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NOTE

Experimental energy response verification of XR type T radiochromic film

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Abstract
This short note investigates the energy response characteristics of a relatively new high sensitivity radiochromic film (XR type T) and compares it to other radiochromic and radiographic films and thermoluminescent dosimeters. Results show that the energy response of the new XR type T film is relatively large over the range of therapeutic energies from 50 kVp superficial x-ray treatment to 18 MV high energy radiotherapy treatment. When normalized to 1 at a standard 6 MV radiotherapy x-ray energy the XR type T film produced a normalized dose response of approximately 6 in the energy range of 30 keV to 70 keV thus representing an increase in sensitivity at lower energies similar to that observed for radiographic x-ray films. This is quite different from previous versions of Gafchromic film where the energy response of the film decreases at lower energies down to levels approximately 0.6–0.7 for the same effective energies. This type of film has been optimized for use in diagnostic energy ranges producing a relatively uniform dose response in the 30 keV to 70 keV range.

Introduction

Gafchromic film, due to its automatic development, has become a significant dosimetry tool in diagnostic and therapeutic radiology (Butson *et al* 2002, 2003, Giles and Murphy 2002, Vuong *et al* 2003). Originally, one of radiochromic film's shortcomings for use in both in-phantom and *in-vivo* dosimetry has been its relatively low sensitivity, normally requiring large doses (5 Gy or more) to produce acceptable results (Klassen *et al* 1997, McLaughlin *et al* 1991,

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Meigooni *et al* 1996). Manufacturers have now introduced a relatively new film type, Gafchromic XR type T, designed to increase dose sensitivity at lower x-ray energies used in diagnostic radiography. Gafchromic XR type T radiochromic dosimetry films have also been developed specifically for the measurement of absorbed dose of low energy photons quoting a relatively energy independent response for low energy x-rays. Manufacturers have quoted sensitivities of these films to photons with energies less than 200 keV as substantially greater than previous dosimetry films such as MD-55. This short note investigates the energy response properties of this new film and compares results to existing Gafchromic films, radiographic film and thermoluminescent dosimeters.

Materials and methods

Gafchromic XR type T film is a commercially available radiochromic film product and is studied for energy dependence to x-ray radiation in this note. The active layer is sandwiched between two sheets of 97 μm polyester, which are transparent and contain a yellow dye. The yellow dye aids the visual contrast of the chromatic changes that occur when the film is exposed to radiation. Gafchromic XR type T dosimetry media employ the same active radiochromic components used in MD-55 film, but also include a proprietary high Z material (ISP Technologies Inc. 2004). The thickness of the active layer in the Type T film is approximately 18 μm. Gafchromic XR type T radiochromic film (Batch no K02b28XRT) was used for the energy response characteristics study. For dose delivery, the films were positioned in a solid water (Constanitinou *et al* 1982) phantom of dimensions 30 cm $\times$ 30 cm $\times$ 30 cm. The phantom was placed on a Pantak, Therapax 300DXT orthovoltage machine (Butson *et al* 1995) and a Varian 2100C linear accelerator and films were given 5 Gy absorbed dose. Absorbed dose calibrations were performed using a Farmer Thimble type ionization chamber and the IAEA protocol. The effective energies of each superficial and orthovoltage beam type were calculated from half value layer measurements. The films were irradiated while placed perpendicular to the central axis of the beam. Precautions in handling of radiochromic film outlined in TG-55 were used (Niroomand-Rad *et al* 1998). The film during storage and film analysis was kept at temperatures of 22 $\pm$ 2 °C thus reducing the effects of time- and temperature-dependent evolution and readout (Meigooni *et al* 1996) of the absorption spectra of the film. The film was only removed from a light-tight envelope during irradiation and readout to reduce any effects of ambient light (Butson *et al* 1998). The absorption spectra results were measured using a Shimadzu UV-160 UV–visible recording spectrophotometer (Butson *et al* 2002). The wavelength range of analysis was from 600 nm to 700 nm in 2 nm steps. This wavelength range was chosen as it forms the most sensitive region of analysis for XR type T radiochromic film. The Shimadzu UV-160 has a spectral bandwidth of 3 nm with an accuracy of $\pm$0.5 nm. The film was held in a quartz holding container. Spectra data were then analysed to calculate the energy dependence of the XR type T film.

Results and discussion

Figure 1 shows the net optical absorption spectra for XR type T radiochromic film when exposed to an absorbed dose of 5 Gy at various energies. These results are the subtraction of 0 Gy absorption spectra from 5 Gy absorption spectra. Energies are quoted as effective mono-energetic energies which have been calculated using half value layer data for the respective beams. The matching peak treatment energies are 50 kVp = 28 keV, 75 kVp = 32.5 keV,

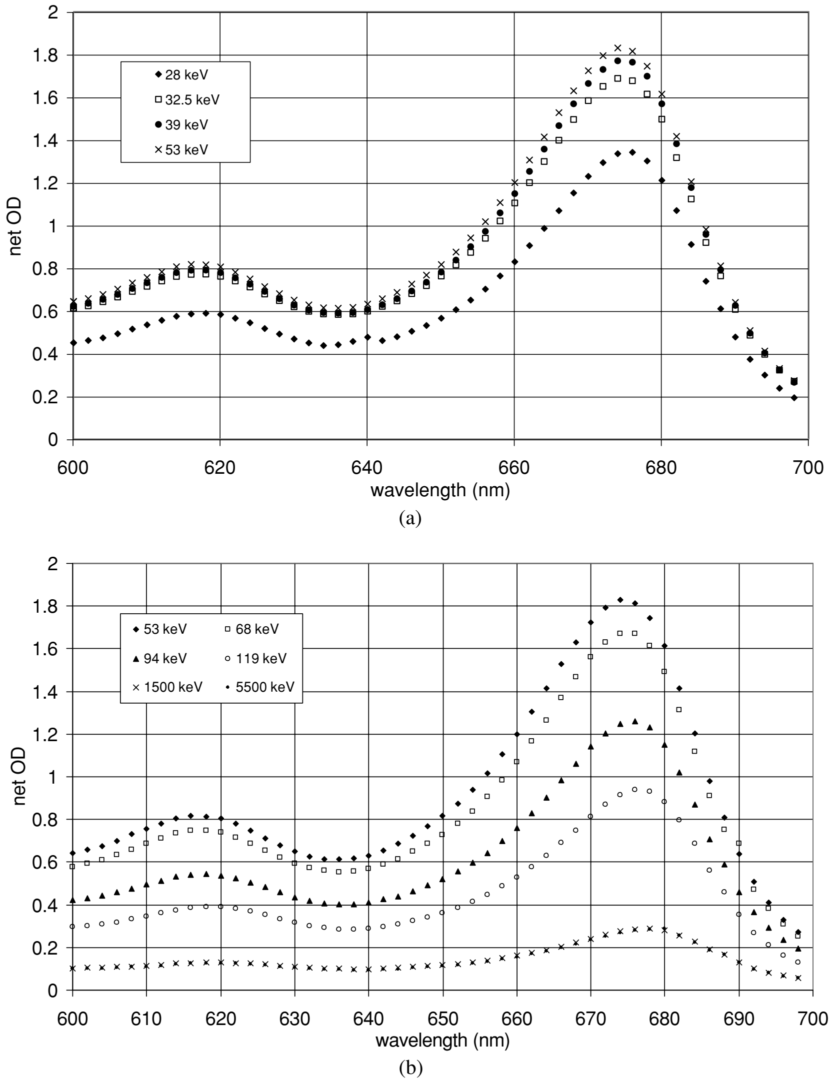

Figure 1. (a) The absorption spectra for Gafchromic XR type T film exposed to 5 Gy x-ray absorbed dose at energies less than 53 keV. (b) Similar results for energies greater than 53 keV.

100 kVp = 39 keV, 125 kVp = 53 keV, 150 kVp = 68 keV, 200 kVp = 94 keV, 250 kVp = 119 keV, 6 MV = 1.5 MeV and 18 MV = 5.5 MeV. The figure is divided into two sections, figure 1(a) which has energies less than or equal to 53 keV (125 kVp), which is the peak energy response and figure 1(b) shows results for energies greater than or equal to 53 keV. The absorption spectra remain relatively the same for all energies with decreasing energy response either side of our measured 53 keV (125 kVp) peak. At energies above 68 keV (150 kVp) a noticeable decline in energy response is seen at all wavelengths of analysis. Figure 2 shows the energy response of the XR type T film normalized to a value of 1 at 6 MV x-ray energy. Results are normalized this way as the 6 MV x-ray beam would be considered in the linear section of energy response for most radiation detectors due to the high percentage of Compton interactions at this energy for most materials. Results are for XR type

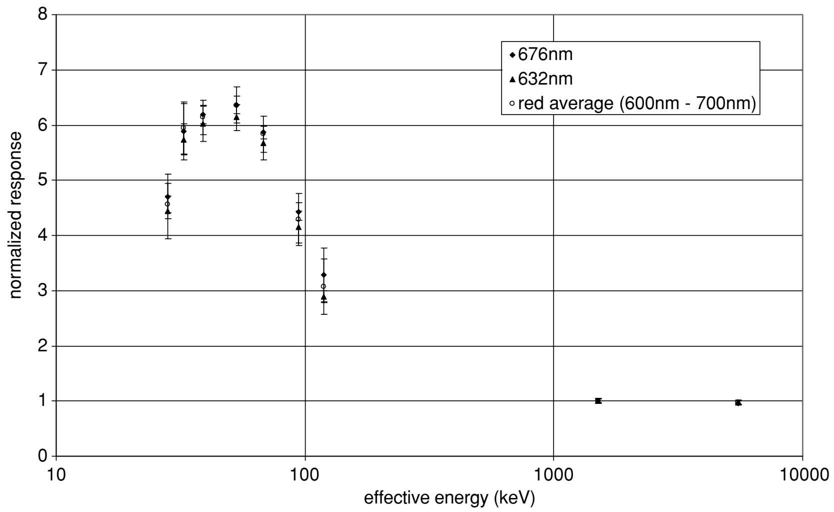

Figure 2. The normalized energy response of XR type T film analysed at various absorption wavelengths.

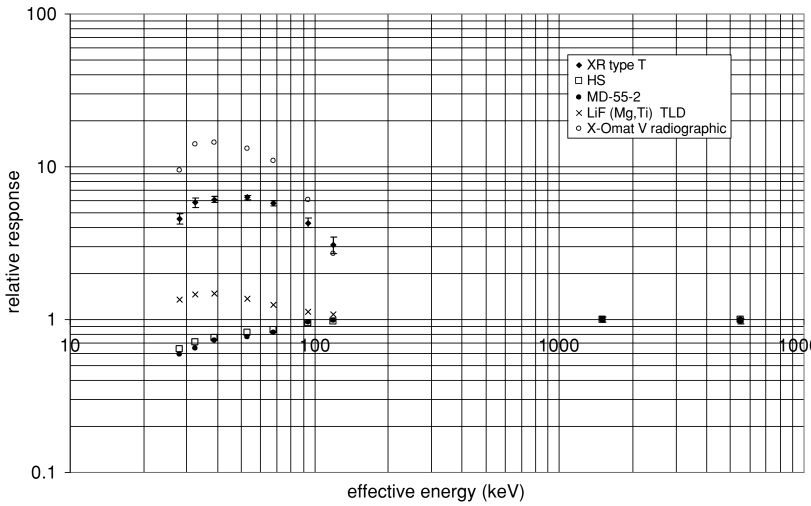

Figure 3. Comparison of the energy response of XR type T radiochromic film with other common radiation detectors.

T film analysed at three specific wavelengths or regions. These being 676 nm, the absorbed peak, 632 nm (He Ne laser readout wavelength) and red average (600–700 nm) which would be a typical wavelength range for a document scanner using the red section of the spectrum. Results show agreement at all wavelengths of analysis with a large increase in sensitivity for lower energy x-rays with the peak response at 53 keV energy. This value is approximately six times more sensitive than at 1.5 MeV effective energy. As highlighted by the manufacturers, the film is specifically designed for diagnostic purposes using the kVp range of 80 kVp to 120 kVp. These results highlight this fact with our measured sensitivities being relatively uniform over the mono-energetic energy range of 32.5 keV to 68 keV. This relates to a kVp range of 75 kVp to 150 kVp. However, the mono-energetic equivalent or effective energy of a diagnostic or therapeutic x-ray beam is determined by the amount and type of filtration placed in its path and thus the same kVp can produce vastly different mono-energetic equivalents with two separate filters. The manufacturer has introduced a high atomic number material into XR type T Gafchromic film to specifically increase its response to low energy x-rays and to produce an optimally uniform dosimeter for diagnostic procedures such as fluoroscopy. This does, however, reduce the energy independence over the larger energy range for superficial and orthovoltage therapy treatment as well as for mega voltage x-ray treatment. This consideration must be taken into account if the film is used in areas outside of the nominal 80 kVp to 120 kVp energy range. As a comparison to other detectors, figure 3 is shown. Results show the energy response for MD-55-2 and HS Gafchromic film along with Lithium Fluoride TLDs and Kodak, X-Omat V radiographic film on a log scale. Results highlight the variation in energy response of the XR type T film compared to MD-55-2 and HS Gafchromic and the similar nature (albeit not in magnitude) of the energy response to TLDs and radiographic film. All detectors were tested and energy response measured using the same x-ray quality beams. The energy dependence of XR type T radiochromic film over the kilo-voltage and mega-voltage x-ray range lies between that of a silver halide radiographic film (up to 14 times overresponse at low energy) and other forms of Gafchromic film which underrespond at low energies (0.6–0.7). XR type T does however have a relatively low energy dependence for the energy range of 75 kVp to 150 kVp.

Conclusion

Gafchromic XR type T radiochromic film produces a peak energy response at 53 keV (125 kVp) compared to other energies tested with decreasing response either side of this energy. A relatively energy independent response (within ±5%) was found for mono-energetic equivalent beams ranging from 32.5 keV to 68 keV which relates to a range of 75 kVp to 150 kVp. At higher energies the response decreases significantly with a relative response of 1/6th at 1.5 MeV (6 MVp) compared to the peak at 53 keV (125 kVp).

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