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# SELF-INDICATING RADIATION ALERT DOSEMETER (SIRAD)

Gordon K. Riel[1,*], Patrick Winters[1], Gordhan Patel[2] and Paresh Patel[2]
[1]Naval Surface Warfare Center, Carderock Division, code 643 (NSWCCD), Bethesda, MD 20817-5700, USA
[2]JP Laboratories Inc., 120 Wood Avenue, Middlesex, NJ 08846, USA

**In an event of a nuclear or dirty bomb explosion and a radiological accident, there is a need for self-indicating instant radiation dosemeter for monitoring radiation exposure. The self-indicating instant radiation alert dosemeter (SIRAD) is a credit card size radiation dosemeter for monitoring ionising radiation from a few hundredths of a Gray to a few Gray. It is always active and is ready to use. It needs no battery. The dosemeter develops colour instantly upon exposure, and the colour intensifies with dose. It has a colour chart so that the dose on the active element may be read by matching its colour with the chart that is printed next to it on the card. However, in this work, the dose is measured by the optical density of the element. The dosemeter cannot be reset. The response changes by $<1\%$ per °C from $-20$ to $+60$°C. The shelf-life is $>3$ y at room temperature. It contains no hazardous materials. The dosemeter would meet the requirements of instantly monitoring high dose in an event of a nuclear or dirty bomb explosion or a radiation accident.**

## INTRODUCTION

In an event of nuclear or dirty bomb exposition and radiation accident there is a need for, monitoring high dose (10 mGy to 10 Gy) instantly and cumulatively[1], and a dosemeter that is small (credit card size), light weight (a few grams), self-indicating (colour developing), inexpensive ($5–$10) and has a shelf-life of at least 1 y[2]. Figure 1 shows dosemeter before and after exposure with a dose of 0.4 Gy. The immediate response of the self-indicating instant radiation alert dosemeter (SIRAD) helps to prevent further exposure and minimises panic and strain on the health care system under such an event. Radiation dosemeters, such as quartz fibre, thermoluminescent dosemeter (TLD) and X-ray film dosemeters, are either expensive, fragile or take days to get the results, as shown in Table 1.

This study shows the uniformity of the SIRAD, its lifetime as a function of temperature, and its response vs. dose and its relative invariance with energy, dose rate and temperature of exposure.

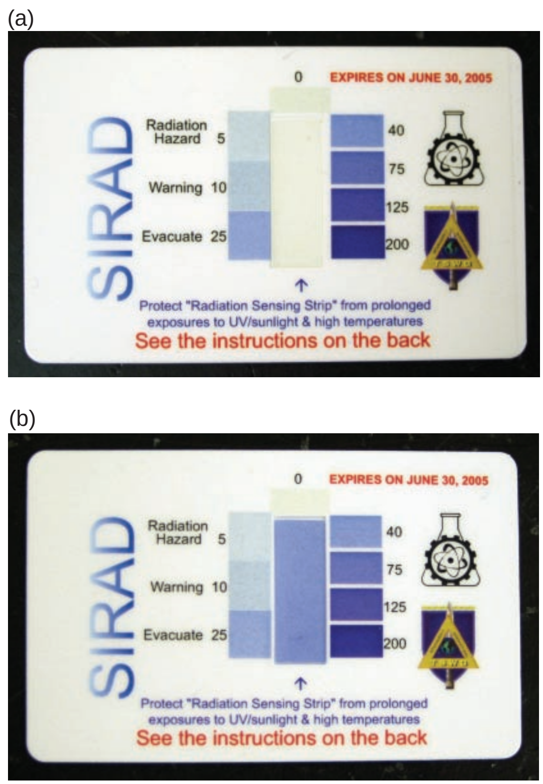


Figure 1. Photos of 0–2 Gy (0–200 rad) dosemeter before (a) and after (b) irradiation with 0.4 Gy of 100 $kV_p$ X ray.

## MATERIALS AND METHODS

### Formulation

Active elements are made from a proprietary diacetylene, polymeric binder and shelf-life extenders. A dispersion of fine crystals of the diacetylene was coated on polyester film and dried. The coating was then laminated with a polyester film. The elements for the dosemeter badges were prepared by cutting the laminated film into 0.8 cm × 2.5 cm pieces.

### Polymerisation

Diacetylenes are colourless solid monomers. They polymerise to highly coloured polymers, $[=(R)C–C\equiv C–C(R)=]_n$, where R is an organic group and

*Corresponding author: gordon.riel@navy.mil

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**Table 1. Comparison of radiation dosemeters.**

| Type | Electronic | Quartz fiber | Film | TLD | SIRAD |
|---|---|---|---|---|---|
| Approximate price | $100 | $50 | $20 | $20 | $5–10 |
| Radiation | Photon | Photon | Most | Most | Most |
| Dose range (Gy) | NA | 0–1 | 0–1 | 0–10 | 0–2[a] |
| LLD (mGy) | ~0.001 | 0.1 | <0.1 | <0.1 | ~50[a] |
| Results | Instant | Instant | Days | Days | Instant |
| Reusable | Yes | Yes | No | Yes | No |
| Disposable | — | — | Yes | — | Yes |
| Archiving | No | No | Yes | No | Yes |
| Light | None | None | Yes[b] | Slight[b] | UV[c] |
| Heat | None | None | Yes | Yes[b] | Slight |
| Humidity | None | None | Yes[b] | Yes[b] | None |
| Shock | Sturdy | Fragile | Sturdy | Sturdy | Sturdiest |
| Shelf-life | NA | NA | Months | Months | Years |

TLD, thermoluminescent dosemeter; LLD, lower limit of detection
[a]Higher and lower dose ranges and LLDs are available
[b]Film and TLDs are usually covered to protect from light and humidity
[c]Light has a negligible effect while the black protective cover is closed

$n$ could be anywhere between 50 and 1000 or more, either upon thermal annealing or exposure to high-energy radiation, such as short wavelength UV light, X ray, gamma ray, electrons and neutrons. Diacetylenes polymerise in the solid state and in the process develop a blue or red colour. Polymerisation of diacetylenes upon thermal annealing (e.g. storage at room temperature) is referred to as thermal reactivity. Polymerisation of diacetylenes by ionising radiation is referred to as radiation reactivity. The diacetylenes selected for the SIRAD have high radiation reactivity and very low thermal reactivity [(1–4)].

## Exposure and reading

JP Laboratories exposed elements to various electron and X ray sources without a phantom, and read them with an optical densitometer. The NSWCCD exposed elements mounted on an ANSI Phantom[(5)] to an NIST traceable $^{137}Cs$ range and read them by using a spectrophotometer. We watched the exposures and saw no delay between the onset of radiation and the colour change. A calibration curve (Figure 2) was established to calculate dose from optical density (OD) by the following formula:

$$D = -\mathrm{LN}\left[\frac{\mathrm{OD} - \mathrm{MaxOD}}{(\mathrm{MinOD} - \mathrm{MaxOD})/r}\right], \qquad (4)$$

where $D$ is the dose in Gy; OD is the observed optical density; MaxOD is the OD of a dosemeter exposed to the maximum dose (200 Gy); MinOD is the OD of an unexposed dosemeter; and $r$ is set to minimise the bias and standard deviation (SD).

The equation is undefined for doses larger than the MaxOD. We have measured doses of 10 Gy, but with reduced precision and by using a MaxOD of 10 Gy and adjusting '$r$' accordingly.

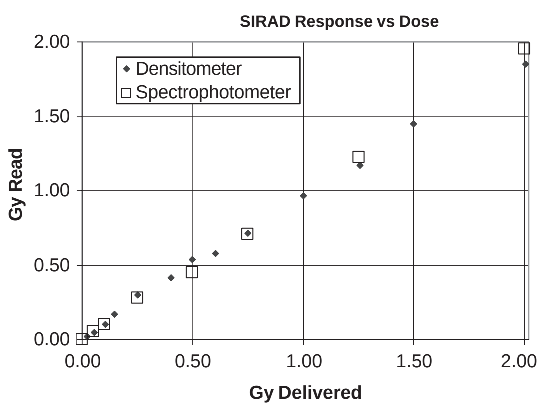


Figure 2. Dose read vs. dose delivered.

One measurement at NSWCCD is the average of ~18 readings. Most are the averages of three elements, and 5–8 different spots are read on each element.

## Spectrophotometer

An Ocean Optics USB2000 with no. 3 grating (350–900 nm) blazed at 500 nm was used. The RPH-1 reflection probe holder kept the R2000 series probe at 45°C to the surface eliminating gloss so that the path length of the reflected light was 2.8 times longer than the thickness of the element. From the transmission spectrum, a 620–625 nm window (the transmission minimum) was selected for analysis. The OD is the negative log (base 10) of the transmission.

**Table 2. Effect of energy.**

| Radiation type | Energy (MV $MeV^{-1}$) | Dose rate (Gy $m^{-1}$) | OD ($\pm$0.01) |
|---|---|---|---|
| Photons | 0.1 | 0.7 | 0.28 |
| Photons | 1.25 | 1.58 | 0.28 |
| Photons | 6 | 2 | 0.28 |
| Photons | 10 | 2 | 0.28 |
| Photons | 18 | 2 | 0.28 |
| Electrons | 6 | 2 | 0.28 |
| Electrons | 9 | 2 | 0.28 |
| Electrons | 16 | 2 | 0.28 |

A 2 Gy SIRAD, irradiated with 0.50 Gy

**Table 3. Effect of dose rate.**

| Radiation type | Energy (MV $MeV^{-1}$) | Dose rate (Gy $m^{-1}$) | OD ($\pm$0.01) |
|---|---|---|---|
| Photons | 6 | 1.0 | 0.28 |
| Photons | 6 | 2.0 | 0.28 |
| Photons | 6 | 3.0 | 0.28 |
| Photons | 6 | 4.0 | 0.28 |
| Photons | 6 | 5.0 | 0.28 |
| Electrons | 6 | 1.0 | 0.28 |
| Electrons | 6 | 2.0 | 0.28 |
| Electrons | 6 | 3.0 | 0.28 |
| Electrons | 6 | 4.0 | 0.28 |
| Electrons | 6 | 5.0 | 0.28 |

A 2 Gy SIRAD, irradiated with 0.50 Gy

## RESULTS

### Linearity of response

The bias + SD from 0 to 2 Gy is 8.5% with the optical densitometer and 7.2% with the spectrophotometer, as shown in Figure 2.

### Batch uniformity of response

Six SIRADs were exposed on a phantom[5] to 0.5 Gy of $^{137}$Cs. The optical transmission was measured at 6–8 different spots on the surface of each SIRAD. The coefficient of variation (COV, the SD divided by the average response of all 41 measurements) is ~4.6%. A normal reading is the average of the measurements on each SIRAD, so that the batch uniformity, the COV of the six averages, is 2.2%. The average COV of the 6–8 measurements on a single element is ~1.3%. So, there is only 1% point of variation from element to element.

### Batch uniformity of blank

The average dose read on 57 unexposed elements is 1.3 mGy with an SD of 5.9 mGy.

### Hot water laundry cycle

Since a small dosemeter may remain with clothing in the laundry, we subjected samples to a normal residential laundry, with a water temperature of 60°C. The temperature reached 70–80°C in the dryer. No false response was seen, and their ability to respond to radiation was not impaired.

The response of 0–2 Gy SIRAD, irradiated with 0.50 Gy does not vary by more than the resolution of the optical densitometer (0.01) with energy or dose rate for electrons or photons (Tables 2 and 3).

### Variation in response owing to exposure at various temperatures

The rate of a polymerisation reaction usually increases with temperature. The SIRAD formula minimises the variation, and the response tends to increase when the temperature is raised or lowered from room temperature. Temperature controlled chambers were placed on the NSWCCD $^{137}$Cs range. Two or three SIRADs were mounted on the window of the chamber to minimise any difference from the dose delivered in free air, and a standard control dosemeter was mounted beside them. From −20 to +50°C, as shown in Figure 3, the average response of the dosemeters at any temperature is neither <0.5 Gy nor >0.6 Gy. The bias of all 12 dosemeters is 8.8% because temperatures higher or lower than room temperature tend to increase the response. Their COV is 8.7%, which is not much larger than the precision of the response vs. dose (7.2%).

### Estimation of shelf-life

Figure 4 shows the apparent dose on elements stored at various temperatures and measured repeatedly for 181 d. The dosemeters were kept on pre-heated insulated aluminium blocks. Thus, the temperature varied slowly between intervals of heating. Selecting an end-of-life dose of 0.25 Gy produces this plot that projects a shelf-life of ~50 y at room temperature. Lower thresholds project a shorter life, ~5 y to acquire a colour equivalent to 0.07 Gy and ~3 y to acquire a colour equivalent to 0.05 Gy. At 62°C (144°F), 0.07 and 0.05 Gy are reached in 25 and 18 d, respectively.

## CONCLUSIONS

The colour development is immediate and is essentially independent of the energy and the dose rate with or without a phantom. Although intended for visual reading, the dose may be read to ~10%

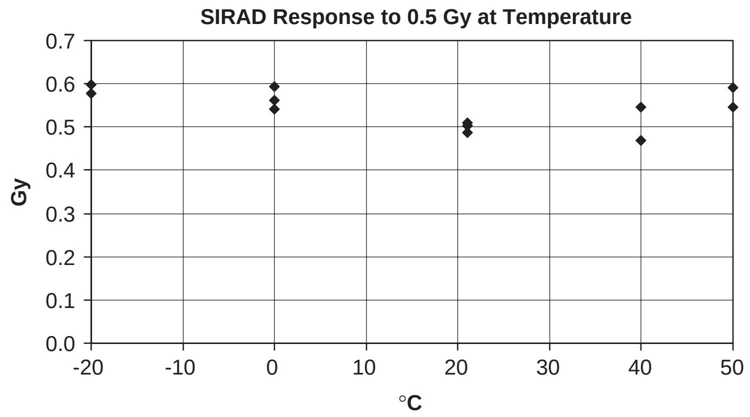


Figure 3. Dosemeters exposed to 0.50 Gy at −20 to +50°C.

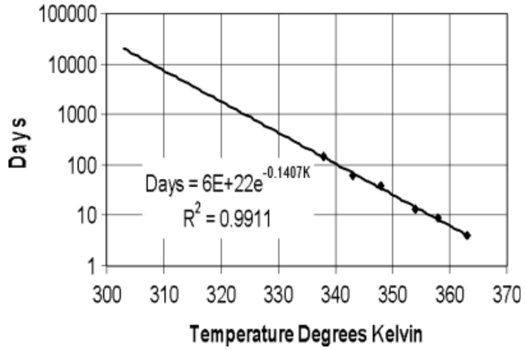


Figure 4. Time to develop a colour equal to 0.25 Gy at different temperatures.

by measuring the OD. Irradiation at −20 to + 50°C tends to increase the response compared with the room temperature, but both the increase in the average response and its COV are <10%. Storage at an elevated temperature produces a false dose, e.g. 0.07 Gy in 25 d at 62°C (144°F), but the SIRAD should last for 3–5 y at room temperature.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. Patel, G. N., Cheng, Y.-M. and Patel, S. H. *Heat fixable high energy radiation imaging film.* US Patent No. 5,420,000, 30 May (1995).
2. Patel, G. N., Cheng, Y.-M. and Patel, S. H. *Polyethyleneimine binder complex film*. US Patent No. 5,672,465, 30 September (1997).
3. Patel, G. N. *Thick radiation sensitive devices*. Patent application No. WO 2004/017095, 26 February (2004).
4. Patel, G. N. *Personal and area self-indicating instant radiation alert dosimeter*. Patent application No. WO 2004/077097, 10 September (2004).
5. Health Physics Society. *American national standard personnel dosimetry performance—criteria for testing*. HPS N13.11-2001 (McLean, VA: HPS) (2001).