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NOTE

Visible absorption spectra of radiation exposed SIRAD dosimeters

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Abstract

SIRAD badge dosimeters are a new type of personal dosimeter designed to measure radiation exposure up to 200 R and give a visual qualitative measurement of exposure. This is performed using the active dosimeter window, which contains a radiochromic material amalgamated in the badge assembly. When irradiated, the badges active window turns blue, which can be matched against the given colour chart for a qualitative assessment of the exposure received. Measurements have been performed to analyse the absorption spectra of the active window, and results show that the window automatically turns a blue colour upon irradiation and produces two peaks in the absorption spectra located at 617 nm and 567 nm. When analysed with a common computer desktop scanner, the optical density response of the film to radiation exposure is non-linear but reproducible. The net OD of the film was 0.21 at 50 R exposure and 0.31 at 200 R exposure when irradiated with a 6 MV x-ray energy beam. When compared to the calibration colour strips at 6 MV x-ray energy the film's OD response matches relatively well within 3.5%. An approximate 8% reduction in measured OD to exposure was seen for 250 kVp x-rays compared to 6 MV x-rays. The film provides an adequate measurement and visually qualitative assessment of radiation exposure for levels in the range of 0 to 200 R.

Introduction

Measurement of personal radiation exposure requires certain characteristics depending on the level of exposure and the accuracy needed. When measuring low-level radiation, devices such as thermoluminescent dosimeters (Guillet *et al* 2005, Soares 2002) are adequate due to their high sensitivity and their portable nature. However, they do not alert the wearer to the levels of exposure immediately. Devices such as Geiger-Muller or scintillation counters (Schwartz *et al* 2003) can also detect low-level radiation, but it is not economically viable to issue these to staff on a mass scale. If higher levels of radiation are of concern, devices such as the SIRAD high dose personal radiation dosimeter may be used. The SIRAD high dose dosimeter developed by JPLabs Inc provides a personal dosimetry tool with the following characteristics. The badge provides an automatic visually readable dose assessment via a calibrated colour change in its active window. The badge is small, light weight and water proof. It is also inexpensive, integrates dose and requires no power supply. The manufacturers developed the badge for personal dosimetry of staff that may be exposed to high radiation levels, such as those who may deal with radiation dirty bombs (Watanabe *et al* 2006) or in areas of radiation accidents. The SIRAD badge is based on a radiochromic dye insert which changes colour automatically when exposed to radiation (Riel *et al* 2006). With the SIRAD badge the change is from a clear to blue colour upon radiation in the dose range of 0 R to 200 R. The radiochromic window is protected from ultraviolet exposure with an opaque cover which can be easily flipped back to reveal the radiochromic window and calibration chart. The colour change occurring within the SIRAD badge is due to changing absorption spectra produced by a chemical reaction initialized by the ionizing radiation. This note investigates the changing visible light absorption characteristics of the SIRAD personal dosimeter after exposure to high energy x-ray beams.

Materials and methods

SIRAD radiochromic based radiation dosimetry badges are analysed for this absorption spectra study. For exposure delivery, the badges were placed in a solid water (Constanitinou *et al* 1982) phantom of dimensions 30 cm × 30 cm × 30 cm during irradiation at 1.5 cm depth. The phantom was irradiated with a Varian 2100EX linear accelerator and applied doses ranging from 0 cGy to 200 cGy (in water) were delivered to the SIRAD badges. A source-to-surface distance (SSD) of 100 cm and a field size of 10 cm × 10 cm were used. The badges were irradiated with the active measurement strip perpendicular to the x-ray beam with the plastic cover plate over the active detector. Standard precautions which apply to radiochromic film handling, such as not touching the active film surface and keeping the badge temperature controlled during irradiation and readout as outlined in TG-55, were employed (Niroomand-Rad *et al* 1998) as these principles should hold for all radiochromic film types. The radiochromic material within the SIRAD badge is a proprietary radiochromic material. Absorption spectra results for the SIRAD badges were measured using an Avantes AvaSpec-2048 reflectance photo spectrometer (Cheung *et al* 2005a, 2005b), 24 h after initial exposure. The AvaSpec-2048 device is a fibre optic Spectrometer with a 300 lines mm^{-1} grating. The bandwidth of operation is from 327 nm to 1100 nm and has a FWHM resolution of 2.4 nm. Measurements were made in absorbance mode, and results are quoted as a reflective optical density (ROD). The reflective optical density (ROD) at each wavelength (λ) is defined as the log of the initial light intensity ($I(\lambda)_0$) over the transmitted light intensity ($I(\lambda)_{(t,r)}$) which has been reflected off the opaque white backing of the SIRAD badge; i.e., ROD = $\log(I(\lambda)_0/I(\lambda)_{(t,r)})$. From the ROD($\lambda$), a set of absorption spectra measurements were obtained over the wavelength region of 500 nm to 650 nm. The SIRAD badges are also analysed using a desktop scanner at least 24 h after irradiation to minimize any effects from post irradiation colouration, which may occur (Cheung *et al* 2005, Rink *et al* 2005). The scanner used was a Hewlett Packard ScanJet with scanning resolution of up to 1200 pixels per inch. The badges were scanned over an area of approximately 0.5 cm × 1 cm in the centre of each active badge

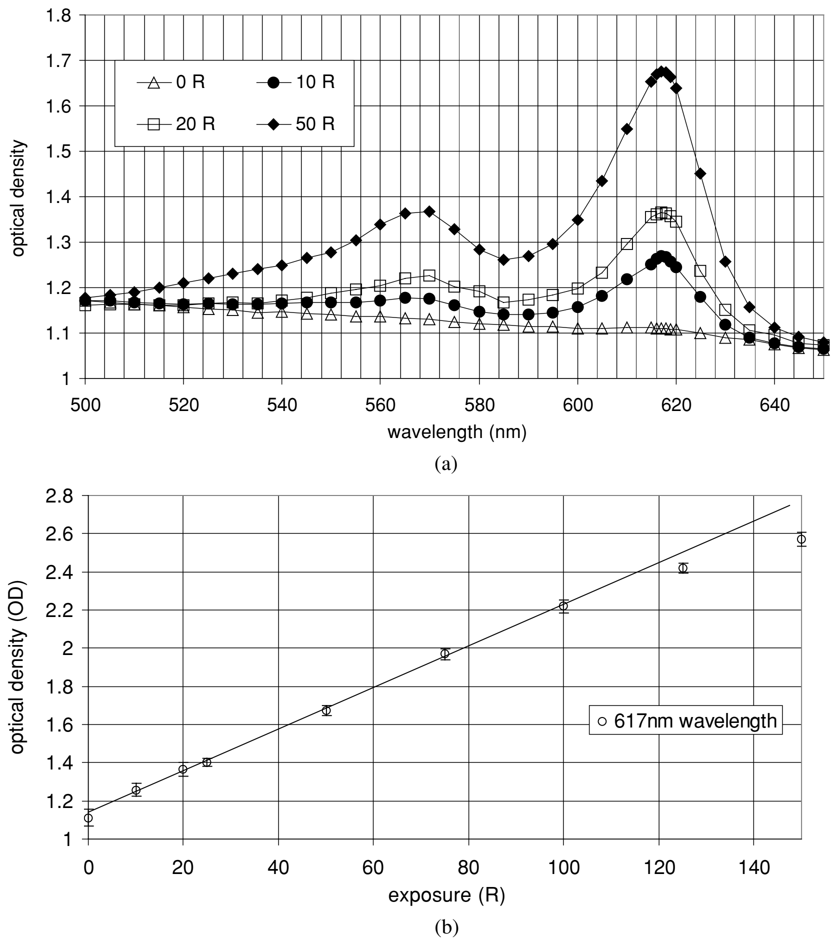

Figure 1. (a) The absorption spectra of the SIRAD badge active window. The film changes to a blue colour, which relates to the two main absorption peaks at 617 nm and 567 nm covering the red regions of the visible spectrum. (b) Exposure response of the SIRAD badge to 6 MV x-rays when measured at the peak wavelength of 617 nm. A relatively linear exposure response is seen up to approximately 100 R exposure.

piece. The images produced were 16 bit RGB colour images. These images were analysed with the full RGB components. Net RODs (subtraction of badge fog levels from the results) for all badges were calculated and compared to evaluate the variations in ROD to exposure response. The desktop scanner used to measure the optical density of the active badge window was also used to measure the optical density of the calibration colour chart on the badge. Direct comparisons are made between these two areas for assessment of the dosimeter's visual to actual exposure assessment accuracy.

Results and discussion

Figure 1(a) shows the optical density absorption spectra for the SIRAD badges in the wavelength region of 500 to 650 nm. Results are given for a selection of badges ranging in applied exposures of up to 50 R. The absorption spectrum for an unirradiated control badge is also shown. As can be seen, there are two main absorption peaks in the spectra, which

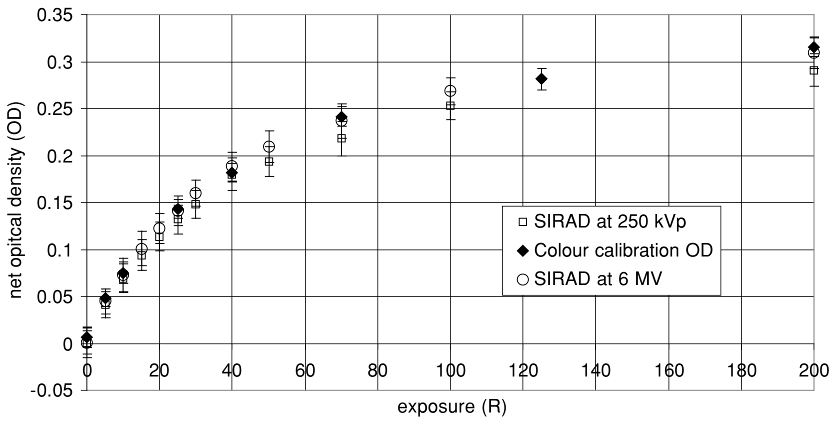

Figure 2. The exposure response of the SIRAD dosimeter compared to the colour calibration chart located on the badge for 6 MV and 250 kVp x-rays. Using a 6 MV x-ray energy beam, the badges tested provide an accurate assessment of exposure over the 0 R to 200 R exposure levels. An under response of approximately 8% was seen for 250 kVp x-rays.

are located at 567 nm and 617 nm. The 617 nm peak produced the largest change in optical density per unit exposure. A net optical density change of 0.564 is seen for the 50 R exposure at its peak wavelength. This response is approximately linear with dose when read out at this wavelength up to exposures of 100 R as seen in figure 1(b). Results become more nonlinear after 100 R exposure. This is expected to be due to the onset of the badge's active window saturation. As the main absorption occurs in the red region of the visible spectrum, the film changes to a blue colour upon irradiation. This is similar to other radiochromic film products such as Gafchromic film; however, the absorption peaks are located at different wavelengths (Butson *et al* 2003). The linear line of best fit is shown for best fit to results from 0 R to 100 R.

When the SIRAD badge is examined using a desktop scanner, a direct comparison between the actual badge colour change and the colour calibration chart can be made. Figure 2 shows a direct comparison of the net optical density of the SIRAD badge film and the calibration chart at 6 MV and 250 kVp energy x-rays. The error bars shown on the graph represent 1 standard deviation, and include uncertainties in measured optical density of ten irradiated badges. As can be seen, the exposure colour chart provides a relatively accurate assessment of exposure at 6 MV x-ray energies over the entire range of 0 to 200 R. When comparing the optical density of the badge film to the calibration chart a mean difference of 3.5% was found in measured values over the exposure values tested. An under response was seen when irradiated with 250 kVp x-rays compared to 6 MV results and the colour change for the badge was slightly less than the values predicted by the calibration chart by approximately 8% on average. Using the desktop scanner, a nonlinear response in net OD change per unit exposure is seen. This is due to the averaging of the colour change over the entire visible wavelengths as occurs with fluorescent light scanners. Although results are nonlinear in nature, they are reproducible and follow similar colour changes for the colour calibration curve as well as the active window.

The badges provide a measure of radiation exposure and have been produced as a dosimetry tool for areas such as dirty bomb monitoring. They can also be used in any area where higher dose levels are expected. The main advantage of the SIRAD badge is that they provide a visually readable analysis of exposure in a lightweight, easily worn design. It must be noted that the SIRAD badge, like most radiochromic materials, produces a post-irradiation colouration effect whereby the chemical reaction caused by ionizing radiation continues for a given period after exposure. This in turn affects the optical density reading of the exposure window whereby a lesser OD reading would be obtained immediately after exposure compared to a period of time after exposure. In most radiochromic materials this time can be from 6 h to 24 h for most of the colouration to occur (Cheung *et al* 2005). This effect has not been tested in detail here; however, it highlights a limitation in the accuracy of results, which can be obtained by the SIRAD badge immediately after exposure to radiation. This note examines the absorption spectra of irradiated SIRAD badges and quantifies the accuracy of the colour scale provided on the SIRAD badge for assessment of radiation exposure after post-irradiation colouration has finished. It is also relatively easy to assess the colour change visually as the film window is positioned in the middle of the colour chart, which allows a quick relative assessment of colour.

Conclusion

The SIRAD badge dosimeter permanently changes colour upon irradiation with high energy x-rays and thus has the ability to measure radiation exposure. Results have shown that the colour change from clear to blue is achieved with an absorption spectrum produced which has peaks at 617 nm and 567 nm. The calibrated colour chart provided on the SIRAD badge provides an adequate qualitative measure of exposure for high energy x-rays over the entire 0–200 R exposure range.

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