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Calibration of Far West Technology (FWT-60) Radiachromic Dye Dosemeters*

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ABSTRACT

Radiachromic dye dosimetry was used to measure kilogray doses absorbed by various liquid samples during gamma-ray exposure in a spent nuclear fuel pool. The source of nuclear fuel was the Advanced Test Reactor (ATR) at the Idaho National Engineering Laboratory (INEL). Calibrations were performed using a ^{60}Co source and were run on bare dosemeters, as well as on dosemeters which were mocked to simulate the samples. These dosemeters were prepared as a dye-impregnated nylon film and are commercially available. When exposed to gamma-ray doses of 0.5 to 200 kGy, a color change occurs which has an optical density proportional to absorbed dose. The difference in the calibration curves demonstrates the importance of irradiation of dosemeters under conditions as close to the actual samples as possible. Since these dosemeters could not be immersed directly in the organic solutions of interest, they were sandwiched between layers of lucite and stainless steel. This simulated the conditions inside an irradiated sample and provides a practical method of measuring absorbed doses. The reproducibility of measurements using the radiachromic dye dosemeters is also shown.

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INTRODUCTION

This study investigates the use of the Far West Technology (FWT-60) radiachromic detector as a measure of absorbed dose for samples which are gamma irradiated with spent reactor fuel. Experiments at the Idaho National Engineering Laboratory (INEL) have shown that many organochlorine compounds are susceptible to decomposition by exposure to kilogray doses.[1] These doses are easily achievable in a cost-effective fashion at the spent fuel canal of the Advanced Test Reactor (ATR) at the INEL. Our research is aimed at developing a hazardous waste treatment process for organochlorine wastes such as polychlorinated biphenyls, pesticides and solvents. A reliable and versatile dosimetry system was required to measure absorbed doses in these analytes.

The FWT-60 dosemeters are nylon films (50 μm x 1 cm^2) impregnated with the colorless cyanide (CN^-) derivative of an aminotriphenyl acetonitrile dye.[2] Upon exposure to ionizing radiation the CN^- group is lost leaving behind the colored dye cation. The color change is measured with a simple optical density reader.

A number of authors have investigated the optical density response to parameters other than dose in an effort to assess the reliability of radiachromic dosimetry under various process conditions. Factors such as dose rate,[3,4] radiation energy,[3,5] and storage time before readout[3,4,5] have been shown to have little influence on the optical density measurement. The dosimetry is sensitive to ultraviolet light and should be protected from

exposure to sunlight.[5] Far West Technology reports that the affect of irradiation temperature on optical density is not significant over the range of about 10 to 70°C.[2] However some authors have disagreed, finding that temperature during irradiation should not exceed 35 to 40°C[5,7] or 60°C.[4] McLaughlin[6] suggests a temperature correction of +0.3% $(°C)^{-1}$. According to Khan and Ahmad[8] humidity effects are negligible given an optical density measurement within 24 hours of irradiation.

This study presents the results obtained when the FWT-60 dosemeters were adapted to organochlorine irradiations at the ATR spent fuel canal. Calibrations were performed using a ^{60}Co source and were run on bare dosemeters, as well as on dosimeters mocked to simulate samples. The difference in the curves illustrates the importance of calibration of dosimetry under conditions as close to that of actual samples as possible. The reproducibility of measurements using radiachromic dye dosemeters is also shown under our process conditions.

EXPERIMENTAL

The FWT-60 radiachromic film was purchased from Far West Technology (Goleta, CA, USA) and is available commercially. The dosemeters were irradiated for calibration at the ^{60}Co source (10,000 Ci) at the Radiological and Environmental Sciences Laboratory (RESL) of the INEL at a dose rate of 3.633 kGy/hr. The dosemeters were irradiated bare (in glassine envelopes) and also sandwiched between layers of stainless steel and lucite. This configuration, shown in Figure 1a mimics the actual samples shown

schematically in Figure 1b. The stainless steel represents the sample capsule and the lucite represents the organic solution.

The optical density of the developed film was read using the FWT-100 reader system supplied by Far West Technology.

It should be noted that the dosemeters were protected from the humidity of the spent fuel canal by the stainless steel sample containers and that although temperatures are elevated in the vicinity of the spent fuel they are not in excess of 40°C.

RESULTS AND DISCUSSION

The dose response of the film optical density versus dose for bare dosemeters at the ^{60}Co source is shown in Figure 2 at 600 and 510 nm wavelength for doses from 0 to 150 kGy. The response at 510 nm best suited the doses required for our experiments and all further optical densities are measured at the wavelength.

Figure 3 compares this calibration curve for bare dosemeters to the curve generated when dosemeters prepared to simulate samples are irradiated. The dosemeters were prepared to simulate samples as shown in Figure 1b. It can be seen that reliance on a calibration curve prepared by simply irradiating bare dosemeters greatly underestimates the actual dose received by the samples; for example by as much as about 25% at an optical density of 0.7. These plots demonstrate the importance of calibrating dosimetry under conditions as close as possible to those of the actual materials to be irradiated. The error in the dose measurement becomes greater as the dose increases.

For dosimetry to be included inside the actual sample containers shown in Figure 1b the optimum situation would be to insert the film inside the sample vials containing the organic solution to be irradiated. However this is impractical due to the possibility that the solutions would leach the radiachromic dye from the film. Therefore, the film was sandwiched between layers of lucite and then placed adjacent to the sample vials in the stainless steel cylinders for irradiation. The lucite simulates the organic sample solution. In this way the dosemeter is exposed to a gamma field as similar to that of the actual samples as possible. The exposure of the calibration dosemeters at the ^{60}Co source is similar, as previously described.

The reproducibility for replicate simultaneous irradiations in the spent fuel canal has been shown to vary with absorbed dose with the more precise measurements being made at high doses. At doses <10 kGy a relative standard deviation of 7% was measured. The relative standard deviation showed gradual improvement with <1% being measured for doses greater than 100 kGy.

While the dose absorbed by a dosemeter is easily measured by the optical density of the dosemeter, the question remains as to whether this accurately reflects the dose absorbed by material other than the dosemeter. The dose absorbed by a dosemeter may be used to estimate dose absorbed by a sample by correcting the measured dose with the mass energy absorption coefficients ratio of the materials, averaged over the estimated photon spectrum.[9,10] Unfortunately the mass energy absorption coefficients for many materials are unknown and must be estimated based upon their elemental composition. Clearly the problem is complex in a study utilizing numerous target compounds and the constantly changing gamma-ray spectrum of decaying fuel. These problems are

circumvented by surrounding the very thin dosemeter with a very thick sample so that an electron equilibrium associated with the sample is seen by the dosemeter.[7] In our case, lucite (having similar carbon/hydrogen/oxygen ratios and thus similar mass energy absorption coefficients) simulates organic solutions.

CONCLUSIONS

A simple and convenient method to measure doses absorbed by organochlorine analytes in alcoholic solutions has been demonstrated. The importance of running dosimetry calibrations in a matrix which simulates actual samples as closely as possible was illustrated graphically. Further, the performance and precision of FWT-60 radiachromic dosimetry under process irradiation conditions was shown.

REFERENCES

1. Mincher, B. J., Meikrantz, D. H., Murphy, R. J., Gresham, G. L. and Connolly, M. J., *Gamma-Ray Induced Degradation of PCBs and Pesticides Using Spent Reactor Fuel*, Appl. Radiat. Isot., 42, 1061 (1991).

2. *Radiachromic Dosimetry Systems for Radiation Processing*, Far West Technology, Inc., 330D South Kellogg, Goleta, CA USA 93017.

3. Humphreys, K. C., Wilde, W. O., and Kantz, A. D., *An Opti-Chromic Dosimetry System for Radiation Processing of Food*. Radiat. Phys. Chem., 22, 291 (1983).

4. Zhan-Jun, L., Radak, B. B., and McLaughlin, W. L., *Food Irradiation Dosimetry by Opti-Chromic Techniques*, Radiat. Phys. Chem., 24, (1985).

5. Bishop, W. P., Humphreys, K. C. and Randtke, P. T., *Poly(halo)styrene Thin-Film Dosimeters for High Doses*, The Review of Scientific Instruments, 44, 443, (1973).

6. McLaughlin, W. L., Radak, B. B., and Farahani, M., *Measurement Quality Assurance in the Radiation Treatment of Foods*, presented at the Trans-American Nuclear Society Annual Meeting, Boston, (1985).

7. Shaffer, H. L., and Garcia, R. D., *Practice Application of Dosimetry Systems Utilized in Radiation Processing of Medical Devices*, Radiat. Phys. Chem., 31, 497, (1988).

8. Khan, H. M., and Ahmad, G., *Effects of Humidity and Temperature During Irradiation on the Response of Blue PMMA Dosimetry*, J. Radioanal. Nucl. Chem. Let., 153, 57, (1991).

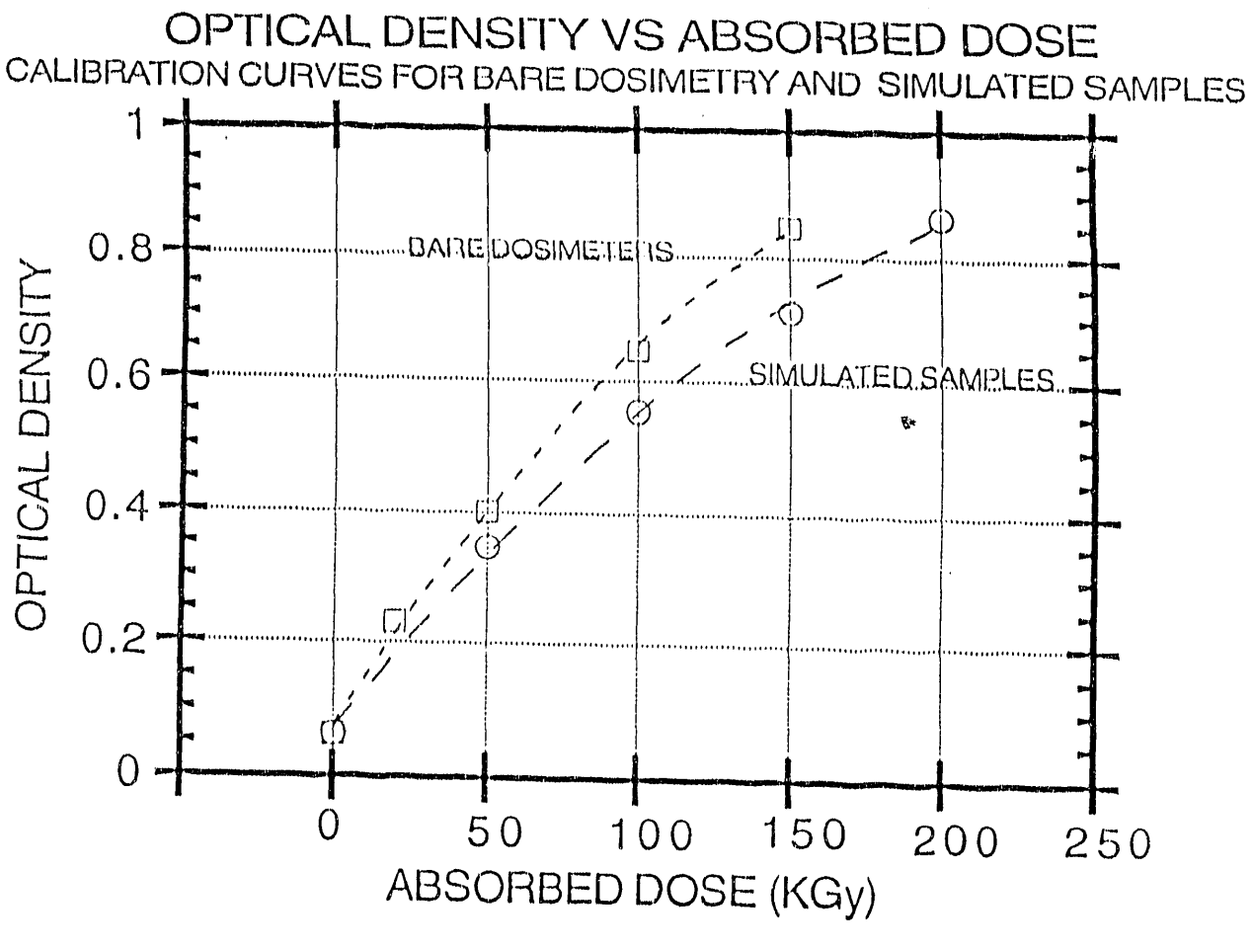
9. Zheng, Z., Jie, F., Hong-Gui, D., and Zhang-Xiong, T., *Some Views Concerning the Absorbed Dose in the Gamma-Ray Irradiation of Traditional Chinese Medicines and Staple Crops*, Appl. Radiat. Isot., 42, 487, (1991).

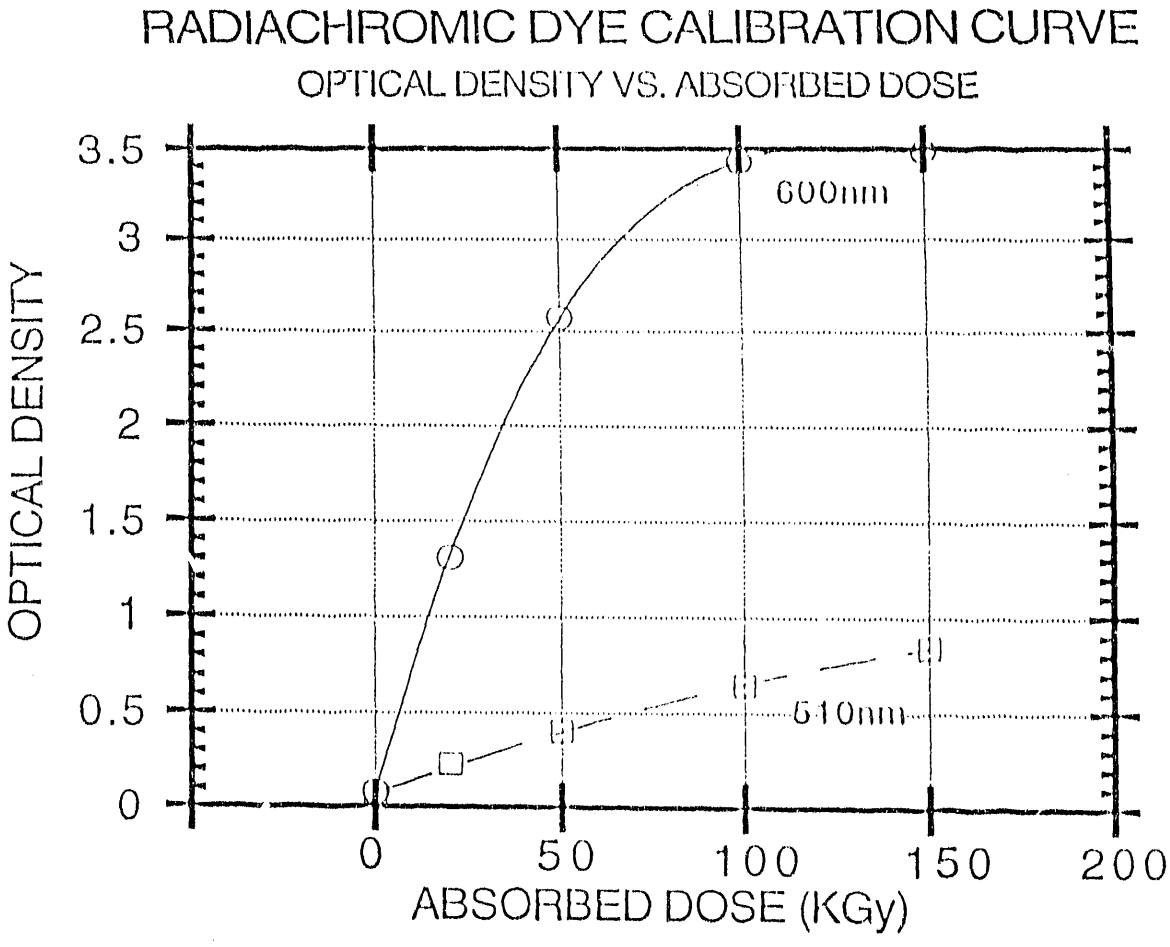
10. Spinks, J. W. T., and Woods, R. J., *Introduction to Radiation Chemistry*, 3rd Ed., Wiley Interscience, New York, 114, (1990).

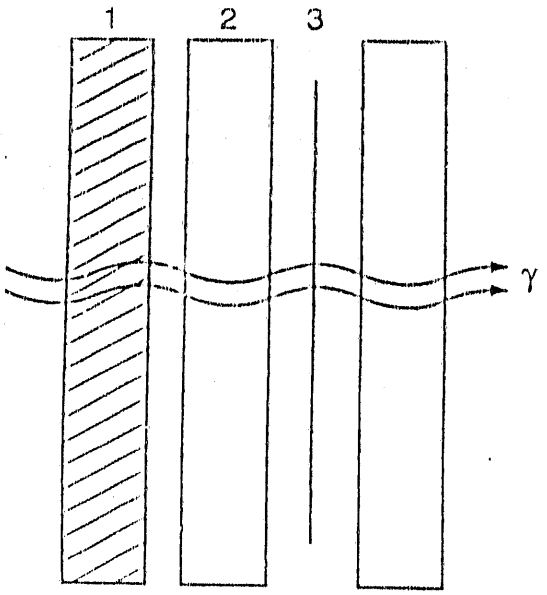
Figure 1. Configuration of dosemeters to mimic actual samples.
1a: Calibration dosimetry, 1: 1/8" stainless steel, 2: 1/8" lucite, 3: 50 μm dosemeter film.
1b: Actual samples, a: 1/8" stainless sample capsule, b: 1 cm diameter sample vial.

Figure 2. Radiachromic dye dosemeter calibration curves for bare dosemeters exposed to ^{60}Co.

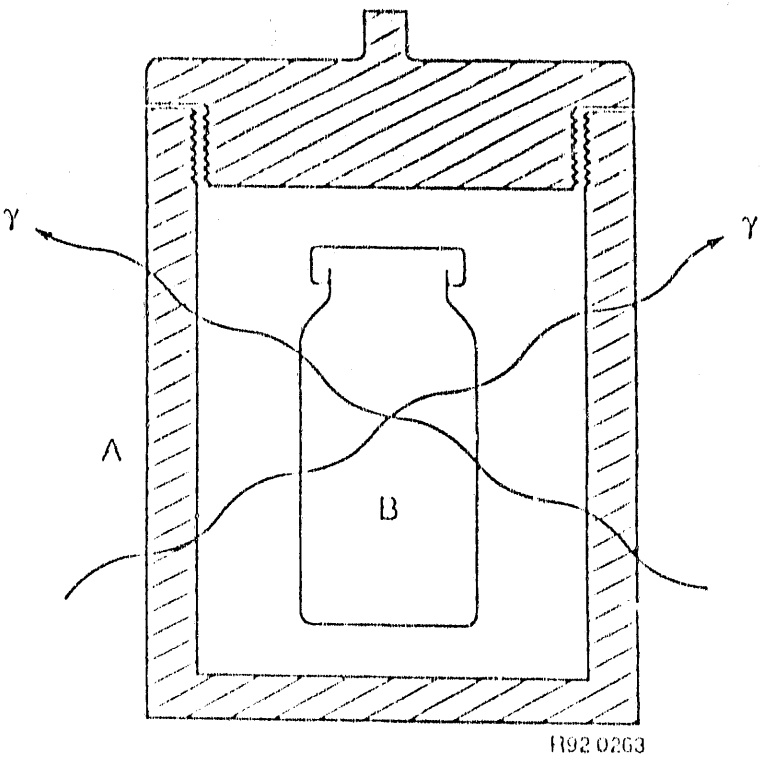
Figure 3. Radiachromic dye dosemeter calibration curves for bare dosemeters and dosemeters which simulate samples.


OPTICAL DENSITY VS ABSORBED DOSE
CALIBRATION CURVES FOR BARE DOSIMETRY AND SIMULATED SAMPLES
BARE DOSIMETERS
SIMULATED SAMPLES
OPTICAL DENSITY
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
ABSORBED DOSE (KGy)


RADIACHROMIC DYE CALIBRATION CURVE
OPTICAL DENSITY VS. ABSORBED DOSE
OPTICAL DENSITY
3.5
3
2.5
2
1.5
1
0.5
0
600nm
610nm
0
50
100
150
200
ABSORBED DOSE (KGy)



1a



1b

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