FAR WEST TECHNOLOGY

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Product Application Literature
PAL-1 February 2019

ABSTRACT

This PAL discusses the use, handling, and calibration of the FWT series of Radiachromic Dosimeters. It gives general use guidelines as well as a wealth of information gathered over the years from users and the manufacturers. Most of the information needed to use these products is represented here.

I. GENERAL

A. Dosimeters

This sheet contains information on the FWT-60 series of dosimeters. This includes:

FWT-60-00	1 cm x 1 cm square
FWT-60-20F	15 cm x 15 cm square
FWT-60-810	8-12.5 µm thick

FWT also manufactures the Opti-Chromic series of dosimeters that are useful for lower doses than the FWT-60 series.

Dose range: 0.5 to 200 kGy; Dose rate independent to 10^{12} Gy s^{-1}

B. Manufacturing

The FWT-60 series of dosimeters are manufactured by Far West Technology (FWT) at its factory in Goleta, California, USA. The manufacturing process involves many steps and is a proprietary process. Each step of manufacturing is closely monitored for quality. Below is a list of the steps used to manufacture the dosimeters.

1. *Manufacturing the Dye and its components.* FWT insures that the dye is of high purity and quality. The nylon matrix that holds the dye goes through several conditioning steps. Clear, blemish free dosimeters are the result of the extra steps in the manufacturing procedures.

2. *Solvent casting large sheets of dosimeters.* Dye/nylon/solvent solutions are evenly spread over extremely flat sheets of glass. The solvents evaporate leaving a free standing film which is then peeled from the glass. The goal in casting the dosimeters is an even thickness which is best performed by casting the dosimeters in sheets. No other form of manufacturing has been found that results in consistent even thickness dosimeters.

3. *Drying and aging the sheets.* The sheets are not completely dry after peeling. They are hung in cabinets with a continuous airflow for 3 months to finish the drying/curing process.

4. *Cutting the sheets into proper dosimeter size.* The sheets are then cut into the required size. They are usually cut into 1 cm x 1 cm squares for the FWT-60-00 dosimeters.

5. *Inspecting and sorting each dosimeter.* Each FWT-60-00 dosimeter is visually checked and sorted by thickness. The thickness of the dosimeters is measured by very sensitive instruments capable of measuring to 0.0001 mm.

6. *Pouching and packing the dosimeters.* Some dosimeters are boxed in quantities of 1000. Others are put into foil pouches, hermetically sealed and then boxed.

Of course shipping is an additional step that is handled by our shipping department.

C. Chemical Composition

The FWT 60 dosimeters are composed of hexa(hydroxyethyl) pararosaniline nitrile. The matrix that holds the dye is nylon. The film has a density of approximately 1.15 g/cm^3 and a composition (by mass) of 63.7% C, 12.0% N, 9.5% H and 14.8% O.

D. Dosimeter lot numbering

The lot numbers are four digit numbers that are sequential according to product production run numbers, thus film lots will not necessarily have consecutive numbers. There is usually only one lot per year and each number is unique.

II. HANDLING THE DOSIMETERS

A. Physical handling

The dosimeters are strong soft nylon films. They can be handled by picking them up with your fingers, but this can be difficult because they are so thin. Picking them up this way will leave fingerprints which can change the optical density readings and thus the exposure data. For these reasons we suggest that dosimeters be handled with round tipped tweezers, the tweezers we use.

B. Ambient light

The dosimeters will change color from penetrating radiation and from UV light below 370 nm. Most artificial lights contain some light in this region and will cause a color change in the dosimeters exposed to the light for very long. Sunlight of course contains a large quantity of UV–even sunlight through a window will contain enough UV to quickly alter the color of a dosimeter. For this reason, we recommend a complete survey of the area where the dosimeters will be exposed to all forms of light. If the area uses fluorescent lights or has some daylight, then the area will probably need filters.

A simple test for UV exposure is to place several uncovered dosimeters of known optical density in the area where dosimeters will be used. Leave the dosimeter in the work area, exposed to ambient light, for 8 hours. If the density change with the exposure is greater than 0.005 OD then the area needs to be filtered. You may want to filter it even if the test shows negative since accidental stray light can have quite an effect on the dosimeter reading. For critical measurements we recommend always filtering all light sources. This includes lights on electronic equipment.

Filtering can consist of covering fluorescent tubes with filter sleeves, covering windows with UV film, covering light fixtures with UV film and purchasing UV free products. Filters are available for fluorescent tubes, incandescent lamps and for windows. All of these materials are designed to block UV light and will do an adequate job of protecting your dosimeters from exposure.

FWT sells both paper envelopes and aluminum laminate pouches to protect the dosimeters when they are in use during irradiation. See section C1 and C2 for information on these products.

Exposing the dosimeters to visible light for prolonged periods (on the order of days to weeks) may cause a decrease in sensitivity. This can occur with no change in background OD. For this reason, we recommend storing the dosimeters in the dark.

C. Packaging

The dosimeters should be protected during exposure. Abrasion, UV light and dirt may all affect the final OD reading and thus the calculated dose. Protecting the dosimeters is as simple as putting them inside an envelope or a pouch. Envelopes protect the dosimeter from UV, dirt and abrasion. Pouches also protect them from humidity change.

1. Envelopes

While most envelopes will work to protect the dosimeters the FWT-80 envelopes are designed specifically for protecting the films. UV light can leak both around the flap and through the corners of conventional envelopes. The FWT-80 envelopes have a large safety flap to prevent UV light leaking through the top and a wide fold at the bottom to cover the corners. The extra thick paper helps to further block UV. They are approximately 1 inch square.

2. Pouches

The FWT-81 aluminized pouches offer the additional advantage over the envelopes of humidity protection. One, two or three dosimeters are placed inside the pouch and the pouch is conditioned (See Section F) and then sealed with a rotary band sealer. The pouches are used where the humidity cannot be controlled during exposure or where a tight control on humidity is necessary for critical readings.

D. Thickness gauge

The dosimeters can be measured for thickness using a thickness gauge. Appendix II lists the equipment that we use at FWT to measure the thickness of all dosimeters. The dosimeters are sorted into the following average thickness bins 0.0425, 0.0435, 0.0445, 0.0455, 0.0465, 0.0475, 0.0485, 0.0495, 0.0505, 0.0515 and 0.0525 mm. Each thickness includes thicknesses in a 0.001 mm range. Thus 0.0425 mm thickness would include all the thicknesses from 0.0420 to 0.0429 mm.

The probes we use are LVDT probes mounted on strong anvils to keep low strain on probes because the equipment measures down to 0.0001 mm. The dosimeters are manufactured of nylon film and are physically soft; the probes used to measure the thickness push into the film and displace it. Thus the thickness is not the actual thickness, but rather the thickness under some pressure. We use low pressure probes which in our experience give the best reproducibility.

E. Storage

We recommend storing unpouched dosimeters at 35-55% RH and 15-30°C. This will assure a long shelf life. Higher temperatures or higher humidity will shorten the shelf life. There is a natural color development that takes place in the film over time and poor storage conditions will speed this up. Under optimum conditions the dosimeters should have a storage life of 3 to 5 years. Shelf life is based on the date the batch is approved through the Batch Characterization process.

Low temperature will retard the aging process. Too low a temperature can cause problems with condensation. High temperatures will accelerate the aging which shows up as a higher initial OD.

Prolonged storage at less than 10% RH can cause a permanent change in sensitivity. High humidity above 70% can cause the films to look cloudy and will cause them to stick together. Exposure above 90% may cause a permanent change in sensitivity.

F. Conditioning

For best dosimetry results the film should be conditioned to a tight temperature and relative humidity range for 24 hours prior to irradiation. We condition pouched film at 47-53% RH and 65-70 °F. Conditioning at a processing facility should be based on the calibration conditions and the ambient conditions.

G. Marking the dosimeters

If you want to mark the dosimeters, we recommend using an extra fine tipped permanent marker. Write the number in the corner away from the center so it will not influence the reading in the reader. See Appendix II for the brands we recommend.

III. USING THE DOSIMETERS

A. Temperature

The dosimeters have some temperature dependence. Figure 1 shows a typical temperature response curve of the dosimeters. This curve is for a constant temperature during irradiation and will vary lot to lot. Most dosimeters will be subject to a varying temperature during irradiation.

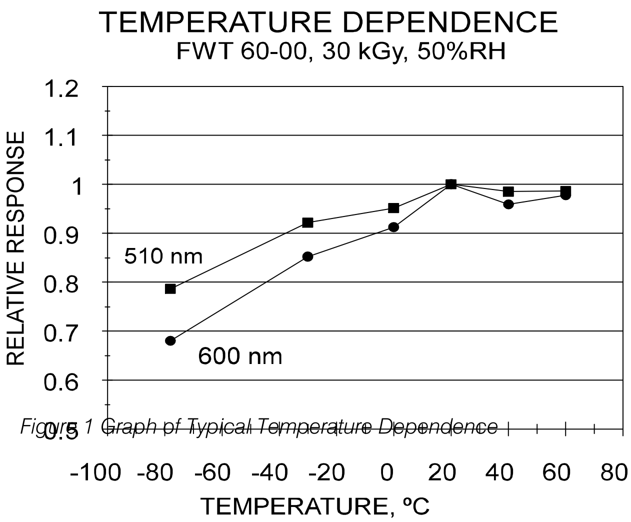

Figure 1 Graph of Typical Temperature Dependence

B. Humidity

The dosimeters have humidity dependence. Figure 2 shows a typical response of the dosimeters to variations in humidity. This curve will vary lot to lot. For critical uses, the dosimeters can be placed in hermetic pouches to stabilize the humidity during irradiation.

C. Color development

The dosimeters may take some time to develop full color. This time will vary depending on the humidity, exposure time, and radiation energy. Typical times are from a few minutes to a few hours. At 24 hours all the color will be developed. The dosimeters can be easily tested to the local conditions by reading some test dosimeters over a period and noting the change. We generally recommend opening pouches for ½ to 1 hour prior to readout.

Generally lower humidity during irradiation will cause the dosimeters to take longer to develop color. Higher dose rates will also delay color change. With long irradiation times the dosimeters may seem to develop quicker–this is because they were developing as they were being irradiated.

The color change can be accelerated by heat treatment. Expose them to 90°C for 2 to 3 minutes or 60°C for 5 to 15 minutes for complete color development

CONDITIONS	EFFECTS
HUMIDITY EFFECTS	
0-10% RH	Possible permanent change in sensitivity
35-55 % RH	Best storage condition
47-53 % RH	Typical pre-irradiation conditioning
70% RH	Film sticks together
90-100 % RH	Possible permanent change in sensitivity
TEMPERATURE EFFECTS	
5° C	Water may condense on film
15-30° C	Best storage condition
60° C	Heat treatment for color development 5-15 minutes at this temperature (If needed)
90° C	Heat treatment for color development 2-3 minutes at this temperature (If needed)

Table 1 Temperature and Humidity Ranges and Their Effects

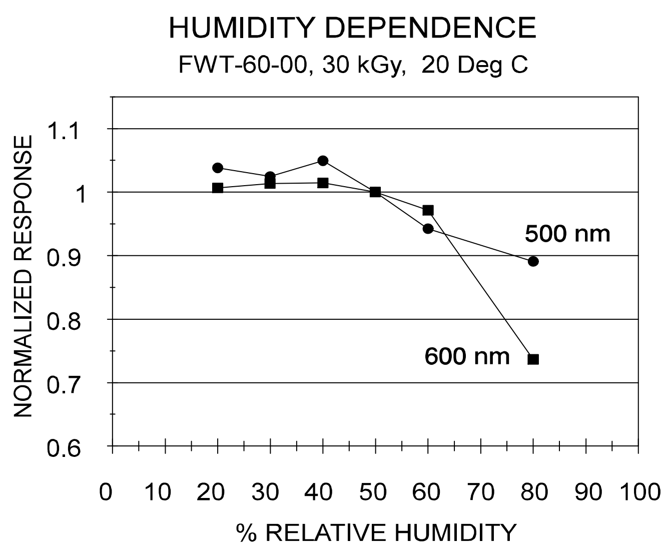

Figure 2 Graph of Typical Humidity Dependence

IV. READING DOSIMETERS

A. Wavelengths of interest

The dosimeters have a peak wavelength for color change. This peak is centered near 605 nm. The wavelengths to use for reading the film are 510 nm and 600 or 605 nm. The two wavelengths are used for different dose ranges.

WAVELENGTH	DOSE RANGE
510 nm	10-200 kGy
600 nm or 605 nm:	1-30 kGy

B. FWT readers

The FWT readers are designed for reading the FWT dosimeters. They read in units of Optical Density (OD, equivalent to Absorbance) and are easy to use. The film holders are sized correctly for the FWT-60 films and they provide a correct and repeatable orientation with respect to the light path. Both analog and digital models are available. Some models have further processing capabilities. A product data sheet is available for each model.

C. Using a spectrophotometer

If you want to use a spectrophotometer there are several points that you should consider. The holder will need to be modified to accommodate the dosimeters and should hold them in the same position for each reading. The holder should also have very little play to keep the angle of light perpendicular to the film. The light beam needs to be small and centered on the dosimeter.

The wavelengths in common use are 510 nm and 600 or 605 nm. Photometers use 600 nm bandpass filters and spectrophotometers are set to 605 nm with a narrow bandpass. Whatever the wavelength or bandpass, it is important that it be the same for both calibration and reading the routine dosimeters.

Beware of contamination from UV or IR light. UV light may color the dosimeter as it is being read. Some spectrophotometers do not have IR or UV filters. Check with the manufacturer. The UV component can be checked by placing a dosimeter in the spectrophotometer and reading it over time. If it changes, then there is a UV component in the instrument and it needs an additional UV filter.

V. CALIBRATION

The FWT Radiachromic Dosimeters, when used to measure absorbed dose, need to be calibrated. Far West Technology can supply a dose calibration curve for the lot; however, it is a typical calibration curve and not traceable to a national standard. If your application requires more than an approximate calibration we recommend a complete calibration of your system, which includes the dosimeters and the reader(s) that may be used. This section describes the techniques to calibrate your dosimetry system.

A valuable reference is ISO/ASTM 51275, *Standard Practice for Use of a Radiochromic Film Dosimetry System*, Annual Book of ASTM Standards. Also useful is ISO/ASTM 51261, *Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing*, and ISO/ASTM 51707 *Guide for Estimating Uncertainties in Dosimetry for Radiation Processing*. If you have stringent calibration requirements we recommend that you purchase these references and use them in your calibration.

The dosimeters are manufactured in lots and each lot will need to be calibrated separately. The lot number is clearly marked on each box. Each reader, if more than one reader is used, will also need to be calibrated. The general procedure for calibration is as follows.

1. Determine how many calibration absorbed dose values are needed. Choose a minimum of five absorbed dose values covering the range of utilization with at least four absorbed dose values per decade of absorbed dose range. For example, if the range of utilization is 10 to 50 kGy, then the absorbed dose values chosen might be 10, 20, 30, 40 and 50 kGy.

2. For each absorbed dose value you need a minimum of five dosimeters. Add an additional set of 5 dosimeters for control. Using the example above, this would be a total of 30 dosimeters (5 dose values x 5 dosimeters/dose value + 5 control dosimeters). All of these dosimeters should be from the same lot. Visually inspect the dosimeters (gently dusting any which need it). Identify the dosimeters by writing a small number in the corner of the dosimeter using a felt tip pen (extra fine permanent markers work best) or label an envelope or pouch containing the dosimeter. Measure the initial absorbance (background) in your reader. The initial absorbance is A_0. Measure A_0 for each dosimeter on each reader you are calibrating.

3. Send all the dosimeters to an irradiation facility whose dose-rate is traceable to national or international standards. Have them irradiate each set to the desired absorbed dose. The control dosimeters should not be irradiated but should be included for a check of the effects of environmental conditions during transport. Alternatively, irradiate the dosimeter in-house with transfer standards that are traceable to national or international standards.

4. Measure the post-irradiation absorbance, A_f, of each dosimeter and calculate the specific net absorbance, k, for each dosimeter: $k = (A_f - A_0)/t$, where t is the thickness of the film. (t may be an average thickness from the lot that you used. Verify that the control dosimeters have not experienced a significant change.

5. Plot the response curve versus absorbed dose. You may also want to perform a regression analysis of the data using an appropriate analytical form. If you are using regression analysis we recommend that it be performed using individual k values rather than averaging k values for a given absorbed dose. Common forms are second and third order polynomials and power series. Regression for power series is discussed below.

6. Examine the calibration for goodness of fit. Repeat the calibration procedure at intervals not to exceed 12 months or after repair of the reader if the manufacturer recommends it. In general, a lamp change will not require recalibration.

7. Calibrate all alternate and backup readers. If you have other readers, calibrate them at this time using the same set of calibration dosimeters. If your primary reader cannot be used you will need to use your backup reader.

8. Keep your dosimeters. Store them in a stable environment in the dark. They may be useful for checking the operation of a reader in the future.

A. Curve fitting

Curve fitting is easiest using a spreadsheet program such as Excel with graph features. To generate the calibration curve, plot the specific response (k) versus the dose. Using a trendline with the equation display enabled you can obtain the calibration equation of the best fit for each wavelength. Typical equation types will be linear, 2nd order polynomial or 3rd order polynomial. You may try different equations to obtain the best fit. From the calibration equation you can then generate a look up table for dose calculations.

Calculations can also be done by hand using linear regression.

B. Example

The data in Appendix I were used as a basis for a calculation of the calibration equation by plotting Column E versus Column A.

Figure 1 shows a response curve derived from the table of data in Appendix I. The data points are plotted using the table. A trendline and equation can be added for analysis of curve fit and trending.

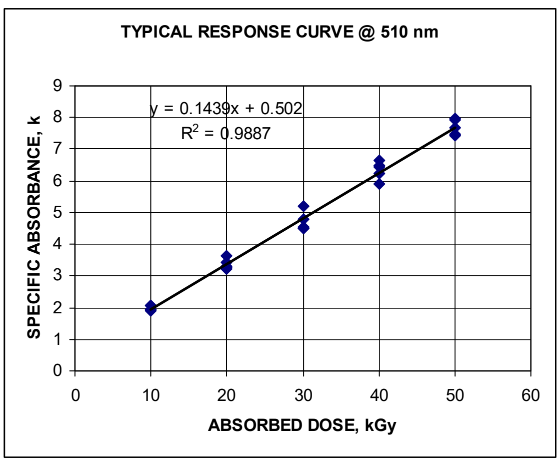

Figure 1 Typical Response Curve

Figure 4 below is a typical curve for the Radiachromic Dosimeters. The net absorbance was read in an FWT reader and shows the approximate net Optical Density (ΔOD, equivalent to net Absorbance) expected for absorbed dose. Background has been subtracted from these readings. The absorbed dose is shown in both kGy and Mrads

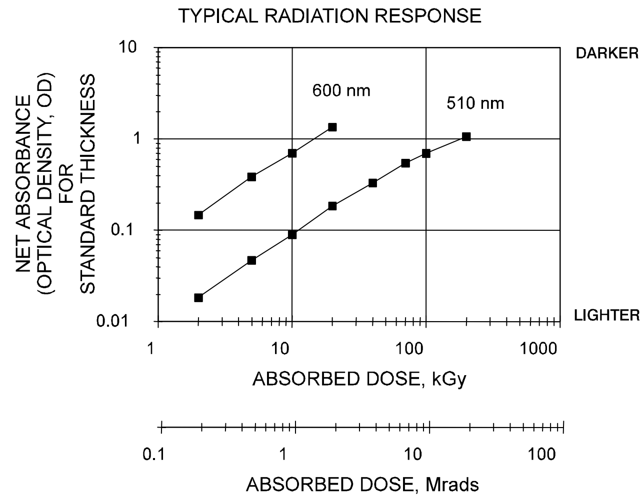

Figure 2 Typical Response Curve in Various Units

APPENDIX I

EXAMPLE OF WORKSHEET FOR CALIBRATION OF RADIACHROMIC DOSIMETERS @ 510 nm				
A	B	C	D	E
DOSE D, kGy	THICKNESS t, mm	INITIAL OD A_o	FINAL OD A_f	NET OD/mm $k = (A_f-A_0)/t$
10	0.0465	0.054	0.151	2.08
10	0.0465	0.053	0.143	1.93
10	0.0465	0.058	0.149	1.95
10	0.0465	0.054	0.141	1.88
10	0.0465	0.063	0.160	2.08
20	0.0465	0.045	0.204	3.42
20	0.0465	0.053	0.207	3.32
20	0.0465	0.050	0.199	3.20
20	0.0465	0.046	0.216	3.64
20	0.0465	0.060	0.212	3.26
30	0.0465	0.051	0.216	4.52
30	0.0465	0.051	0.261	4.53
30	0.0465	0.057	0.298	5.19
30	0.0465	0.051	0.274	4.79
30	0.0465	0.057	0.267	4.52
40	0.0465	0.051	0.341	6.22
40	0.0465	0.047	0.346	6.45
40	0.0465	0.047	0.348	6.49
40	0.0465	0.052	0.361	6.63
40	0.0465	0.065	0.339	5.89
50	0.0465	0.048	0.404	7.67
50	0.0465	0.053	0.400	7.46
50	0.0465	0.062	0.430	7.92
50	0.0465	0.053	0.398	7.44
50	0.0465	0.057	0.429	7.98
0 (control)	0.0465	0.051	0.048	-0.07
0 (control)	0.0465	0.054	0.066	0.27
0 (control)	0.0465	0.043	0.049	0.13
0 (control)	0.0465	0.048	0.065	0.36
0 (control)	0.0465	0.055	0.056	0.02

Description of the columns in this table:

A. The radiation dose that the dosimeters received.

B. The average thickness of the batch of dosimeters

C. The initial absorbance (background OD) before the dosimeters were irradiated.

D. The final absorbance (OD) after the dosimeters were irradiated.

E. The Net absorbance (ΔOD) per mm of thickness

APPENDIX II

THICKNESS GAUGES

Thickness gauges are available manufactured by several companies. Two types we use come from:

Mitutoyo, 18 Essex Road, Paramus NJ 07652
Tel: 201-368-0525 Fax: 201-343-4969

Solartron Metrology
Steyning Way
Bognor Regis
West Sussex
PO22 9ST
Sales
Tel: +44 (0)1243 833333
Fax: +44 (0)1243 833332
Email: sales.solartronmetrology@ametek.com
Reception
Tel: +44 (0)1243 833300
Fax: +44 (0)1243 861244

MARKING PENS

Sharpie Extra Fine Point Permanent Markers in black work very well on the film dosimeters. The fine tip is small enough to write small numbers. The manufacturer is Sanford and they are available in most stationary stores.

HIGH DOSE IRRADIATION FACILITIES

National Institute of Standards and Technology (NIST)
BLDG 245 Room C229
Gaithersburg, MD 20899
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Tel: +1.301.975.5581
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