FAR WEST TECHNOLOGY

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Product Application Literature
PAL-1 April 1998 REV A

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 not only from users but also from the factory itself. 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-60-20	15 cm x 15 cm square
FWT-60-810	8-10 µm thick

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

B. Manufacturing

The FWT-60 series of dosimeters are manufactured by Far West Technology (FWT) at its factory in Goleta, CA. 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 manufactures its own dyes that are used in the dosimeters. This 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 batch numbering

The batch numbers consists of three characters, for example 5E4. The first character is a number and is the code for the batch of dye that was used in the process. The second character is a letter and is a code for the batch of resin that was used in the process. The third character is a number and relates to the year of manufacture.. There is usually only one batch per year and each number is unique. In the example the dye batch was 5, the resin batch was E and the year ended in 4. In this case the year was 1994.

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 you handle the dosimeters with tweezers. Most customers use pointed tweezers which work well for moving them into and out of the envelopes and also when slipping the dosimeters into the film holders of the FWT readers. Some customers prefer small forceps or larger tweezers. We at FWT use tweezers which have very fine round points and are 4 ¼" long. See Appendix II for more information about our supplier.

Tweezers can create their own problems. If the ends of the tweezers are bent, they can cause marks in the film. Inspect the points of the tweezers often and if they are bent replace the tweezers. We have not been able to straighten bent tweezers to the same level of finish as when they were new. If they are dropped we replace them and save the dropped tweezers for other uses.

B. Ambient light

In addition to changing color from penetrating radiation the dosimeters will also change color 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 fluorescents 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. See Appendix II for UV blocking films .

FWT sells both paper envelopes and 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 will 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 sealed with a hot sealing iron. The pouches are used where the humidity cannot be controlled during exposure or a tight control on humidity is necessary for critical readings.

3. Polyethylene bags

Polyethylene bags can retard moisture transport between the dosimeter and the environment but they will not prevent it. They are useful for short term storage but their effectiveness is reduced as temperature increases. Nevertheless, bags which can be sealed (zipper style or hot seal) may provide adequate protection for many processing facilities.

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, and 0.0515 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 the 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.

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 film at 47-53% RH and 20-21 °C. 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.

The color change can be speeded up 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

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 batch to batch. Most dosimeters will be subject to a varying temperature during irradiation.

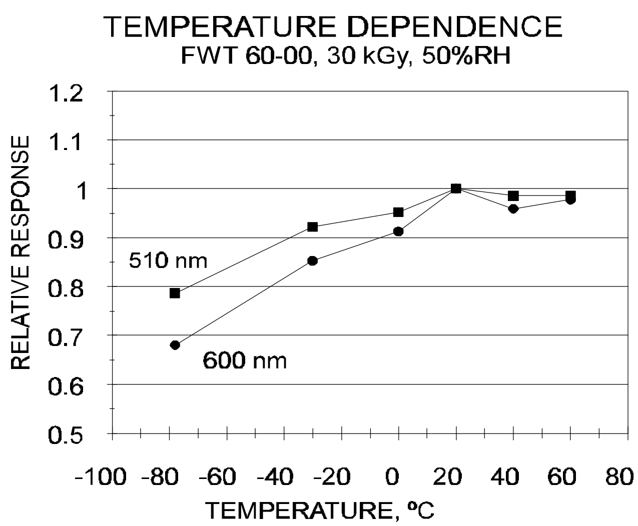

Figure 1 Graph of Typical Temperature Dependence

CONDITIONS	EFFECTS
HUMIDITY EFFECTS	
0-10% RH	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	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
90° C	Heat treatment for color development 2-3 minutes at this temperature

Table 1 Temperature And Humidity Ranges And Their Effects

B. Humidity

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

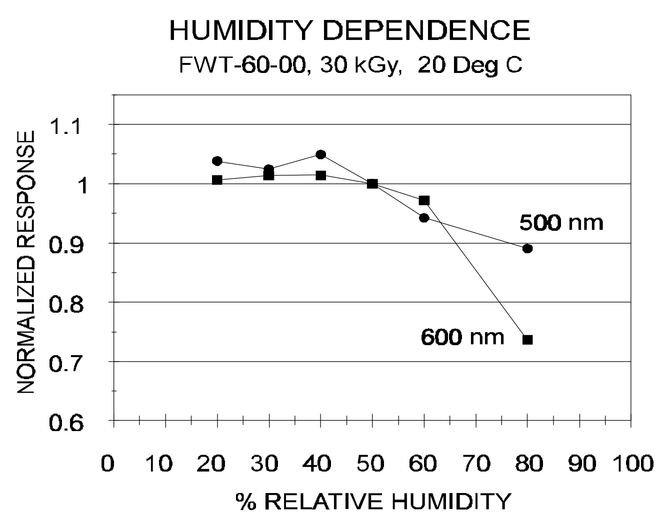

Figure 2 Graph of Typical Humidity Dependence

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.

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.

IV. READING DOSIMETERS

A. Wavelengths of interest

The dosimeters have a peak wavelength for color change. This peak is centered on 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) 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 small size of the films 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.

Watch out for contamination from UV or IR light. UV light will 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 batch; however, it is a typical calibration curve. If your application requires more than an approximate calibration we recommend a complete calibration of your system, which includes the dosimeters and the reader. This section describes the techniques to calibrate your dosimetry system.

A valuable reference is ASTM E 1275, *Standard Practice for Use of a Radiochromic Film Dosimetry System*, Annual Book of ASTM Standards, Vol. 12.02. The information that follows is compatible with E 1275-93. Also useful is ASTM E 1261, *Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing*, and ASTM E 1707 *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 batches and each batch will need to be calibrated separately. The batch 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 batch. 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 containing the dosimeter. Measure the initial absorbance (background) in your reader. The initial absorbance is A_0. Measure A_0 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.

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 batch 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 to a power series using linear regression

The power series form of the calibration curve is $k=aD^b$, where D is the absorbed dose and a and b are calibration constants. In practice this equation is then rearranged to the form $D=(k/a)^{1/b}$, allowing dose to easily be calculated from the specific net absorbance. A logarithmic transformation of the power series allows the constants a and b to be determined from a linear regression. Taking the base 10 logarithm of the power series gives $\log(k) = \log(aD^b) = \log(a) + b\log(D)$, an equation of the form $y = c + mx$. The regression is performed using log(D) as the dependent variable and log(k) as the independent variable. The linear regression gives the y-intercept, sometimes called the constant, and the slope or x coefficient. These values are c and m, respectively. Finally the desired constants are calculated as $a = 10^c$ and $b = m$

B. Example

The data in Appendix I was used as a basis for a calculation of c and m. Column F is the log of the dose and column G is the log of k. k is in column E. Columns F and G were entered into the linear regression function of a hand held calculator. The values of c (y intercept) and m (slope) were -0.558 and 0.844 respectively. Using the formula:

$a = 10^c$ and $b = m$, results in

$a = 0.276$ and $b = 0.844$.

a and b can now be used to calculate the dose from an unknown dosimeter. For example, using the following values, thickness = .0465, background OD = 0.060, post irradiation OD = 0.255, a = 0.276, and b = 0.844 the dose would be: 25.1kGy.

$$D = [(A_f - A_0)/(ta)]^{1/b}$$

$$= [(0.255 - 0.060)/(0.0465 * 0.276)]^{1/0.844}$$

$$= 25.1 \text{ kGy}$$

Figure 3 shows a response curve derived from the table of data in Appendix I. The data points are plotted using the table. The line through the points was plotted visually.

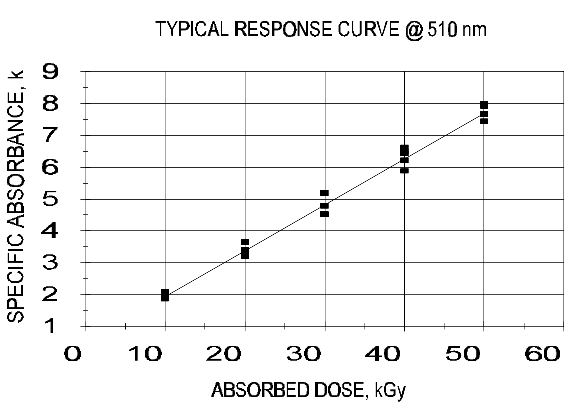

Figure 3 Typical Response Curve

VI. OPTICAL DENSITY

To measure the amount of light transmitted through a colored material requires a photometric sensor to change light energy to electrical energy. If the original light intensity is I_o and the intensity with a Radiachromic dosimeter in the light path is I then the transmittance T is:

$$T = I / I_o$$

The optical density is given by:

$$OD = \text{Log}(1/T) = \text{Log}(I_o/I)$$

The typical response curve known for the Radiachromic dosimeters indicates that the change in optical values is proportional to the absorbed dose.

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

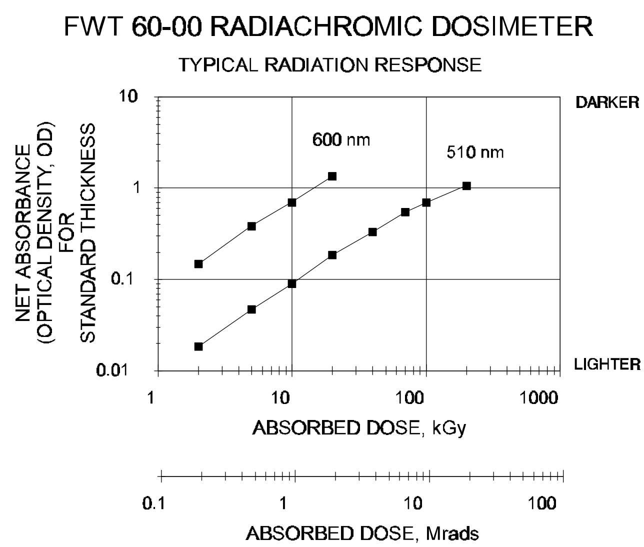

Figure 4 Typical Response Curve in Various Units

APPENDIX I

EXAMPLE OF WORKSHEET FOR CALIBRATION OF RADIACHROMIC DOSIMETERS @ 510 nm						
A	B	C	D	E	F	G
DOSE D, kGy	THICKNESS t, mm	INITIAL OD A_o	FINAL OD A_f	NET OD/mm $k = (A_f - A_0)/t$	LOG DOSE	LOG k
10	0.0465	0.054	0.151	2.08	1.0	0.318
10	0.0465	0.053	0.143	1.93	1.0	0.286
10	0.0465	0.058	0.149	1.95	1.0	0.290
10	0.0465	0.054	0.141	1.88	1.0	0.273
10	0.0465	0.063	0.160	2.08	1.0	0.319
20	0.0465	0.045	0.204	3.42	1.301	0.534
20	0.0465	0.053	0.207	3.32	1.301	0.521
20	0.0465	0.050	0.199	3.20	1.301	0.505
20	0.0465	0.046	0.216	3.64	1.301	0.562
20	0.0465	0.060	0.212	3.26	1.301	0.613
30	0.0465	0.051	0.216	4.52	1.477	0.655
30	0.0465	0.051	0.261	4.53	1.477	0.656
30	0.0465	0.057	0.298	5.19	1.477	0.715
30	0.0465	0.051	0.274	4.79	1.477	0.681
30	0.0465	0.057	0.267	4.52	1.477	0.655
40	0.0465	0.051	0.341	6.22	1.602	0.794
40	0.0465	0.047	0.346	6.45	1.602	0.809
40	0.0465	0.047	0.348	6.49	1.602	0.812
40	0.0465	0.052	0.361	6.63	1.602	0.822
40	0.0465	0.065	0.339	5.89	1.602	0.770
50	0.0465	0.048	0.404	7.67	1.699	0.885
50	0.0465	0.053	0.400	7.46	1.699	0.873
50	0.0465	0.062	0.430	7.92	1.699	0.899
50	0.0465	0.053	0.398	7.44	1.699	0.871
50	0.0465	0.057	0.429	7.98	1.699	0.902
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

F. The log of Column A, used in linear regression calculations

G. The log of Column E, used in linear regression calculations

APPENDIX II

TWEEZERS

We use part NO: 758TW474. These are No 3 tweezers from
Techni-tool, 5 Apollo Road, Plymouth Meeting, PA 19462
Tel: 610-941-2400 Fax: 610-828-5623

UV FILTERS

Sleeves for fluorescent tubes and window coverings are available from: UV Process Supply, 1229 W. Cortland St., Chicago, IL 60614
Tel: 312-248-0099

THICKNESS GAUGES

Thckness gauges are available manufactured by:
Mitutoyo, 18 Essex Road, Paramus NJ 07652
Tel: 201-368-0525 Fax: 201-343-4969
These parts are available through machine shop suppliers. The part numbers are:

Mu-Checker Digital Readout: 519-605 or 519-615

LVDT Probe: 519-890 or with lift: 519-891

Vacuum lift for use with 519-891: 523349

Digital Gauge Stand: 7004 (Includes flat anvil)

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
USA
Contact: James Puhl
Tel: +1.301.975.5581
Fax: +1.301.869-7682
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Fax: +44.181.943.6680
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