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Technical note

X-Ray energy dependence of the dose response of SIRAD radiation dosimeters

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Abstract

SIRADs (self-indicating instant radiation alert dosimeters) are designed to measure accident radiation doses. As the energy of radiation is usually unknown in such situations, a detector with a weak energy dependence of its response to dose would be ideal. We have studied the energy dependence of the dose response of SIRADs in the range from 50 kVp to 10 MV, which corresponds to photon equivalent energies from 25.5 keV to 2.2 MeV. The response to the same dose at 25.5 keV is $(29 \pm 4)\%$ ($\pm 1s$) lower than the response at 1.4 MeV. The response to a dose slowly increases with radiation energy. This energy dependence is relatively weak in comparison with the dependence for radiographic films and similar in magnitude to the dependence for lithium fluoride thermoluminescence dosimeters. This energy dependence of the response diminishes the accuracy of dose assessments in radiation fields of unknown energy, but does not significantly compromise the core ability of the devices to provide visual estimates of radiation doses.

Keywords: SIRAD; Accident dosimetry; Dose response; Energy dependence; Radiochromic film

1. Introduction

SIRADs (self-indicating instant radiation alert dosimeters) are a relatively new commercially available product for personal radiation dosimetry. These devices have a radiochromic, radiation sensitive active window, which changes color upon irradiation. In general, measuring radiation doses requires knowledge of certain characteristics of the dosimeter, the volume of which depends on the dose and the needed accuracy. SIRAD, developed by JPLabs, Inc., automatically provides a visually readable dose estimate. The inexpensive badge is lightweight, waterproof, and requires no batteries. It can be worn, like an identification card, around the neck or clipped to an article of clothing. The manufacturers have developed the badge for personal dosimetry of people who may get exposed to high-level radiation, such as those who may have to work in the areas of dirty bomb explosions (Watanabe et al., 2006) or radiation accidents. The SIRAD badge comprises a radiochromic dye insert, which changes its color automatically when exposed to radiation (Riel et al., 2006). The color change is due to changes in the absorption spectrum resulted from a radiation-induced chemical reaction (Butson et al., 2003). The degree of the color change depends on several factors, including the energy of the radiation. An ideal dosimeter would change its color to exactly the same degree per unit dose for all possible photon energies. In reality, virtually any dosimeter suffers some energy dependence of its responses. The response of radiographic films, which are based on silver halide materials, is significantly energy dependent: it is up to 15 times higher at low energies than at high energies. The dose response of thermoluminescence dosimeters, such as lithium fluoride (LiF), is higher at low energies due to the higher effective atomic number of the materials. For radiochromic films, the energy dependence of the dose

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response is usually weaker because they are made of lower-density materials. However, some radiochromic films still exhibit fairly strong energy dependences of their responses to the dose due to high-density dopants used to improve their sensitivity to low-energy radiation. This short note describes the energy dependence of the SIRADs to X-rays of energies between of 50 kVp and 10 MV.

2. Materials and methods

SIRAD (JP Laboratories, Inc., Middlesex, NJ, USA) represents a plastic card (8.5 cm × 5.5 cm, 1 cm thick) similar to a personal identification card (Fig. 1).The active window is located in the center of the badge; it hosts a proprietary radiochromic material changing its color under irradiation. The material is protected from UV light by a thin opaque window, which can be easily flipped back to allow visual inspection of the radiochromic material. The background layer behind it is a reflective white sheet, which allows the film to be analyzed with a reflective-type scanner. Our measurements were made with a reflective-mode desktop scanner, and the results are quoted as reflective optical densities (RODs). The ROD is defined as the logarithm of the ratio of the intensity I_0 of the incident light to the intensity $I_{(t,r)}$ of the transmitted light, which has been reflected by the opaque white background sheet of the SIRAD badge. Radiation turns the colorless film blue.

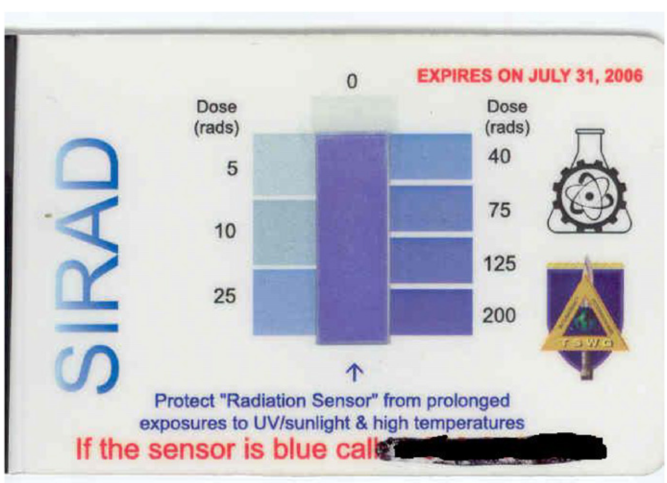

Fig. 1. Self-indicating instant radiation alert dosimeter (SIRAD). Dimensions: 8.5 cm × 5.5 cm × 1 mm.

To evaluate the energy dependence of the dose response, irradiations up to 2 Gy were performed using X-ray beams with peak energies of 50, 75, 100, 125, 150, 200, 250 kVp, 6, and 10 MV. The badges were irradiated in a 30 × 30 × 30 cm^3 solid–water (Constantinou et al., 1982) phantom using a GULMAY D3300 orthovoltage machine and a Varian 2100C linear accelerator. The doses given to the dosimeters were measured in terms of dose to water. They were determined with a Farmer thimble-type ionization chamber according to the IPEMB protocol for kilovoltage X-rays (IPEMB, 1996) and IAEA TRS-398 protocol for megavoltage X-rays (Andreo et al., 2002). No corrections were applied for the difference between water and the SIRAD badge material. The equivalent photon energy of each beam was calculated from half value layer (HVL) measurements (Johns and Cunningham, 1983).

All SIRAD badges were analyzed with a Hewlett Packard ScanJet scanner (75 pixels/in) and Image J software on a PC workstation at least 24 h after irradiation to minimize effects from post-irradiation coloration (Niroomand-Rad et al., 1998; Cheung et al., 2005). The films were scanned over the active window area of approximately 2 × 1 cm^2 located in the center of each badge to obtain 16-bit RGB color images. All of the RGB components were used in the analysis. Net RODs were calculated for all films by subtracting film fog levels from the results.

3. Results and discussion

Fig. 2shows the dependence of the SIRAD response to the dose on the energy of the beam. The responses are normalized to the response at the equivalent photon energy of 1.4 MeV, which corresponds to a 6 MV X-ray beam. Beams of 50, 75, 100, 125, 150, 200, 250, 6 and 10 MV were

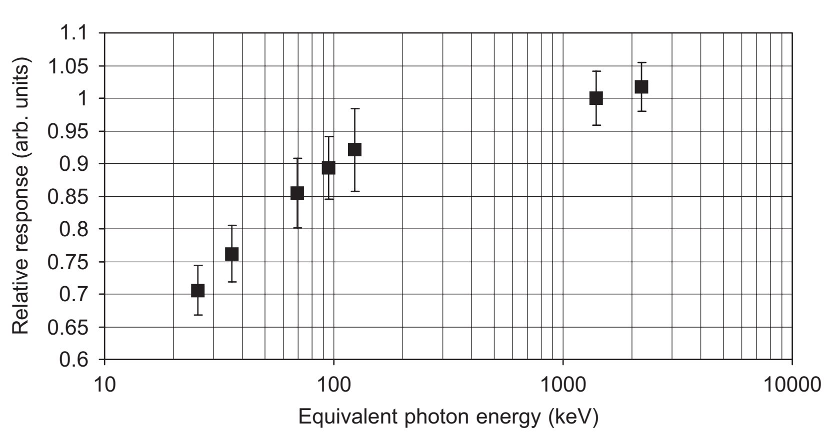

Fig. 2. Energy dependence of the dose response of SIRAD.

used. HVL measurements resulted in the following equivalent photon energies for these beams, respectively: 25.5, 30, 36, 54, 69, 95, 123, 1400, and 2200 keV. The responses shown in Fig. 2 are averages of the responses to the doses of 0.1, 0.2, 0.5, 1 and 2 Gy. A slight decrease in response is seen at higher doses, presumably due to saturation effects. One can see an approximately 30% variation in the optical density per unit dose in the used range of beam energies. Results for the 6-MV X-ray exposure are closest to the calibration chart shown on the SIRAD badges. It follows from our results that a dose provided by a 25.5 keV photon equivalent beam would be underestimated by the dosimeter by approximately 30%. However, a significant color change would still be visually noticeable under these conditions, and that would alert the wearer to a potential radiation risk and provide an immediate rough estimate of the dose. Table 1 lists responses of SIRAD, X-omat V radiographic film and LiF TLD at different energies for an easy comparison of the energy dependences of their responses. The data for the film and TLD are taken from a paper by Cheung et al. (2006), and measurements with the SIRAD badges were performed at similar photon equivalent X-ray energies. One can see that the response of the radiographic film in the kilovoltage range is significantly higher than at 1.4 MV, which is due to the high atomic number of silver in the emulsion. The energy dependence of the response of LiF TLDs is of about the same magnitude as that of the badges, but, in contrast to the badges, the response increases with decreasing energy.

Table 1
Energy dependences of the responses of SIRAD dosimeters, radiographic film, and LiF thermoluminescent dosimeters

Equivalent photon energy (keV)	Relative response (normalized to the response at 1.4 MeV)		
	SIRAD	X-Omat V radiographic film	LiF TLD
25.5	0.706		
28		9.5	1.345
32.5		14	1.456
36	0.762		
39		14.5	1.485
53		13.2	1.368
68		11	1.256
69	0.855		
94		6.1	1.132
95	0.893		
119		2.7	1.075
123	0.921		
1400	1	1	1

Fig. 3shows responses of SIRAD badges to X-ray beams of various equivalent photon energies. The sensitivity of the badge to kilovoltage X-ray beams is lower than to megavoltage ones. As mentioned above, there is an up to 30% variation in OD changes per unit dose in the tested energy range. This may, or may not, be of concern, depending on the energy of the radiation involved. The badge itself cannot analyze the spectrum of the radiation. It does develop, however, an immediate coloration to alert the wearer to irradiation. The coloration can be used to estimate the dose with an uncertainty of 30%, if the energy dependence of the response is not taken into account.

4. Conclusion

The energy dependence of the response of SIRAD badges to radiation dose in the range of equivalent energies from 25.5 keV to 2.2 MeV has been studied. The response variation is about 30%, with a lower response at lower energies. This energy dependence is similar in the magnitude, but opposite in the direction to the energy dependence of LiF TLDs; it is significantly weaker than the energy dependence of the response of radiographic films. When exposed to ionizing radiation, a SIRAD badge develops a color automatically; its intensity provides an estimate of the radiation dose.

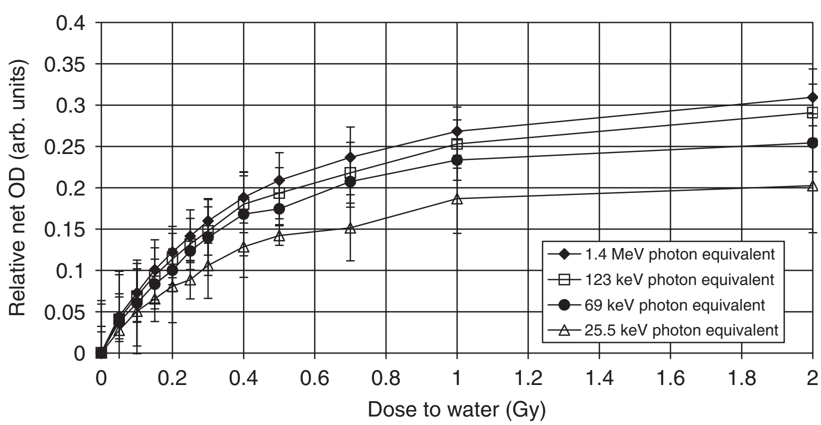

Fig. 3. Dependences of the optical density of SIRAD on dose at various X-ray energies.

Acknowledgements

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