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A Radiation Dosimeter for First Responders

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Abstract

A self indicating, credit card sized radiation dosimeter for monitoring harmful high dose of 10 mSv – 10,000 mSv is presented. It is designed for minimizing the panic and worry in an event of a radiological accident, such as an explosion from a dirty bomb or a serious accident at nuclear power plant. When exposed to radiation, the sensing strip develops blue color instantly and the color intensifies as the dose increases. Thus, it provides the wearer and medical personnel instantaneous information on cumulative radiation exposure. Radiation exposure can be estimated simply by matching the colors of the sensing strip with the adjacent color reference bars. This user-friendly dosimeter is always active and needs no batteries, calibration or maintenance. The dosimeter has shelf life of one year at room temperature and a red liftable filter to protect the sensor from sunlight. Effects of dose, sunlight, temperature, dose rate and energy are presented.

Key Words: RADTriage™, self-indicating, casualty, dosimeter

Introduction

People and governments around the world are concerned about terrorist attacks using a dirty bomb. When detonated, such a device could cause wide spread panic, massive disruption and render the surrounding area uninhabitable for years. Property damage could be in billions of dollars and make millions of people worried for the rest of their lives about their radiation exposure. Affected people want to know their radiation exposure immediately. First responders (police, firefighters, medical personnel, etc.) need to quickly assess radiation exposure among the affected to ensure that treatment is first provided to those who need it the most. RADTriage™, a member of SIRAD® (**S**elf-Indicating **I**nstant **R**adiation **A**lert **D**osimeter) family of dosimeters developed by and manufactured by JP Laboratories, Inc answers those questions quickly and inexpensively. It can take days to get that information by other methods which are also expensive. The first generation of SIRAD was field tested for one year with about 800 first responders in the states of New Jersey, New York and Illinois in 2005 – 2006 by the Department of Homeland Security (Klemic et al, 2007). RADTriage is the second generation of SIRAD with improved sensor, a red protective filter and an indicator for monitoring false signals, shelf life and tampering.

RADTriage™ Dosimeter

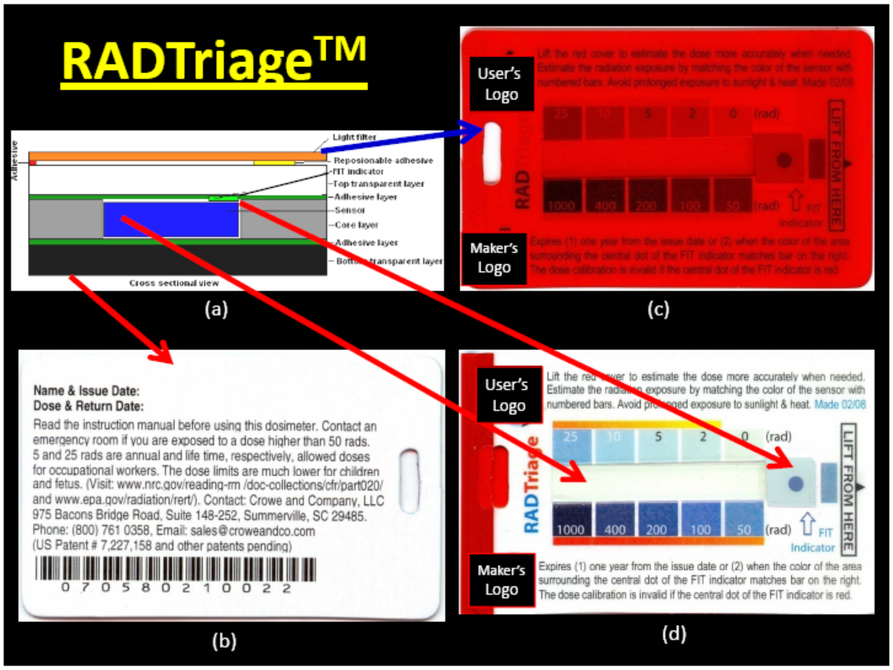

Fig. 1. Cross sectional and top views of bottom, top and core layers of RADTriage.

Design: The cross sectional and top views of the bottom, top and core layers of RADTriage are shown in Figs. 1a-1d respectively. The bottom layer, Fig. 1b is a 100% opaque plastic film printed with identification information and instructions for the user. The user can write his/her name with a ball pen, pencil or a marker. The core layer, Fig. 1d has two monitors, a rectangle sensor (8 mm x 55 mm) in a cavity in the center of the card for monitoring radiation and a square centimeter sized indicator, called FIT™ (for False signals, Inactivation and Tampering) for monitoring false signals, tampering and shelf life. The FIT indicator makes RADTriage much more reliable. The core layer is printed with instructions and color reference bars, 0, 2, 5, 10 & 25 rad bars on its top and 50, 100, 200, 400 & 1,000 rad bars on its bottom for triaging information in an emergency. As dosimeter shown here is made for users in the USA, the radiation unit used on the card is rad (1 rad = 10 mSv = 0.01 Gy). As the sensor is sensitive to ultraviolet light, it is protected with a UV absorbing clear film. These three layers are sealed with hot melt adhesives to make it tamper resistant and evident. In order to further protect the sensors from UV and near UV light, the dosimeter has a repositionable red color filter on the top, Fig. 1c, having a permanent PSA (pressure sensitive adhesive) on the left and repositionable PSA on the right hand side.

FIT™ Indicator: False signals can create unnecessary problems for users and issuing organizations. Under the normal circumstances and if used as per instructions, the sensor of RADTriage will not provide false signals. RADTriage is a smart and reliable personal casualty dosimeter, equipped with a simple-to-use revolutionary indicator for monitoring shelf life and the deliberate or inadvertent exposure to high temperatures and/or UV/sunlight. It is called **FIT™** (acronym for **F**alse-positive, **I**nactivation and **T**amper). The FIT indicator simultaneously monitors false positives & negatives, overexposure to heat & UV/sunlight, shelf-life, inactivation and/or altered sensitivity.

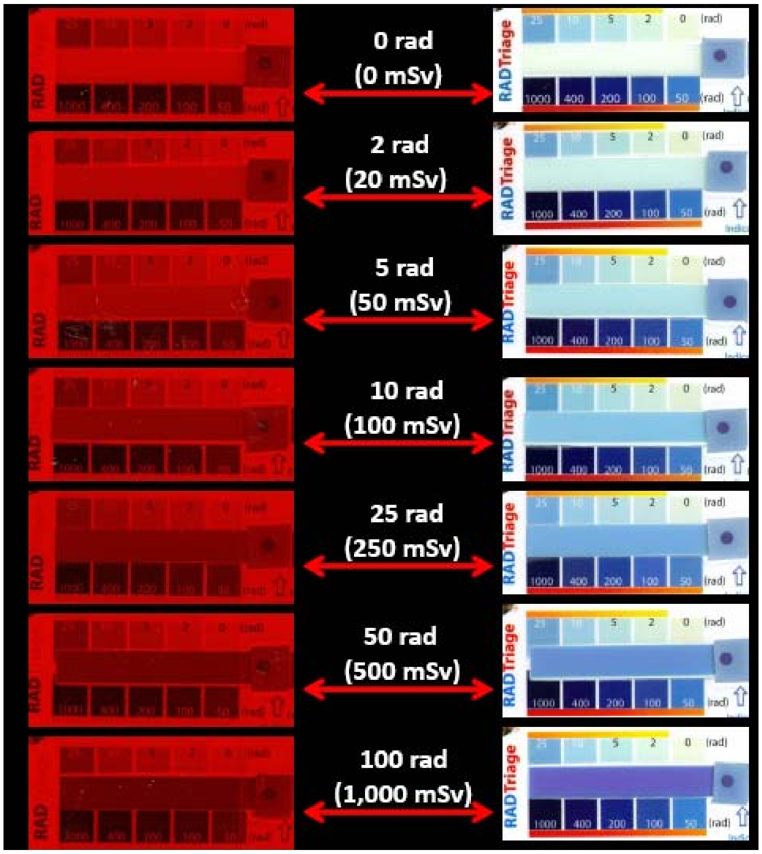

Fig. 2. RADTriage dosimeters radiated with different dosages of 100 KeV X-ray with and without the red filter.

Effect of Dose: When exposed to radiation, e.g., from a "dirty bomb", the sensor of RADTriage develops blue color instantly. Fig. 2 shows the dosimeters radiated with different dosages up to 100 rad (1,000 mSv) of 100 KVp X-ray with (left) and after lifting (right) the red filter. For this and the rest of the figures only sensor portions of the dosimeters are shown. The color of the sensor at higher doses is proportionally darker. The sensor appears gray/black under the red filter which helps color blind people to determine the exposure. The sensor material which develops blue color is a proprietary diacetylene (R-C≡C-C≡C-R, where R is a chemical group). The color development is due to formation of a colored polydiacetylene [=(R)C-C≡C-C(R)]^n upon radiation. The color changes are instant, permanent, cumulative and proportional to the dose, thereby providing the wearer and medical personnel instantaneous, easy to read information on radiation exposure of the victim to assess the health risks and guide treatment. The dose can be estimated with an uncertainty of less than 20% with a color-matching reference chart and less than 10% with a spectrophotometer, an optical densitometer or a scanner/CCD camera (Bak at el 2005, Riel et al 2006). The dose is estimated under a fluorescent light by comparing the color of the sensor with the color reference bars printed on the top and bottom of the sensor. If the sensor develops a color in-between any two adjacent bars which indicates an in-between dose. The sensitivity of the FIT indicator to X-ray is hundreds of times lower than that of the sensor. It will also develop a very faint blue color at 5,000 mSv.

Guidance: If during or after a radiological incident, the color of sensor has not changed, the wearer of RADTriage has not received radiation exposure large enough to cause acute medical effects and therefore has *peace of mind*. If the sensor develops color equivalent to less than 5 rad (50 mSv) it is a yearly allowed limit for occupation workers. In this case, further exposure should be avoided. If the sensor has developed a darker color equivalent to about 25 rad (250 mSv) which is a life time allowed dose for the occupational workers, the user should seek a medical evaluation. If the exposure is higher than 50 rad (500 mSv), the person should get immediate medical treatment depending upon the dose. At exposure of 1,000 rad (10,000 mSv) almost most of the victims will die if no medical treatment is given immediately. The exposure indicated on the RADTriage can be used by medical personnel to prioritize and guide treatment.

Other effects: Color development of the sensor is essentially independent of dose rate (0.1 – 100 rad.min^{-1}). The sensor responds to gamma/X-ray (energy higher than 30 KVp) and high energy (e.g., above 1 MeV) electrons/beta particles. However, protective films attenuate low energy (below 200 KVp) X-ray (Klemic et al 2007). For a given dose, the color of the sensor is about 10% lighter if radiated at 60^{o}C compared to that at minus 10^{o}C (Riel et al, 2006). The sensor is not affected by a normal exposure to diagnostic X-ray (e.g., chest or dental) or security X-ray machines. Multiple (more than five) exposures to medical or airport luggage CAT scans will result in sufficient exposure to produce a detectable color change in the sensor.

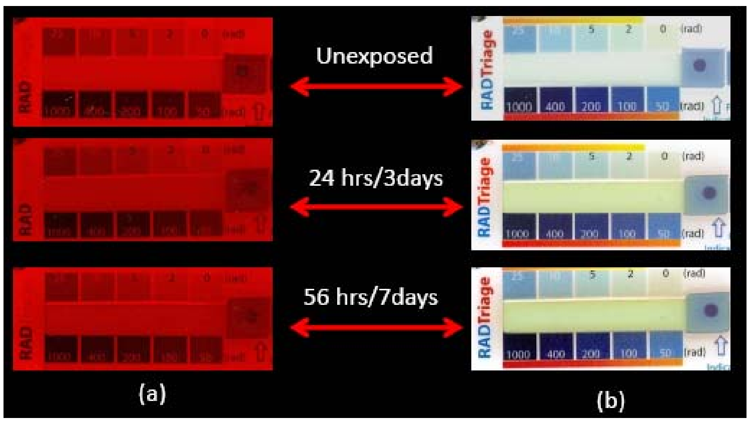

Fig. 3. A RADTriage dosimeter exposed to sunlight with the red filter.

Effects of UV/sunlight with the red filter: A RADTriage exposed to sunlight with the red filter on for 3 and 7 days of direct summer sunlight (August 2008 at Middlesex, NJ) are shown in Fig. 3a and after lifting the red filter in Fig. 3b. The sensor develops light yellow color rather than the blue color even after a week of direct summer sunlight with the red filter on. Thus, the red filter provides sufficient (days in summer and weeks in winter) protection from sunlight.

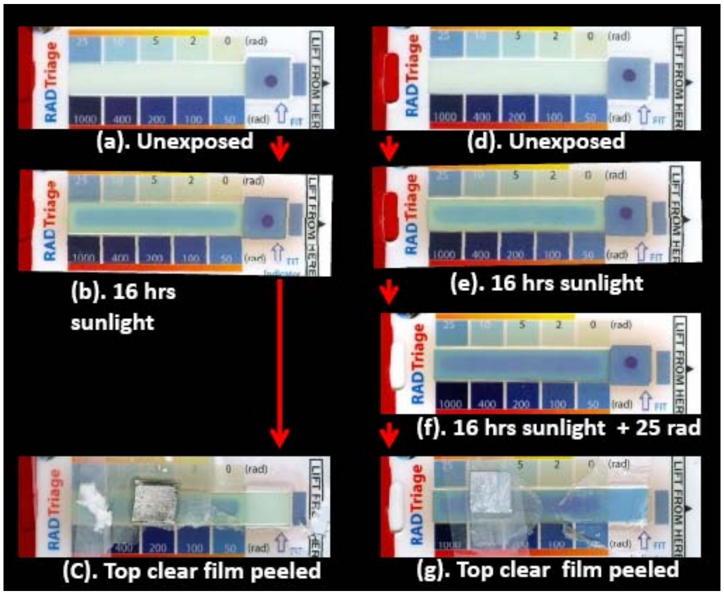

Fig. 4. Two RADTriage dosimeters exposed to sunlight without the red filter.

Effects of UV/sunlight without the red filter: Two RADTriage dosimeters exposed to direct sunlight without the red filter, e.g., 2 days in August 2008 at Middlesex, NJ are shown in Figs 4b and 4e. If the sensor is intentionally or accidentally exposed to direct sunlight for a prolonged period, it will be indicated by (1) the FIT indicator which develops dark blue color. Compare the color of the FIT indicators of Fig. 4a with that of Fig. 4b and Fig. 4d with that of Fig. 4e, (2) the sensor develops greenish blue color instead of the blue color and (3) a halo develops around the sensor, the sensor is darker in the middle than the edges. Thus, one can differentiate the UV exposure, i.e., tampering from the X-ray exposure just by looking at the dosimeter. The metallized substrate of the FIT indicator protects the portion of the sensor under it from the sunlight. Hence, in case of a dispute, the UV/sunlight or X-ray exposure can be confirmed by peeling the clear film of the dosimeter and determining the color of the sensor under the FIT indicator as shown in Fig. 4c. The right hand end of the sensor under the FIT indicator is colorless, indicating no X-ray exposure. It is also possible to determine gamma/X-ray dose of a sensor exposed to both sunlight and X-ray e.g., as shown in Fig. 4f by peeling the clear film and determining the color of the sensor under the FIT indicator as shown in fig. 4g. The right hand end portion of the sensor under the FIT indicator in Fig. 4g, is blue. The color of the sensor under the FIT indicator will be only proportional to X-ray dose as shown in Fig. 4g. Thus, one can differentiate between a false positive signal and a genuine X-ray exposure.

Laundry cycle: The sensor of RADTriage is heat sealed between plastic films and hence is unaffected by humidity and water. A normal residential laundry cycle of washing and drying (below 80^{o}C) has a negligible effect on RADTriage. However, repeated laundry cycles or exposure to temperatures higher than 80^{o}C, especially above 90^{o}C (the maximum operating temperature) will damage the sensors.

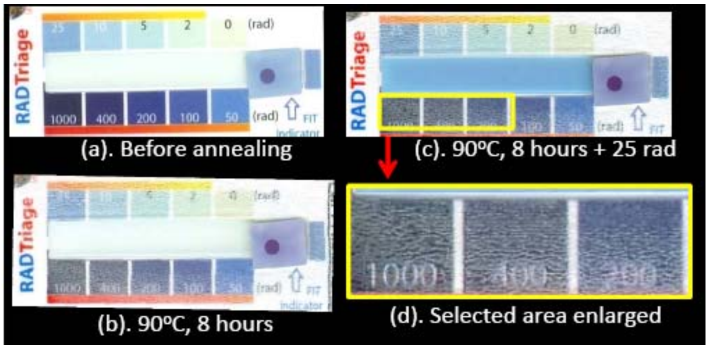

Fig. 5. A RADTriage dosimeter annealed at 90^{o}C and then radiated with 25 rad/250 mSv.

Maximum operating temperature: Maximum operating temperature of the sensor of RADTriage is 90^{o}C. A sensor annealed at 90^{o}C for 8 hrs is shown in Fig. 5b. The sensor develops only negligible color after 8 hours at 90^{o}C. When the annealed sample is exposed to 25 rad/250 mSv the sensor develops color equivalent to 25rad/250 mSv as shown in Fig. 5c. Annealing at 90^{o}C and above is also evident by mud-cracking of the color reference bars and the surrounding area as shown in an enlarged portion in Fig. 5d.
The temperature near the dash board of a closed car in a sunny summer day can reach as high as 85^{o}C. In an unlikely event if the temperature exceeds 90^{o}C, the central blue dot of the FIT indicator develops red color depending upon the temperature as shown in Figs. 6b-6d. The sensitivity of the sensor starts changing at above 90^{o}C and becomes inactive if the temperature exceeds 120^{o}C. The calibration is valid only up to 90^{o}C. The sensor changes reactivity above 90^{o}C and becomes inactive if heated above 120^{o}C. Sensors exposed to temperature of above 90^{o}C can give false negative signal. Heating above 90^{o}C is indicated by the color change (blue-to-red) of the central dot of the FIT indicator. Thus, if the sensor has become inactive for monitoring X-ray, it (a false negative) will be indicated by the FIT indicator as well. Thus, the FIT indicator makes RADTriage very reliable.

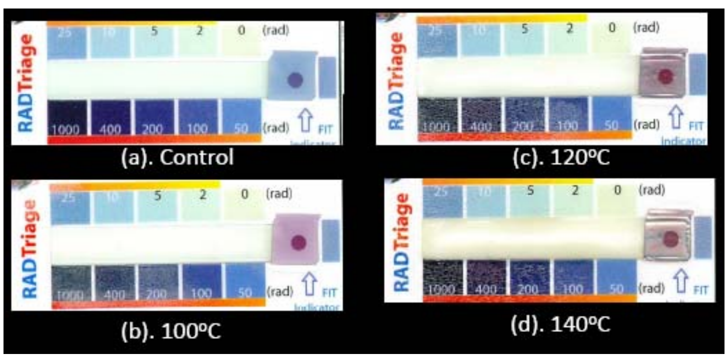

Fig. 6. A RADTriage dosimeter annealed for ten minutes at higher temperatures.

Effect of annealing and Shelf life: The sensor develops color equivalent to about 10 mSv in about one year if stored at 25^{o}C. One can extend the shelf life by storing the dosimeter at lower temperatures, e.g., more than 5 year at minus 5^{o}C or below. If exposed to higher temperatures for prolonged periods, the reduced shelf life will be indicated by the color of the area surrounding the blue dot of the FIT indicator. The expiration of shelf life is indicated when the color of the area surrounding the blue dot of the FIT indicator matches or darker than its color reference bar on its right. The shelf life decreases as storage temperature increases. It will develop color equivalent to about a rad within a week at 60^{o}C and only within a day at 80^{o}C. The shelf life or remaining usable shelf life can be estimated by comparing the color of the FIT indicator with its color reference bar on it right. The shelf life expires when the area surrounding the blue dot matches or becomes darker than the color reference bar.

Summary/Conclusion: There was a technological gap and a need for a user friendly, reliable, inexpensive, light weight, wearable, instant, self-indicating, always ready without a power source, shelf life of at least one year, practically non-destructible dosimeter for monitoring harmful high dose (10-10,000 mSv) with an indicator for monitoring tampering, false signal and shelf life. Such a dosimeter was not available. RADTriage fills that gap and meets the needs. In an event of nuclear/dirty bomb explosion or any radiological accident, RADTriage has almost all desired properties for instantly and reliably monitoring harmful high dose (10 – 10,000 mSv) and thereby minimizing the panic, worry of general public and strain on the healthcare system.

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