV-160 UV-visible recording spectrophotometer [18]. Wavelength range of analysis was from 350nm to 800nm in 5nm steps with the absorption peaks located by the spectrometer within 1nm. The Shimadzu UV-160 has a spectral bandwidth of 3nm with an accuracy of ±0.5nm. The film was held in a quartz holding container during analysis. Spectra data was then analysed to calculate sensitivity values at various specific wavelengths and band passes.

Precautions in handling of radiochromic film outlined by Butson et al[27] were adhered to. Film pieces of 4cm x 4cm were cut for experiments. Five film pieces were exposed at each dose level and results show the average for this data set. The same orientation of film pieces relative to the reflectance photo spectrometer were used to minimise polarization or orientation effects on film absorption spectra assessment[28,29]. The film during storage and film analysis were kept in temperatures of 22 °C ± 2 °C to reduce any effects of time and temperature dependent evolution or readout of the absorption spectra[11]. Whilst manufacturers quote that the light resistance of the new EBT2 is much greater than EBT film, the film was only removed from a light tight envelope during irradiation and readout to reduce any effects of ambient light[30]. Films were left for 24 hours before readout to minimize the uncertainties associated with incomplete post irradiation coloration[31].

Results and discussion

Figure 2 shows the visible light absorption spectrum in the wavelength range of 400nm to 700nm for EBT2 Gafchromic film when irradiated with 6 MV X-rays. Results shown are for a non-exposed film through to exposures up to 500 cGy absorbed dose. The film before irradiation has a distinct yellow colour due to the yellow dye placed within its structure. This is shown by the large increase in visible light absorption below wavelengths of approximately 525nm effectively producing a "blue light" band pass. At wavelengths above 525nm the non – irradiated film shows a small degree of colouration with a small but distinguishable peak at 636nm. As absorbed dose levels increase, the films absorption spectra increases at all

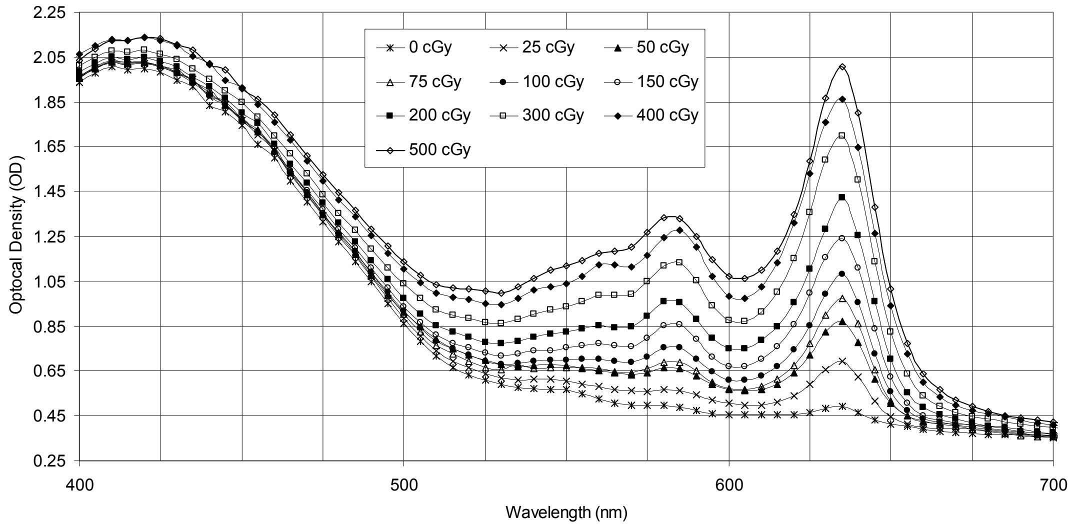

Figure 2. *Absorption spectra results for EBT2 film when irradiated with high energy x rays.*

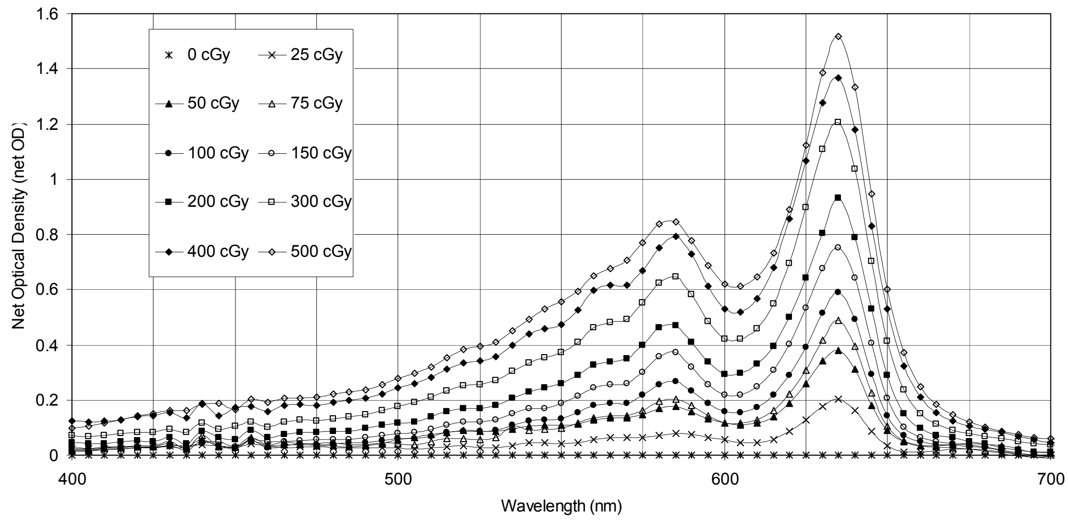

Figure 3. *Net absorption spectra for EBT2 when irradiated with high energy x-rays.*

wavelengths with the major increases occurring in the wavelength range of 525nm and above. Two absorption peaks become clear and are located at 636nm and 585nm as is the case for the original EBT film and other Gafchromic film products such as XRQA. Smaller but distinguishable changes in optical density do occur at the lower wavelengths below 525nm however the percentage change is small compared to the total optical density due to the inherent yellow dye. The optical density of a non-irradiated film at 636nm was found to be 0.492. This value changed to 1.082 at 100 cGy irradiated and up to 2.009 at 5Gy irradiation. Figure 3 shows the net absorption spectra for EBT2 Gafchromic film. It is essentially the subtraction of the non-irradiated film optical density value from the irradiated film optical density at each wavelength of analysis. This highlights the change in optical density that occurs within the EBT2 film with radiation exposure. Of interest are the two absorption peaks, which appear very similar to the original EBT film as well as the removal of the large absorption at lower wavelengths caused by the yellow dye. The absorption peak at 636nm does not change wavelength with applied dose.

Measurement of absorbed radiation dose using EBT2 Gafchromic film can be performed with various measurement densitometers or devices. Probably the most common method is with the use of a desktop fluorescent or LED light scanner. These scanners can be used with analysis performed in either the red component of the RGB scan or using the whole “white” light scan. Other currently popular methods include analysis at the 636nm absorption peak, using a photo spectrometer to obtain the highest level of dose sensitivity possible, scanning with red narrow band LED’s with wavelength FWHM ranges of around 20nm or sometimes HeNe scanners[26]. Each device due to the wavelength of analysis or range of wavelengths has a defined sensitivity per dose for analysis. Figure 4 shows the

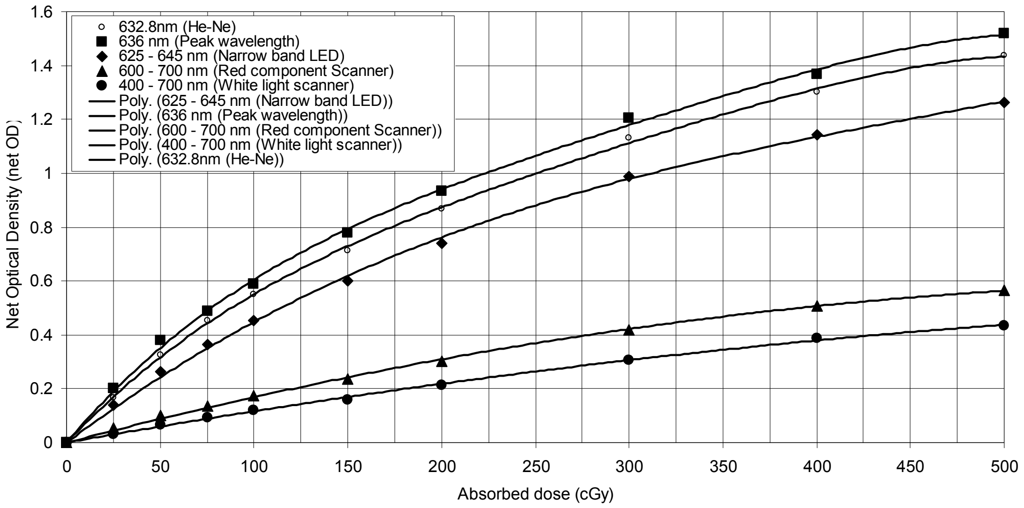

Figure 4. *Dose response curves for EBT2 film to 6 MV x-rays when analysed at various wavelengths and band passes.*

dose response of EBT2 film when analysis is performed using various wavelengths or band passes as would occur with these commonly used devices. As can be seen the 636nm absorption peak provides the highest level of sensitivity with a optical density change of 0.590 for 1 Gy irradiation. This is compared to 0.5515 for He Ne (632.8nm), 0.454 red LED (625nm – 645nm), 0.175 red channel, desktop scanner (600nm – 700nm) and 0.119 for white light desktop scanner (400nm to 700nm). The optical density to dose response in each case can be easily modeled by a 2nd or 3rd order polynomial function for dose calibration purposes.

A significant change in physical design characteristics as well as visual representation has occurred with the new generation EBT2 film compared to the original EBT film. The original film started as a clear to light blue shade and after irradiation changed to a distinct blue colour. The new format EBT2 however has a very distinct yellow colour before irradiation and changes to a green colour after irradiation. These optical properties changes are caused by two effects, the coloured dye and the new substrate, construction material used within the film layers. Figure 5 shows the visible light absorption spectra for the original EBT film as well as the new EBT2 film at three dose irradiation levels of 0 cGy, 50 cGy and 200 cGy. These dose values are chosen as representative values. As can be seen, not only is there a significant difference in optical density at the wavelengths below 525nm where the yellow dye affect spectra absorption, but there is also a difference in optical density properties above this wavelength with the older type EBT film producing a higher optical density than the new film at all wavelengths from approximately 525nm to 800nm. This is caused by the different substrate materials used to construct the film types. Figure 6 shows net optical density results for two batches of the old EBT film and the new EBT 2 Gafchromic film at 300 cGy applied dose. The two EBT films were from lot no 37122-04I (expiry date 2006 with analysis performed in 2005) and lot no. 47277-06I (expiry date 2009). This highlights the fact that the same active radiochromic chemical is used for EBT2 film as was used in EBT. However what can also be seen is the difference in net optical density between the 2 different batches of original EBT film. This difference is approximately 8-9 % in magnitude. It appears that the older EBT film has a very similar sensitivity to the new EBT2 film in this case whereas the newer EBT produced film has a smaller sensitivity compared to EBT2 film. This highlights the variation in sensitivity in Gafchromic films that can occur from different batches, albeit production was more than 3 years apart. A similar affect may occur for EBT2 film as the production process may change in future years from batch to batch. It is always recommended to perform a sensitivity analysis for any new batch of radiochromic film product. The difference in sensitivity between the EBT and EBT2 films whilst noticeable is not of significant importance as the new EBT2 film provides a high sensitivity for radiotherapy dose analysis. Figure 7 shows results for a dose response curve for the latest produced EBT film and the new EBT 2 as measured with a Epson V700 desktop scanner in reflection mode. These results show a similar trend in dose response as the spectrophotometer results with the EBT2 film being approximately 15% more sensitive than EBT film in this batch (reflection mode requiring 2 passes through the active layer). The manufacturers have highlighted a few reasons for their change of design. These include, minimizing coating anomalies, reducing UV sensitivity reducing damage when cut. These factors are important and certainly the new EBT2 film types provides a dosimeter whose net optical changes from x-ray irradiation still provide an accurate dosimetry device in the 0 to 5 Gy region using absorption spectra analysis. Uncertainties of analysis using Gafchromic film come from various sources with the major ones including scanner uniformity, film uniformity, film orientation effects as well as scratches and surface defects. Using the systems mentioned in this work, uncertainty of

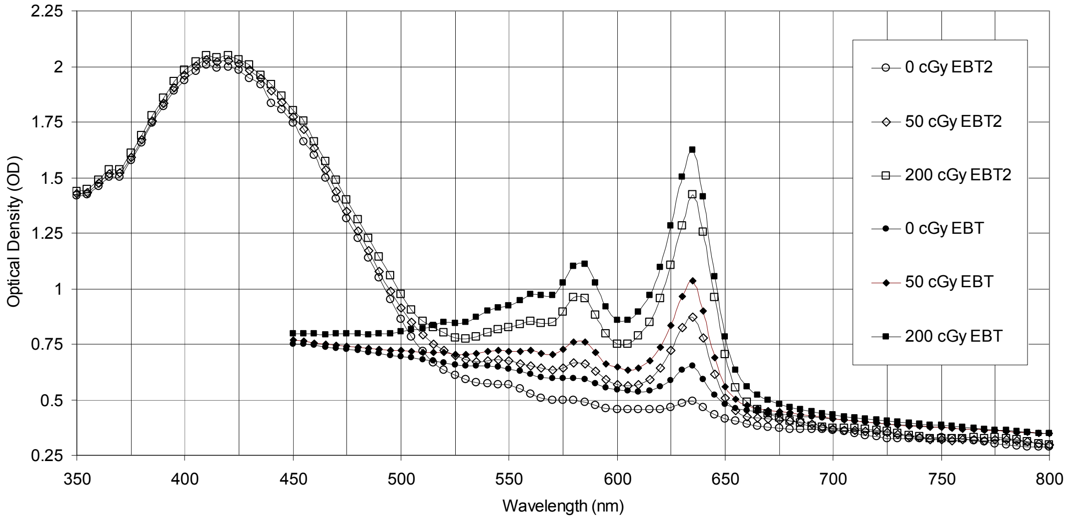

Figure 5. *Comparison of the absorption spectra of EBT and EBT2 Gafchromic film. Of note is the yellow dye absorption (wavelengths below 525nm) as well as the difference in absorption at other wavelengths due to changed substrate and over laminate materials.*

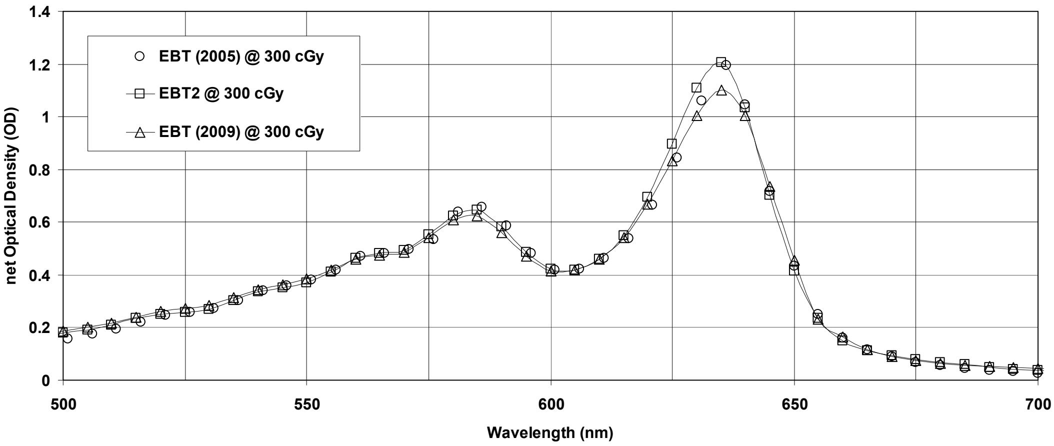

Figure 6. *Comparison of the net optical density changes for EBT and EBT2 Gafchromic film to 6 MV x-ray beams.*

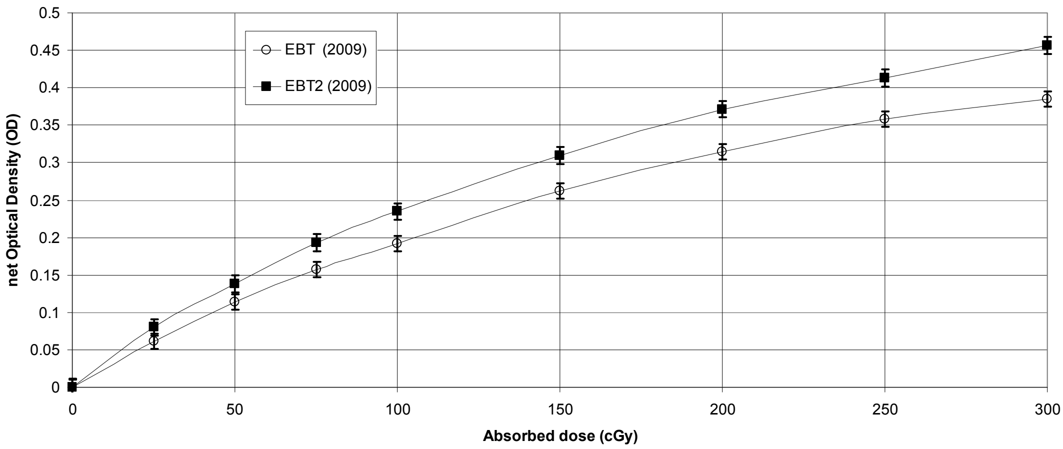

Figure 7. *Dose response curves for EBT (Lot no. 47277-06I) and EBT2 (Lot no F02060902B) using an Epson v700 desktop scanner in red component mode.*

dose measurement is on average of the order of 3% to 4% at dose levels of 1Gy. Bouchard et al[32] and Ferreira et al[33] have shown that these uncertainties can be reduced down to less than 1% with careful dosimetry techniques.

Conclusion

The absorption spectra properties of the new EBT2 Gafchromic film have been examined by photo spectroscopy and compared to the original EBT film. A significant visible colour change (i.e. EBT2 turns from yellow to green as opposed to clear to blue for EBT) is noted due to the presence of a new coloured dye. Other changes have occurred in the visible absorption spectra of EBT2 film due to the different physical construction of the substrate and over laminate. Results have shown that the net absorption spectra changes due to irradiation are similar for the old EBT and the new EBT2 film. Sensitivity of the film is also different to a late batch EBT film by 10% to 15%.

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