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Comparison Study of the Response of Several Passive PDA Based Personal Dosimeter to Gamma and X-Ray Radiation

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INTRODUCTION

In the case of a radiological terror event or a nuclear accident, there is a need to perform a fast and reliable personal dosimetry measurements for first responders and other intervention forces. The dosimeters should be (i) simple, instant and cumulative readout (ii) small and lightweight (iii) energy independent (iv) wide dose range (v) withstand intense environments (vi) cheap, and disposable. In the last decade, two simple dosimeters were presented for radiological emergencies (i) self-indicating radiation alert dosimeters (SIRAD) and (ii) RADview by J.P Labs(1) and M/s RADeCO(2), respectively. Both dosimeters contain radio-chromic films based on PDA (poly-di-acetylene) material that change the colors in their active window as a function of radiation dose(3).

In the current study, the dose response of SIRAD and RADview personal dosimeters to ^{137}Cs and M150 X-Ray radiation at the range of 0.01-11 Sv is presented. In addition, the environmental, fading effects and usage effects on the response of these dosimeters is evaluated.

MATERIALS AND METHODS

Three types of dosimeters in two configurations (credit card\badge and stamp size) were irradiated by ^{137}Cs and M150 X-ray sources, according to category I (photons, accidents) of the ANSI/HPS N13.11-2009 standard(4). All three types of dosimeters were mounted on a poly-methyl methacrylate (PMMA) phantom surface facing the central ray of the radiation sources at a distance of at least 1 m. Five dosimeters of each configuration type were exposed to gamma and X-Ray radiation doses in the range of 0.01-11 Sv. In addition, the angular response of each dosimeter to radiation was evaluated at 40°, 60° and 180° degrees for exposure of 1 Sv. At the end of each irradiation, both SIRAD and RADVview dosimeters were scanned by a CANON 5600F scanner and MP Navigator Ex software. The scanned images were evaluated by an image processing software in order to analyze the RGB color values of the active material as a function of radiation dose.

Visual Readout Test

A visual estimation of the readout of delivered dose to the radiochromic films was performed by 16 employees of NRCN working as first responders and radiation supervisors. The visual readout test used 36 dosimeters irradiated to doses ranging from 0 to 11 Sv. Each participant was given instruction to evaluate if the dosimeter has been exposed and to estimate the absorbed dose.

Fading Effect

Dosimeters were measured at different time intervals after irradiation to different doses (0.1, 0.5 and 1 Sv) in order to determine the fading (time dependence of the readout after exposure) effect on the RGB color (dose) readout. The dosimeters were evaluated each day for a period of one month. In addition, dosimeters reading were also taken at the end of each month for a period of one year.

Environmental and Usage

Environmental and usage condition were performed in order to verify the manufactures specifications and test the dosimeters performance at extreme conditions. Three dosimeters of each type were exposed to temperatures ranging from 20 to 100 °C and relative humidity of 30%-90% at 40 °C for one hour. In addition, the color change of the dosimeters were evaluated after UV exposure (1-24h), laundry cycle and applied stress ranging from 1 to 4 Tons.

RESULTS AND DISCUSSION

The red and green color intensity for all three types of dosimeters after exposure to ^{137}Cs radiation source as a function of absorbed dose are presented in Fig 1 and Fig. 2. For all three types of dosimeters, the change of the blue color absolute intensity was small (compared to the red and green) and therefore found impractical for dose calculation (this result is not presented in the current work).

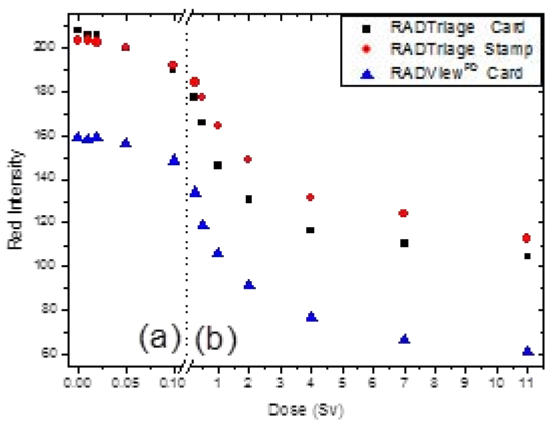

Figure 1. Red color Intensity vs. Absorbed Dose of RADTriage and RADview Dosimeters

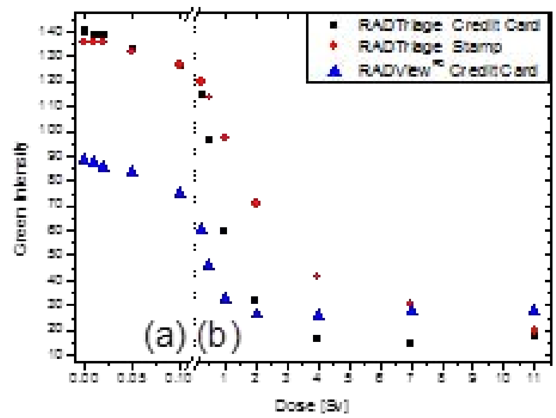

Figure 2. Green Color Intensity vs. Absorbed Dose of Radtriage and RADview Dosimeters

For low doses (up to 0.05 Sv) the change of the green and red color intensity (area (a) in Fig. 1 and 2) on all dosimeters is negligible. In addition, all the PDA materials have completely reacted at doses above 4 Sv (area (b) in Fig. 1 and 2). The red and green intensity decreases significantly above 0.1 Sv, with increasing dose (area (b) in Fig. 1 and 2) for all dosimeters. However, the absolute and the gradient of the color intensity measured in each dosimeter type is different.

The change in the red intensity of RT card is higher for the high dose range and therefore will be more appropriate for accurate dose estimation.

The relative standard deviations for green and red intensities were up to 10% and 40% for blue intensity. The corresponding X-Ray beam experiments (this result is not presented here) show similar curve behavior results for all colors and dosimeters. However, RV card and ST stamps green and red intensities were lower compared to results obtained after exposure to the ^{137}Cs source radiation. This is probably due to energy dependence of this two dosimeters. Yet, the RT card didn't reveal any energy dependence and X-ray RGB intensity results were with good agreement with the ^{137}Cs RGB results.

Angular dependence test didn't indicate on any change of the dose response for all three dosimeters types at 40° and 60° degrees. At 180° degree, after 1 Sv radiation exposure, the dose is attenuated by ~50% compared to 0° due to the radiation absorbance by the phantom. In conclusion, all three dosimeters were found to be appropriate for accurate dose estimation by image processing tools for doses in the range of 0.1-4 Sv according to the red and green intensities. The RV card was found more sensitive to dose change then the red intensity analysis while the RV and ST cards are more sensitive to change in the green intensity. The RT card has the most sensitive film to dose changes (for the green intensity) and has no energy dependence.

Visual Readout Test

Visual dose for RT and RV cards were performed by NRCN first responders and radiation supervisors as a function of delivered dose. The results showed large variation of the visual dose estimation compared to the 20% error declared by both manufactures; but this error decreases with increasing dose.

All of the subjects were able to identify exposure for doses above 0.1 Sv, similar to the RGB analysis results. ST stamps visual test results (not presented here) were similar to the RT and RV cards, but the first responders were able to identify only radiation exposure above 0.25 Sv.

Fading Effect

The relative change in the green and red intensity for all dosimeters after 0.5 Sv and 1 Sv exposure, as function of time are presented at Figs. 3 and 4, respectively.

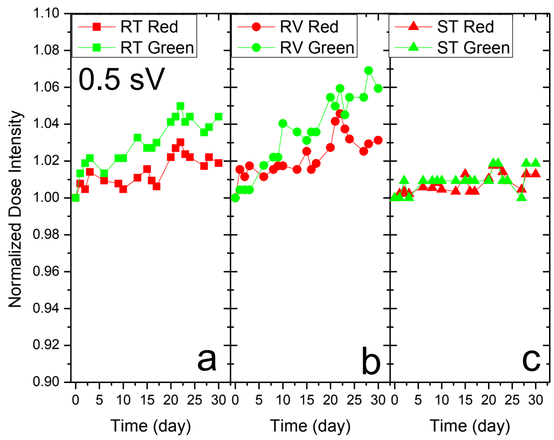

Figure 3. Daily Fading Effect of (a) RT card (b) RV card (c) ST stamp

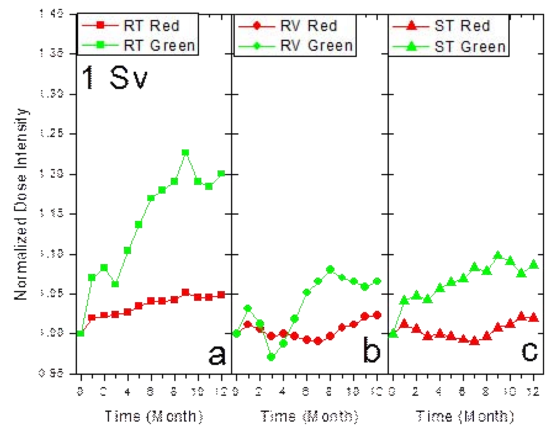

Figure 4. Monthly Fading Effect of (a) RT card (b) RV card (c) ST stamp

For all three dosimeters types there is a fading effect (darkening) within a month from the radiation exposure (Fig 3) due to continuation of the polymerization reaction. It seems that the fading effect of the green color intensity is larger compared to the fading effect of the red intensity due to its higher sensitivity to radiation exposure. RT (Fig. 3a) and RV (Fig. 3b) radio-chromic films exhibited an average color increase of 3% after five days, while no significant color change was observed for the ST stamps (Fig. 3c) up to 20 days later. At the end of the first month, the RV cards had the highest darkening effect. However, for all dosimeters this post-irradiation colorations is less than 10% after 30 days and therefore does not alter significantly the accuracy of the dose readings.

The general trend of the green intensity fading effect continues for all PDA films up to one year post irradiation time (Fig. 4). Both RT and ST dosimeters (Figs. 4a and 4c) present a steady red color intensity (~5% darkening) but the green coloration increases up to 10% and 23% for the ST and the RT dosimeters, respectively. In contrast to the other two dosimeters, the RV card (Fig. 3b) show a somewhat different time dependent behavior with initially decrease in the color intensity (up to 6 month post irradiation) and later both RV colors intensities increase with time. It is therefore concluded that for all PDA's a fading effect dose correction after one month is needed in order to estimate accurate absorbed dose. The red color intensity is less sensitivities to fading effects and therefore is more adequate for accurate dose calculation after long time periods.

Environmental and Usage

The environmental tests aimed to assess the dosimeter performance under wide range of environmental conditions and extreme usage. Relative dose response of all three dosimeter types after 0.5 Sv exposure as a function of temperature and relative humidity at 40 °C is presented in Figures 5 and 6.

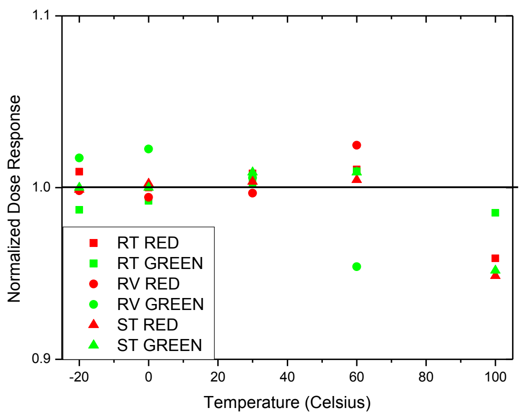

Figure 5. Relative Dose Response vs. Temperature for RT, RV and ST dosimeters

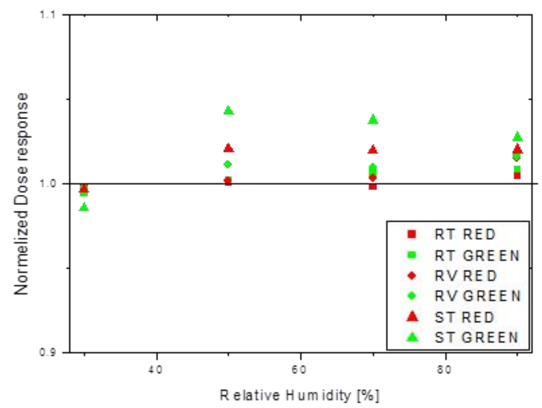

Figure 6. Relative Dose Response vs. Relative Humidity for RT, RV and ST dosimeters

Analysis of the normalized green and red intensity at the temperature range of 20-60 °C after 0.5 Sv exposure (Fig.5) do not show any change from the target value and it is within the statistical error (up to 4%). After exposure to 100 °C for 1 hour the efficiency decreases by more than 5% for all dosimeters types. Both manufactures stated that the dosimeters can withstand temperatures of up to 60 °C, and therefore all of these dosimeters are still compliant within their specification. Relative humidity tests after 0.5 Sv exposure (Fig. 6) didn't reveal any measurable change compared to the expected dose and therefore are with accordance within the manufactures specifications.

The influence of extreme usage that the first responders might encounter was estimated by exposing the dosimeters to UV light, applied mechanical pressure and laundry cycle. No coloration were identified after 24 H exposure to UV-C light. This result is due to a UV light protective filter that cover the dosimeter. However, it is important to note that both manufactures state that the dosimeters do react after long UV light exposure. Applying pressures of 1-4 tons for one min and then exposing the dosimeters to 0.5 Sv didn't exhibit any change in the dose response. This result is consistent with the manufactures statement that the dosimeters can withstand falling and heavy loads. However, after one laundry cycle in all three dosimeters water penetration into the active matrix was observed, causing the green and red color intensity to decrease by up to 10% even before exposure. After exposure to 0.5 Sv, dosimeters showed variations of 10-37% lower compared to the expected dose.

CONCLUSIONS

The physical response of RADview and SIRAD personal dosimeters to gamma and X-Ray radiation was measured according to the ANSI/HPS N13.11-2009 standard[4]. It has been found that all three dosimeters can determine accurate dose measurements in the 0.1-4 Sv dose range by image processing analysis of the red and green color intensity. Visual readout tests indicated that first responders can identify doses above 0.1 Sv. Fading experiments show a coloration increase of up to 20% but by the red color analysis, and an accurate dose estimation of 6% can be achieved. Environmental and usage tests indicate that the dosimeters performance is compliant with manufacturer specification (temperature, relative humidity, etc) except for the laundry cycle experiments.

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