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HIGH LEVEL DOSIMETRY AT THE STANFORD LINEAR ACCELERTOR CENTER*

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The Stanford Linear Accelerator Center (SLAC) operates a high energy electron accelerator (capable of energies up to 50 Gev). During operation the instantaneous dose rates in the vicinity of the beam pipe due to beam losses can be extremely high. This results in large accumulated doses to beamline components and nearby devices. Since these large doses can cause damage to some of these components and devices, there is always a need for high level dosimetry at SLAC.

Several types of high level dosimeters are used in order to cover a wide range of doses extending from about 10 Gy to 1 MGy. These are optichromic, radiachromic, red perspex, cinemoid (bright rose film #48), and lexan dosimeters. The response curve for each of these dosimeters is presented. Some practical difficulties associated with their use in the field will also be reported.

INTRODUCTION

The Stanford Linear Accelerator Center (SLAC) operates a high energy electron accelerator (capable of energies up to 50 (Gev). Duing operation the instantaneous dose rates in the vicinity of the beam pipe, due to beam losses, can be extremely high. This results in large accumulated doses (from electrons, photons and neutrons) to beamline components and nearby devices. In addition synchrotron radiation from storage rings can deliver very high doses. Since these large doses can cause damage to some of these components and devices, there is a need for high level dosimetry at SLAC.

Radiation damage depends on both integrated dose as well as the dose rate, in addition to environmental factors such as temperature and humidity. Equal doses from different types of radiation do not necessarily produce equal damage(1). For instance, for electronics and semiconductor devices, the displacement of atoms by neutrons is more damaging than ionization by electrons or photons. Whereas for organic insulating materials, the damage depends mainly on the dose and is independent of the type of radiation.

Exposure of plastics and films to electrons and photons results in a number of temporary and permanent changes, such as in appearance, chemical and physical states and in mechanical properties. Some substances undergo a change in color upon irradiation, which affects their light transmission. The change in transmission (T) or optical density (OD = log 1/T) of a material at a suitable wavelength can be used as an index for dose. This is essentially the principle behind the high level dosimeters used at SLAC.

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are optichromic, red perspex, radiachromic, cinemoid and lexan dosimeters.

EXPERIMENTAL METHODS

The opti-chromic (FWT 70-40M, Batch 0-1 and FWT 70-83M, Batch 0-3) and radiachromic dosimeters were obtained from Far West Technology, Inc.[a]

The opti-chromic dosimeters were exposed in holders which provided protection from stray light. The radiachromic dosimeters were sealed in aluminum laminate pouches for protection from humidity changes and stray light during exposure. The radiachromic dosimeters were about 0.05 mm thick. The red perspex[b], cinemoid[c] (bright rose film #48), and lexan[b] dosimeters were about 0.32, 0.023, and 0.32 cm. thick.

The perspex and lexan dosimeters were wrapped in black opaque plastic and together with cinemoid were held in a plastic badge whose front surface was about 0.5 mm thick.

Gamma Irradiation

Dosimeters were exposed to gamma radiation using the ^{60}Co sources (Hotrodder Model U, Nuclear Systems) at U.C. Santa Cruz, California and Lawrence Berkeley Laboratory, California. Build-up materials consisting of plexiglass or polycarbonate were used to achieve electronic equilibirum. The dose rates range from 74-81 MGy/s and 0.6 mGy/s to 0.4 Gy/s (exposure rates were converted to dose rates using a conversion factor of 0.95). The opti-chromic, red perspex, cinemoid and lexan dosimeters were exposed to doses ranging between about 0.15 kGy and 90 kGy. All irradiations were performed at room temperature.

Electron Irradiation

The electron irradiations were performed using an electron beam accelerator (energy = 4.5 MeV).[d]

The surface doses were monitored using radiachromic films which wre calibrated by the National Institute of Standards, Washington D.C. The dose rates ranged between 6.7 and 8 kGy/s. All irradiations were performed at room temperature. All dosimeter types were exposed to electrons.

Dosimeter Readout

The Macbeth quantalog densitometer (TD-102) was used to determine the optical density for red perspex (using gold/visual and red filters) cinemoid (green filter) radiachromic (green filter) and lexan (gold and blue filters).

The Far West Technology Opti-chromic (FWT-98) and Radiachromic (FWT-91R) readers were used to read the opti-chromic and radiachromic dosimeters, respectively. Wavelengths of 600, 656 and 680 nm were used for the opti-chromic and 510 nm for the radiachromic dosimeters (the 610 nm wavelength was not useful for this study).

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[a] Far West Technology Inc., 330-D S. Kellogg, Goleta, CA 93017, USA.

[b] Port Plastics, Inc., 1047 N. Fair Oaks Blvd., Sunnyvale, CA 94089, USA.

[c] Rank Strand Ltd., PO Box 51, Great West Rd., Brentwood, Middlesex TW89HR, UK.

[d] E-Beam Services Inc., 32 Melrick Rd., Cranbury, NJ 08512, USA.

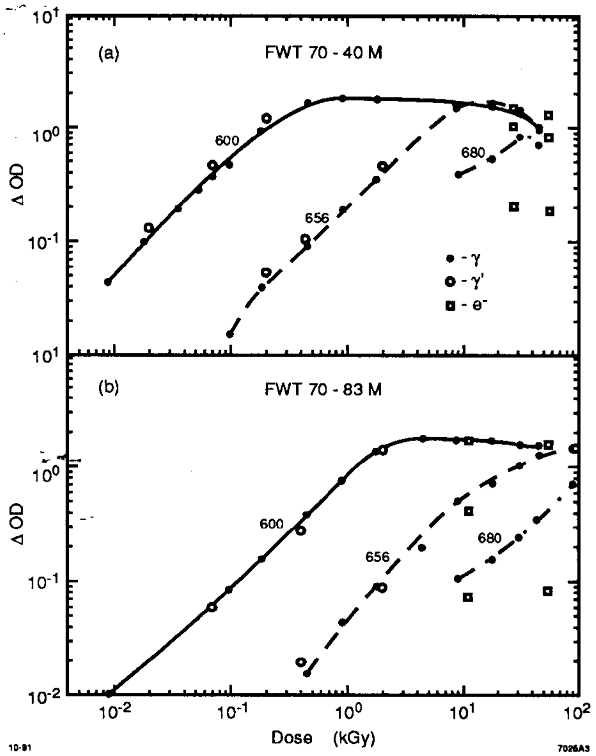


Fig. 1: Response of Opti-chromic Dosimeters.

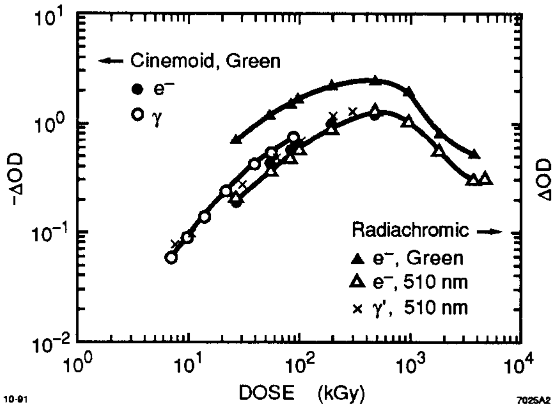


Fig. 2: Response of Radiachromic and Cinemoid Dosimeters.

Two dosimeters were used per irradiation condition and at least four readings were taken per dosimeter (except radiachromic, for which only one reading was taken). Two controls were used for each dosimeter. The difference in the average optical density between the irradiated dosimeter and the control (ΔOD) was then determined.

RESULTS

Opti-chromic and radiachromic dosimeters

The response of the opti-chromic dosimeters for gammas (γ) and electrons (e^-) is shown in Figure 1. The data provided by the manufacturer for ^{60}Co irradiation is also shown (γ'). The curves have been drawn only to aid the eye.

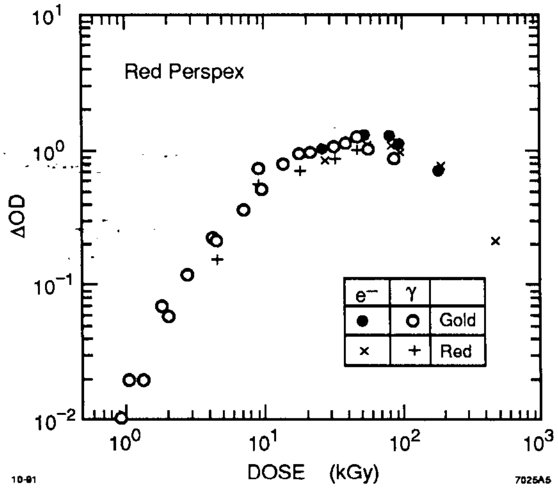
For both FWT 70-40M and 70-83M, the manufacturer data agrees reasonably well with the data obtained in this study at 600 and 656 nm. At these two wavelengths, the gamma and electron responses are fairly equivalent. However, at 680 nm, the electron response is much lower than the gamma response. At doses of about 75 KGy, the dosimeters started disintegrating.

Opti-chromic dosimeters consist of the liquid form of a radiachromic material in an optical waveguide(2). Radiachromic materials are so-called because they exhibit a change in color upon irradiation. The optical properties of the waveguide change with the formation of color centers and hence these dosimeters are called opti-chromic.

The response of radiachromic dosimeters is shown in Figure 2. The response to electrons obtained with the densitometer (green) is higher than the response obtained with the reader, though the shape of the curves are very similar. The data provided by the manufacturer for ^{60}Co gamma irradiation (γ') is also shown. The response for gammas and electrons appears to be fairly equivalent. The response decreases for doses greater than 500 KGy. The radiachromic dosimeters change from a clear colorless film to a deep blue with increasing radiation doses. These dosimeters are dose-rate independent to 10^{13} Gy/s, have an equivalent response to x-rays, gammas and electrons, small temperature dependence and a long shelf life$^{(3)}$.

Red Perspex

The response of red perspex is shown in Figure 3. The response to electrons (e^-) and gammas (γ) is almost the same. The response obtained with the gold filter is similar to that obtained with the red filter. The response begins to decrease for doses greater than 50 kGy. Red perspex changes from a deep red to a dark red and then to brown with increasing doses. The material begins to become opaque as doses approach 1 MGy, and disintegrates thereafter.



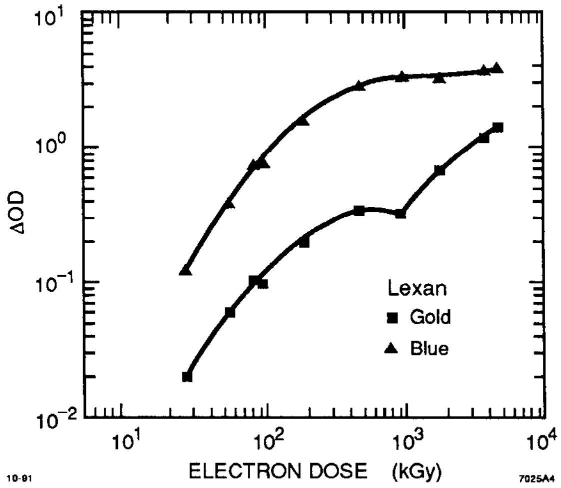


Fig. 3: Response of Red Perspex. **Fig. 4:** Response of Lexan.

Red perspex (polymethyl methacrylate) is sensitive to temperature and humidity effects and suffers from fading$^{(4)}$. Studies in progress indicate a 20% decrease in response for a storage period of about two weeks for doses greater than 50 KGy$^{(5)}$. The response of red perspex is dose rate dependent for doses greater than 10^5 Gy/sec$^{(4)}$.

Cinemoid

The response (-ΔOD) of cinemoid (using green filter) is shown in Figure 2. The response for gammas is slightly higher than the response for electrons. The optical density of cinemoid decreases with increasing doses. Cinemoid changes from a bright rose to paler shades of salmon with increasing doses. The response decreases (optical density increases) for doses greater than 500 kGy. At doses approaching 500 kGy, the cinemoid becomes brownish yellow and very brittle. At higher doses, the cinemoid disintegrates. Cinemoid stored at room temperature for two weeks after irradiation did not show any significant fading$^{(5)}$. The response of cinemoid (dyed cellulose nitrate) is independent of dose rate for dose rates up to 10^{12} Gy/s(6). Temperature rises of more than 80° destroys the dosimeter.

Lexan

The response of Lexan using blue and gold filters is shown in Figure 4. A higher response is obtained with the blue filter, for which the response levels off at doses greater than 1 MGy. The response with the blue filter decreases at doses greater than 600 kGy and then sharply increases with increasing doses. Lexan changes from a clear plastic to yellow and then dark brown with increasing radiation doses. Lexan also suffers from fading(5). For doses between 25 and 100 kGy, there was a 40% reduction in response after storage for about two weeks.

CONCLUSIONS

Table 1 lists the useful ranges of the various high level dosimeters used at SLAC. Since most of these dosimeters have responses that decrease at very high doses, the use of a single dosimeter type can lead to erroneous results at high doses. Hence, a combination of dosimeter types should be used to determine doses. There are some practical difficulties associated with the use of these dosimeters in the field. Fading, sensitivity to temperature, light, humidity and dose-rate dependence can sometimes lead to large uncertainties. A typical accelerator operating run may last for months and the exact time at which the beam losses take place is not known. Hence it is difficult to correct for fading during the run. In addition, mixed fields of photons and neutrons exist in the vicinity of the accelerator, and the responses of these dosimeters to neutrons is not known. All these factors can lead to uncertainties that range from factors of about 2 to 5 in dose determination.

Dosimeter	Wavelength (nm) or Filter	Range (kGy)
Opti–chromic FWT 70–40 M	600 656 680*	0.01 – 1 0.1 – 10 – 30 (γ)
Opti–chromic FWT 70–83 M	600 656 680*	0.07 – 4 0.4 – 100 – 30 (γ)
Red Perspex	Gold Red	1 – 50 1 – 50
Radiachromic	600 510 Green	1 – 40 5 – 500 – 500
Cinemoid	Green	7 – 500
Lexan	Gold Blue	25 – 600 25 – 1000

*Lower limit not established

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Table 1: Range of Dosimeters.

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REFERENCES

1. Schonbacher, H., Radiation Damage Studies for Detector Materials, CERN-TIS/CFM/89-16/CF, CERN, Geneva (1989).
2. Reader's Manual FWT-98 Opti-chromic Reader for Radiation Processing, Far West Technology, Goleta, CA, USA.
3. Humphreys, K. C. and Kantz, A. D., Radiachromic: A Radiation Monitoring System, Radiat. Physics Chem. 9, 737-747 (1977).
4. Whitaker, B., Red Perspex Dosimetry in *Manual on Radiation Dosimetry,* edited by N. W. Holm and Roger Berry (New York: Marcel Dekker, Inc.) (1970).
5. Ipe, N. E. and Liu, J. C., High Level Dosimetry at the Stanford Accelerator Center, SLAC-PUB-5686 (extended version), Stanford Linear Accelerator Center, Stanford, CA, USA (1991).
6. Goldstein, N., Cinemoid Color Films in *Manual on Radiation Dosimetry,* edited by N. W. Holm and Roger Berry (New York: Marcel Dekker, Inc.) (1970).