"LOW COST SELF INDICATING DOSIMETER (LOCSID)"
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LOW COST SELF INDICATING CASUALTY DOSIMETER

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1. Purpose

The SICD is a self indicating casualty dosimeter which can be used for determination of personnel exposure from radiation sources which may be encountered during a potential conflict or radiological accident. It will allow quick assessment of personnel exposure in the range of 0.5 to 10 Gy so that further exposure may be avoided and the need for medical intervention indicated. Self reading is of great importance Dosimeters requiring readers are little regarded by first responders because, before they are read, the dose will be known from analysis of blood, erythema, and the time to onset of symptoms. The immediate response of the SICD helps prevent further exposure and identifies the time of exposure so that the time to the onset of symptoms may be measured.

2. Description

2.1. Diacetylene Element Radiation is measured by the polymerization of a diacetylene monomer. The G-value (200,000 monomers polymerized per 100 eV) is the highest reported. The colorless monomer develops a color when irradiated with ionizing radiation, i.e., X-ray, gamma ray, electrons and neutrons, and the color intensifies with dose. (Patel 97)

Diacetylene-344: $R-C\equiv C-C\equiv C-R$ $R= (CH_2)_3OCONH(CH_2)_4H)$

Diacetylene-4BCMU: $R-C\equiv C-C\equiv C-R$ $R=(CH_2)_4OCONHCH_2COO(CH_2)_4H)$

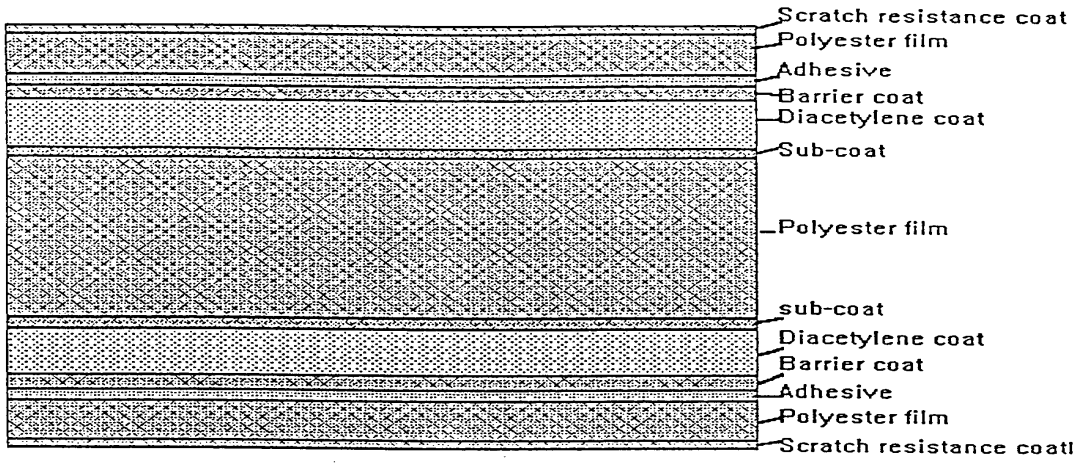


Figure 1. Cross sectional view of the dosimeter element-344 (not to scale)
The active diacetylene is 15 microns thick, and the polyester film is 100 microns. It is protected from exposure to ultraviolet (UV) light by a film that passes visible light.
Type 344 was selected because accelerated aging tests projected a 20 year life before it developed a color corresponding to 0.2 Gy. The more sensitive types, including 4BCMU developed a color faster than type 344 at elevated temperatures.

2.2. SICD Badge

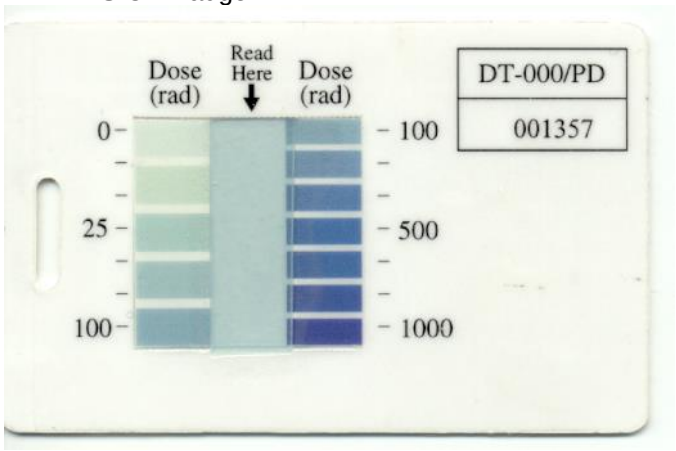


Figure 2. SICD Front
It is approximately the size of a credit card and has an active element marked "Read Here", a color chart, a type number, and a unique sequence number. By comparing the dosimeter element to the color chart, you can estimate the exposure. The color of exposed dosimeters does not fade, and they remain active. If more radiation is encountered, the SICD will record it. The back has space to write the person's name and dates of issue and return. The return address is listed above a bar code which contains the sequence number.

3. Reading

3.1. Visual: Different people see colors differently, and one individual sees colors differently under different lights.
Ten dosimeters were exposed to 360 rad and read by fluorescent light.
Ten were read by three individuals with an average response (dose read/dose given) of 80% and a relative standard deviation of 8%. Three were read by 13 individuals with a response range from 74% to 235% and a relative standard deviation of 0% to 43%.
Four dosimeters exposed to 500, 1,000, 1,530 and 1,530 rad were read by two people. The average response was 102% and the average relative standard deviation was 36%.

3.2. Densitometer: MacBeth 504 Optical Transmission Densitometer, Gold Filter about 600 to 630 nm, spot size 3mm (maximum, to reduce variation across the surface of the element). It read elements, but not badges. Since the coating is not uniform, eight to 24 spots are read and the mean and coefficient of variation is reported.

3.3. Spectrophotometer: Ocean Optics USB2000 with # 3 grating (350-900nm) blazed at 500nm. A 25um entrance slit and L-2 detector collection cylindrical lens increase light-collection efficiency from the LS-1-LL long life Tungsten-Halogen light source. The OOIBASE 32 standard operating software is a 32-bit user-customizable, advanced acquisition and display program that we operated in the transmission mode. From the spectrum we selected five windows each 5 nm wide for analysis. Of these, the 620 to 625 nm window had a lower coefficient of variation than any other single window or sum of windows. The RPH-1 reflection probe holder kept the R2000 series probe at 45 degrees to the surface eliminating gloss. This allowed us to read badges and the path length of the reflected light was 2.8 times longer than the thickness of the element. Usually, eleven spots are read and the mean and coefficient of variation is reported.

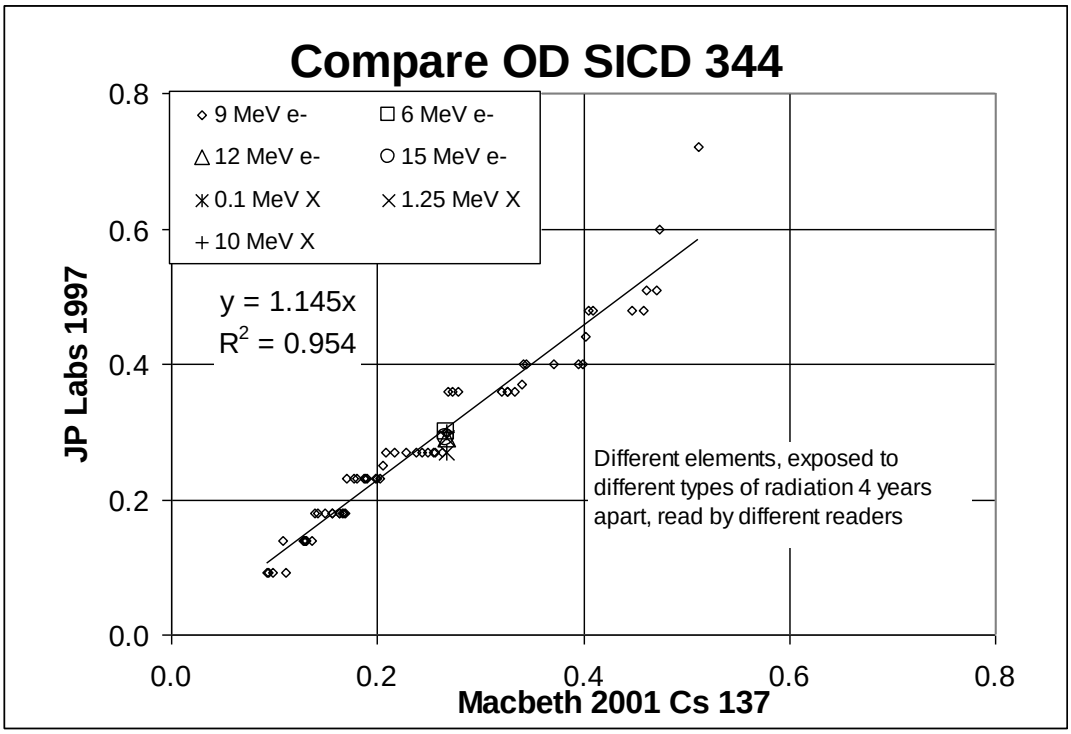
4. Tests For Dosimeter with No Reset
Standards used for guidance are listed in the glossary. None is an exact match to this dosimeter that is always active and never reset. However, draft international standard ISO/DIS 21909 "Passive personal neutron dosemeters-performance and test requirements" is interesting because it covers five types. Rather than one fits all, they allow the tester to determine if the dosimeter in hand is acceptable within the general limitations of the type. IEC 61525 "Radiation protection instrumentation-X, gamma, high-energy beta, and neutron radiations-Direct reading personal dose equivalent and/or dose equivalent rate monitors" was used for further guidance.

4.1. Batch Uniformity:
4.1.1. Optical Densitometer: Since the COV of different points measured on one dosimeter is not greatly different from the COV of different dosimeters, we conclude that the batch is uniform.
4.1.2. Spectrophotometer: The more sensitive instrument detected a slight non uniformity. The COV of different points measured on one dosimeter is about half of the COV of different dosimeters
4.1.3. Of Zero: Twenty seven unexposed badges read in 2002 on the OOI 2000 spectrometer at 620 to 625 nm had a transmission COV of 4.8%. Eleven spots were read on each badge. The average COV of those eleven readings is 2.2%. The calculated dose has a COV of 24% because the response is non linear.
4.1.4. Of Response: Ten dosimeters exposed to about 370 rad had a COV of 3% in optical density. Five dosimeters exposed to about 200 rad had a COV of 4%. The average element had a COV of 3.2% when measured at 18 different points. Ten badges were exposed over the range from 20.2 to 650 rad in 2002 and read with the OOI Spectrophotometer. The COV of the dose was 25%, which is only one point more than the 24% of the badges before exposure. The bias was zero so the bias+COV passes the ANSI 2001 accident category.

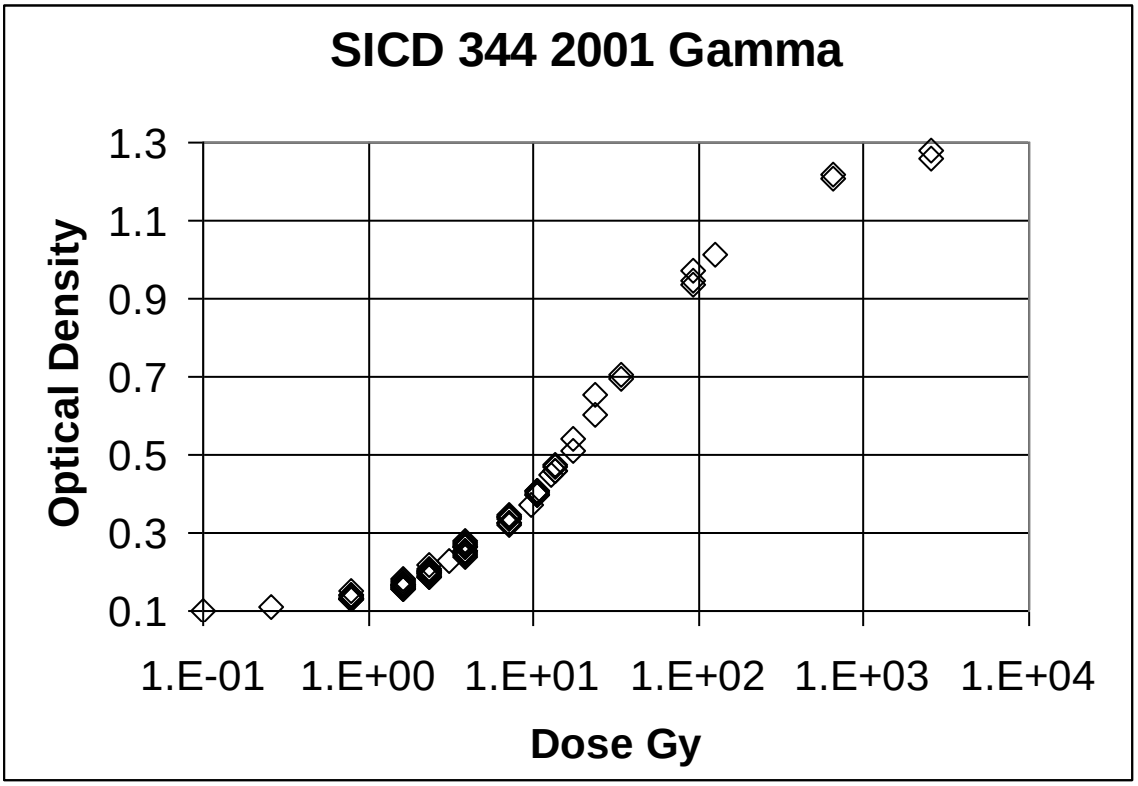
4.2. Response

4.2.1. Versus Energy and Type of Radiation

Since the SICD has the same chemical elements as a person, we expect it to be “tissue equivalent”. It appears to be so, except that the response/dose of neutrons is about half that of Cs-137. Elements that we exposed to Cs-137 have about the same optical density as those that the contractor exposed to x-rays and electrons of various energies.



4.2.2. Versus Integrated Dose: The response per unit dose is reduced as the monomer is consumed. Some other dosimeters and detectors also consume their active material, but the change is usually neglected, except at very high doses, as in a nuclear reactor core. Even though the SICD looks black, doses of 1,000 Gy still make a measurable increase in the optical density.



4.2.3. Versus Dose Rate: This system should produce no variation with dose rate, nor did the contractor find any from 120 to 300 Gy/h. We found none from 0.80 to 13 Gy/h.

4.2.4. Versus Post Irradiation Time: Unlike some self indicating dosimeters, the color change is immediate and does not develop over time.

4.2.5. Versus Irradiation Temperature: At both -50 and +20 degrees C, the nominal response is observed, but at 0 degrees C it is three times higher. At +30 degrees C, the response is about 70%, and at +50 degrees C, the response is about 30% of the delivered dose.

4.3. Retention of Response

4.3.1. Versus Time: No loss in response has been observed in five years.

4.3.2. Versus Temperature: Storage at elevated temperature does not appear to reduce the response, nor would we expect it to.

4.3.3. Versus Humidity: The binder, poly vinyl alcohol, unlike the gelatin used in some dosimeters of this type, is little affected. It is sealed under layers of plastic and then built into an impervious badge that even survives machine washing.

4.4. Retention of Reading

4.4.1. Versus Time: Elements dosed four years ago retained their reading.

4.4.2. Versus Temperature: Storage at elevated temperature tends to increase the reading, not reduce it.

4.4.3. Versus Exposure to Light: Light increases the reading. Badges worn shaded for 20 months retained their reading, as did badges exposed to indirect sun for 20 days. However badges exposed to direct sun for 20 days became significantly darker.

4.5. Retention of Zero:
4.5.1. Versus Time The zero appears to have increased over time, although part of the change may be due to a different reading method as discussed in section 5.
4.5.2. Versus Temperature: Storage at elevated temperature tends to increase the reading. One month at 78 degrees C produced a barely measurable increase.
4.5.3. Versus Exposure to Light:: Light increases the reading. Badges worn shaded for 20 months had a visible increase, as did badges exposed to indirect sun for 20 days. However badges exposed to direct sun for 20 days have a significant color change.

4.6. Lower Limit of Detection
4.6.1. Visual: The LLD depends very much on the observer. Some can see 0.2 Gy, and most can see 0.5 Gy. One colorblind person read it without difficulty, and was less confused by the lack of an exact match between the color chart and the element than were color seeing persons.
4.6.2. Spectrophotometer: The standard deviation of unexposed badges is 0.027 Gy, so at the 2 sigma level we could detect 0.06 Gy.

5. Improvements wanted

5.1. In the element: The COV is largely due to the nonuniform coating, and that is because the coating process was not suited to the small batch size. The sensitivity scales with thickness, so a more efficient process to deposit the active material in a thicker layer could make smaller doses visible.
5.2. In the badge: The color chart must match the color of the element more closely, and it appears that there are color standards to aid us. The badge needs to make the visual reading obvious and to provide basic instructions.

6. Conclusion: The SICD provides an immediate indication of doses that may require medical attention. Using a spectrophotometer produces a COV of 25% over that range. Higher doses can be read, but with less precision. Doses of about 0.5 Gy can be seen, and doses of 0.06 Gy can be read with a spectrophotometer. It is little affected by its environment, except for the temperature during irradiation. The authors have developed confidence by wearing them with no false alarms.

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JP Labs applied for a patent on the SCID Diacetylene formula

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Type Tests:

ISO 4071(1978) "Exposure Meters and Dosimeters-General Methods for Testing". It has been withdrawn and replaced by ISO 11934 (1997) "X and gamma radiation -- Indirect- or direct-reading capacitor-type pocket dosemeters".

Draft international standard ISO/DIS 21909 "Passive personal neutron dosemeters-performance and test requirements". Substantial portions are generic, but most are specific to one of the five types of dosemeters (sic) covered. They range from the old neutron film to the new direct ion storage, and include bubble detectors as well as the more common Albedo TLNDs and solid state track detectors. Each has some variation in the standard set of 14 parameters to be tested, and we may be able to make choices that are specific to the SICD.

IEC 61525 "Radiation protection instrumentation-X, gamma, high-energy beta, and neutron radiations-Direct reading personal dose equivalent and/or dose equivalent rate monitors"