MODEL FWT-91R RADIACHROMIC READER

Operations Manual

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Revision 2

Far West Technology, Inc.

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Goleta, California

93117 USA

MODEL FWT-91R RADIACHROMIC READER INSTRUCTION AND OPERATIONS MANUAL

This instrument was manufactured in the United States of America by:

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93117-3814

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FUSE

The fuse in the back of the instrument is 1/2 A, type 3AG, fast acting.

REPAIR SERVICE

If service is needed on this instrument please call our service department before shipping the instrument to us for repair. Often we can help you with simple problems. If you do decide to return it to us for repair then please include:

1. Contact person’s name
2. Organization or Company name
3. Address
4. Phone number of Contact person
5. Description of the problem
6. Anything else you may think important

We will inform you of the repair charges and wait for your authorization before we repair your instrument.

TABLE OF CONTENTS

1. INTRODUCTION 3
2. RADIACHROMIC DOSIMETERS 3
Figure 1 Typical Response Curve FWT 60-00 3
3. INSTRUMENT OPERATION 4
Figure 2 Location of Controls 4
3.1. SETUP 4
3.2. X 10 CONTROL 4
3.3. ROUTINE INSTRUMENT OPERATION 5
Figure 3 Filter Holder Positions 5
Figure 4 Inserting Dosimeter into Dosimeter Holder 6
4. ROUTINE RADIACHROMIC DOSIMETER MEASUREMENTS 6
5. CALIBRATING RADIACHROMIC DOSIMETERS 7
5.1. GENERAL CALIBRATION 7
5.2. CURVE FITTING TO A POWER SERIES USING LINEAR REGRESSION 8
5.2.1. Example 8
Figure 5 Sample Response Curve 8
Table 1 Worksheet 9
5.3. CHECKING AND RECALIBRATION OF READER 10
5.3.1. Neutral Density Filters Option 10
5.3.2. Checking The Reader Using Irradiated Dosimeters 10
5.3.3. Recalibrating A Reader Using Irradiated Dosimeters 10
Table 2 Recalibration for Repair Items 11
6. OPTICAL DENSITY 11
7. PRINCIPALS OF OPERATION 11
7.1. LAMP 11
7.2. LIGHT PATH/PHOTOCELL/PREAMP 11
7.3. GAIN CONTROL 11
7.4. POWER SUPPLY 12
8. MAINTENANCE AND ADJUSTMENTS 12
8.1. LAMP CHANGE 12
8.2. TO ACCESS ALL ADJUSTMENTS 13
8.3. SETTING THE GAIN AT 510 NM 13
8.4. SETTING THE GAIN AT 600 NM 13
APPENDIX SCHEMATICS 14

1. INTRODUCTION

The FWT-91R Radiachromic Reader is a photometric instrument for the read-out of FWT Radiachromic dosimeters. It measures optical density (OD) and transmssion (T) on two scales. The instrument uses a miniature incandescent lamp, narrow band three-cavity band pass filters, and a sensitive silicon photovoltaic cell to measure the OD. The instrument can read the film at the two wavelengths of 510 nm and 600 nm. The range of the readout is from 0 to 100% transmittance and from 0.01 OD to 1.0 OD. The X10 switch increases the sensitivity by 10. The FWT-91R Reader is part of the FWT Radiachromic Dosimetry System. This system includes Radiachromic dosimeters, photometers and accessories.

2. RADIACHROMIC DOSIMETERS

This general purpose radiation dosimeter is radiochromic; that is, upon exposure to ultraviolet or ionizing radiation it changes from a colorless to a deeply colored state. The intensity of this coloration is proportional to the radiation dose received.

The dosimeter contains in the nylon matrix the leuco-dye hexa(hydroxyethyl) paraosaniline nitrile. The standard dosimeters are one centimeter square and about 50 microns thick. They change from a colorless transparent film to a deep blue. The dosimeter remains pliable and easy to handle even after exposure to 200 kGy. The dosimeters exhibit long shelf life, small fade after irradiation, linear response over a wide dose range, and minimum variation with environmental parameters.

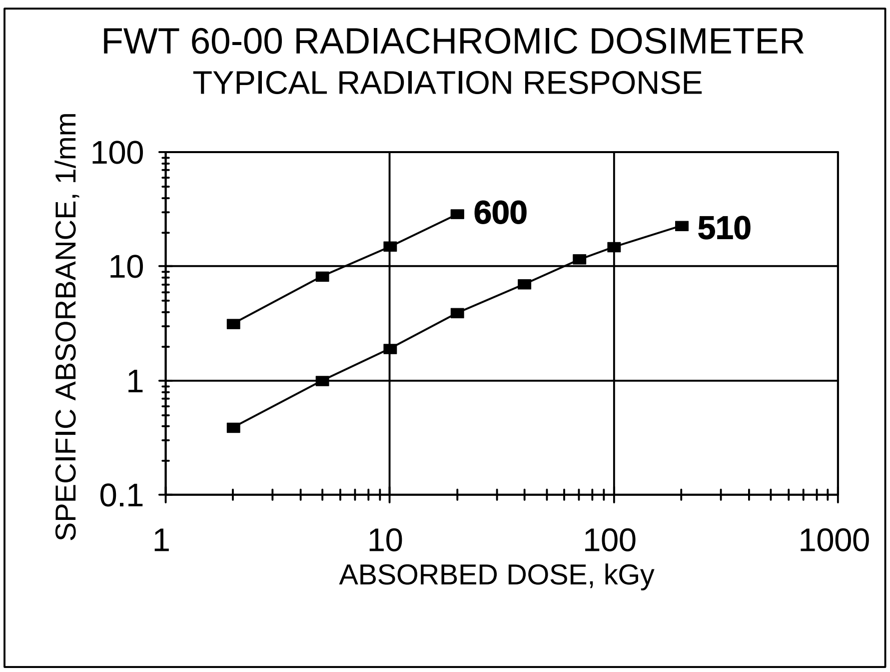

Figure 1 Typical Response Curve FWT 60-00

3. INSTRUMENT OPERATION

The operation of the instrument is straightforward. Setting up the instrument, reading the optical density (OD) of the film, and using the optional neutral density filters are discussed below.

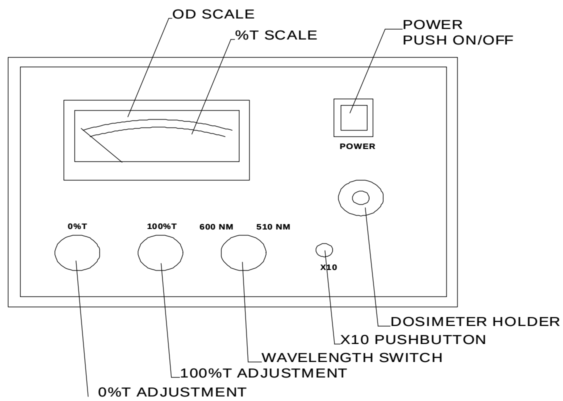

Figure 2 Location of Controls

3.1. Setup

1. ***Connect the instrument to a power source***. Plug the power cable into the back of the instrument. Plug the other end of the cable into a wall outlet. The instrument is offered in two voltages: 110 and 220 volts. The correct voltage for the instrument is marked on the plate where you plug in the power cable. Make sure your unit is the correct voltage.
2. ***Turn the instrument on***. The power switch is on the top right of the control panel. It is a push on, push off switch. When the power is on, the power light is illuminated. The meter reads in % Transmission or %T and in Optical Density or OD. It has a practical range of 0.01 to 1.0 OD. The X10 range will multiply the transmission values by 10 and decrease the OD by 1.00. If the OD reads .35 on the meter with the X 10 button depressed, then the OD is 1.35.
3. ***Allow the unit to stabilize***. This usually takes just a few minutes.
4. ***Adjust the Zero or 0%T.*** Select the wavelength you need. lift the dosimeter holder slightly from the standard index position, rotate it 45 degrees to block the light path and simulate an infinite OD (see Figure 3). Adjust the 0%T knob to give a meter reading of zero transmission.
5. ***Adjust Full Scale or 100%T.*** Remove any dosimeter that may be in the dosimeter holder. Rotate the dosimeter holder until the standard index falls into the standard position. Keep the same wavelength. Adjust the 100%T knob to ‘read 100%T on the meter. This sets 100% transmission or 0 OD. If the low value cannot be set, then the lamp may be too dim or burned out and the lamp will need to be replaced.
6. ***Repeat step 4 and 5*** until both readings are correct. There is some interaction between the two.

This completes the Setup. The instrument is now ready for routine measurements. The 0%T and 100%T adjustments may change for several minutes after turn on. This is the light bulb stabilizing at its temperature. It has a life of around 8000 hours consequently we do not recommend leaving it on all day every day. Use it as you would any normal electronic device. If you don’t need it, turn it off. If you do need it leave it on.

3.2. X 10 Control

The X10 control increases the sensitivity of the instrument by a factor of 10. It is useful for transmission measurements below 10% and OD measurements above 1.0. To activate the control, push the button down while taking a measurement. With the X10 button pushed, the transmission measurements will be multiplied by 10 and the OD measurements will be decreased on the scale by 1.0 OD. 8% transmission will measure 80% on the scale with the X10 button pushed down and a 1.5 OD measurement will read 0.5 OD on the scale with the X10 button pushed down.

3.3. Routine Instrument Operation

Measuring the optical density of the dosimeters is the routine operation.

NOTE: The dosimeters are sensitive to UV radiation or light. Operate the reader in an area that has been tested for UV light. Most lamps and of course daylight contain fair amounts of UV light and need to be filtered. Check the work area by reading an unexposed dosimeter. Leave the bare dosimeter on the work counter for 4 to 8 hours. Reread the dosimeter. If the difference is very great the area is not safe from UV light. Filters are available for most light sources and for windows.

1. Check the adjustment of the 0%T and 100%T settings described above in steps 4 thru 6. This should be done every half hour or so.
2. Remove the dosimeter holder from the well.
3. Insert the dosimeter into the holder using a pair of tweezers. See ***Figure 4 Inserting Dosimeter into Dosimeter Holder***.
4. Insert the dosimeter holder into the well.
5. Read the OD or %T from the meter. Use the X10 button if necessary.
6. Remove the dosimeter holder from the well and remove the dosimeter from the holder.
7. Repeat steps 3-6 for each dosimeter.
8. Replace the dosimeter holder into the well when you are done with measurements. This keeps dust from settling into the well.

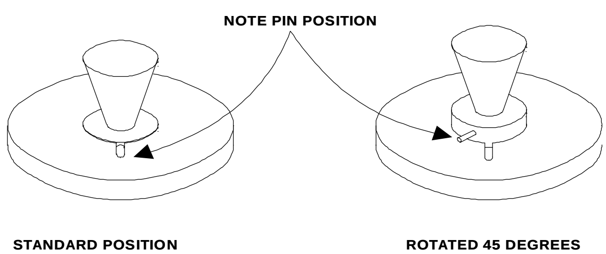

Figure 3 Filter Holder Positions

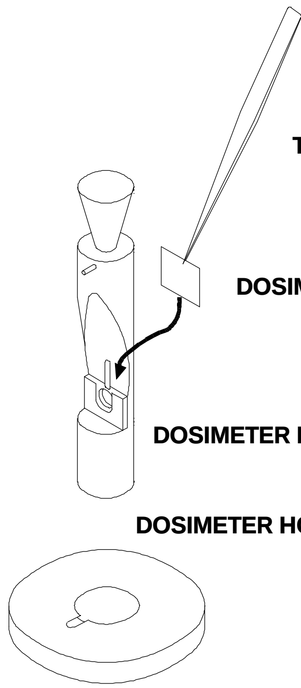

Figure 4 Inserting Dosimeter into Dosimeter Holder

4. ROUTINE RADIACHROMIC DOSIMETER MEASUREMENTS

The dosimeters are measured with the Model FWT-91R reader.

1. ***Determine the background OD.*** Remove the dosimeter holder, place an unirradiated dosimeter in the holder, and insert the holder in the standard position. Record the background OD. Individual backgrounds may be required for each dosimeter, but for most routine applications an average of several measurements provides a single value to apply to all dosimeters.
2. ***Expose the dosimeter to the radiation field.*** Place the dosimeter on or with samples to be irradiated. Detectors are sensitive to ultraviolet light and placing them in exposure envelopes is a convenient way to shield the films and to handle them in laboratory areas. Unfiltered fluorescent lighting, unprotected windows or other sources of UV radiation can cause the dosimeters to change color and increase the background OD. The envelopes are also useful for recording various data: position, exposure times, conditions, dates and background OD values.
3. ***Determine the final OD.*** Read the dosimeter with the reader. Note the OD.
4. ***Calculate the change in OD/unit thickness,*** ΔOD/t. Subtract the background OD then divide by the thickness.
5. ***Determine the exposure.*** Compare the change in OD with a calibration curve or calculate it by using a response function. For an explanation of the calibration curve, see section 5, CALIBRATING RADIACHROMIC DOSIMETERS.

5. CALIBRATING RADIACHROMIC DOSIMETERS

5.1. General Calibration

The Radiachromic dosimitry system needs to be calibrated. Far West Technology can supply dose and environmental information for the dosimeters. The dose information supplied is a typical calibration curve. If your application requires more than an approximate calibration we recommend a complete calibration of your 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***.

The dosimeters are manufactured in batches and each batch will need to be calibrated separately. 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 (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 it involved a change in the optical path or replacement of the filters. 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. For more information see section 5.3, Checking And Recalibration of Reader on page 10.

5.2. 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 $b = m$

5.2.1. Example

The data in Table 1 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 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.

$D=[(A_f-A_0)/(ta)]^{1/b} = [(0.255 - 0.060)/(0.465 * 0.276)]^{1/0.844} = 25.1$ kGy

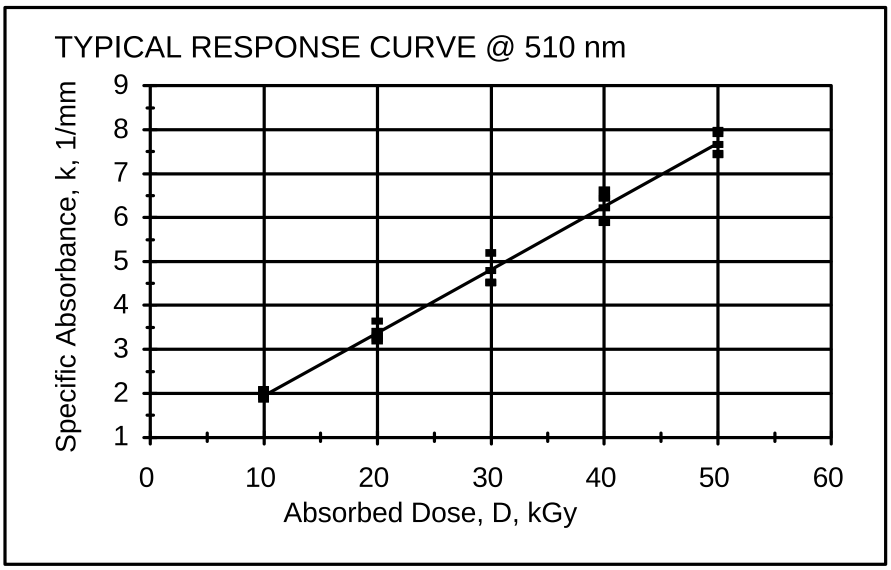

Figure 5 Sample Response Curve

Example of a response curve derived from the table of data below. The data points are plotted using the table. The line through the points was plotted visually.

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

Table 1 Worksheet

5.3. Checking And Recalibration of Reader

5.3.1. Neutral Density Filters Option

Neutral Density filters are used as a check of your Radiachromic reader's consistency. A periodic, daily, weekly, or monthly reading of the filters will assure you of proper reader operation. These filters may be purchased as a separate item and are not included in the price of the reader.

The neutral density filter set consists of three filters having approximate OD values of 0.3, 0.6, and 1.1. A nominal OD value is marked on each filter box. The actual value will vary slightly from reader to reader and should be determined for your reader at the time you perform a calibration of Radiachromic dosimeters. Thus the entire system (reader, neutral density filters, and dosimeter batch) will be calibrated.

Because of the potential long term deterioration or changes in the filters a new set of OD values should be determined each time a new dosimetry batch calibration is performed or following any major instrument repairs. The ND Filters cannot be used to calibrate a reader because they do not duplicate the spectral response of the dosimeters.

5.3.2. Checking The Reader Using Irradiated Dosimeters

We recommend, if you are doing precise measurements, that your reader(s) and backup reader(s) be periodically checked using irradiated dosimeters. The neutral density filters will only check if the reader is performing properly with respect to only OD. While it checks most of the reader, it does not check all of it, for example, it does not check the spectral response of the two bandpass optical filters that limit the photometer to 510 or 600 nm. It is a good idea to include irradiated dosimeters in your monthly checking.

The dosimeters that you use for this test should be irradiated. It is best if they are irradiated at the dose level that you consistently use. You could also use the same dosimeters that were used for the original calibration.

The dosimeters will need to be closely monitored over time. We recommend reading them every month in your reader(s) and also in your backup reader(s). Plot their response over time so you can see the trend of the dosimeter. The dosimeters will have more change just after irradiation then they do later. Use multiple dosimeters, as was done in the original calibration; this will insure that you have a good measurement even if one dosimeter is damaged.

5.3.3. Recalibrating A Reader Using Irradiated Dosimeters

If a reader needs to be repaired and the optical properties are changed during repair, it is necessary to recalibrate the reader. Usually this is accomplished by calibrating the whole system as described in section 5.1, General Calibration on page 7. This is a costly and time consuming operation. For high accuracy measurements this is the only method to certify that the reader is operating properly. Using the original dosimeters for recalibration will induce errors. These dosimeters have changed their response over time. Both their absorbance spectra and optical density (OD) have changed.

Irradiated dosimeters can be used, not to calibrate the system, but to measure the change of the reader from the repair. The change in the reader, and thus in the system, is measured as a bias. This is different from the original calibration.

The dosimeters that you use for this measurement can be the same dosimeters that you use to periodically check the reader under section, 5.3.2. ***Checking The Reader Using Irradiated Dosimeters*** or they can be another set that you keep just for repairs. They will need to be monitored over time as described in section 5.3.2. Measuring the dosimeters once a month is sufficient once they have stabilized. Dosimeters should be changed every 2 years.

The absolute value that is obtained from the dosimeters should not be used for recalibration. Instead the difference between pre and post repair should be used to form a bias for the reader that can then be applied to each reader reading.

Table 2 Recalibration for Repair Items

Item Repaired	Recalibration? No	Recalibration? YES
Lamp Replaced	√	
510 or 600 Filter Replaced		√
Photocell Replaced		√
Well Replaced		√
Dosimeter Holder Replaced	√	
Electronics Replaced or Repaired	√	
Line Voltage Changed (220 V to 110 V or 110 V to 220 V)	√	

6. 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.

7. PRINCIPALS OF OPERATION

The Radiachromic reader measures optical density. The instrument is divided up into the following sections: analog amplifier, panel controls and power supply. Please refer to the schematic in the appendix for the following discussion.

7.1. Lamp

The lamp LP1 is powered by the power supply through two dropping diodes, D1 and D2.

7.2. Light Path/Photocell/Preamp

The light path is from the light, through the dosimeter, through the optical bandpass filter and onto the photocell. There are 2 bandpass filters that are switched into the light path. One peaks at 510 nm and the other at 600 nm. The silicon photocell is D3. The current from it is converted into a voltage by U1A, an op amp. The output of this inverting amplifier goes negative with increasing light on the photocell, and rests near ground with no light. R6, the front panel 0%T control trims the output of V1 to 0 volt output 0%T on the meter with the light path blocked.

7.3. Gain Control

U1A has 2 gains, one for the 510 nm wavelength, and the other for the 600 nm wavelength. They are switched by S3 the front panel wavelength switch. The output of U1A goes to U1B, a noninverting op amp. This stage is used to increased the gain by a factor of 10 when S2 is pressed. R9 is the front panel 100%T control and changes the current to the meter, M1.

7.4. Power Supply

The power supply, PS1 supplies 5 volts for the instrument. -5 Volts is supplied by U2. The line input is through J5 power switch S1 and fuse F1.

8. MAINTENANCE AND ADJUSTMENTS

There are 2 adjustments in the instrument. These should be carried out by electronic technicians. The lamp change will need to be carried out whenever the lamp burns out or becomes too dim for normal operation. The gain may need to be set if the instrument cannot be adjusted with a new lamp, or because the 510 and 600 wavelengths need a large amount of adjustment. The reader does not need to be recalibrated because of any of the following adjustments.

NOTE: Many repairs are needed because the reader is dirty. Keeping your reader clean and out of a dirty, dusty environment will reduce the chance of repair. Also keep the dosimeter holder in the dosimeter well when the reader is not in use. This keeps dust out of the well and out of the light path.

CAUTION: There are dangerous voltages inside the case that can cause serious harm. The adjustments should be carried out by qualified personnel only.

8.1. Lamp Change

If the lamp burns out or is too dim, it can be easily changed. You should be able to see the light from the lamp by removing the detector holder and looking into the well. If there is no light, and the instrument is turned on, then the lamp is probably burned out. The other reason for replacing the lamp is if it is too dim. As the lamp ages, it grows dim. It may be so dim that the LO adjustment cannot be adjusted. If this is the case, then the lamp should be replaced. The lamp change will not require a recalibration of the reader.

1. Turn the instrument off.
2. Disconnect the power cord from the back of the instrument.
3. Remove the top panel by removing the 4 screws in the corners.
4. Loosen the thumbscrew that holds the lamp in place.
5. Remove the lamp from the well housing.
6. Unplug the other end of the lamp from the circuit board.
7. Plug the new lamp into the circuit board.
8. Insert the new lamp part way into the well housing. About half of the metal base of the lamp should be sticking out of the well housing. Do not install the lamp too far into the housing or the OD readings will be incorrect.
9. Tighten the thumbscrew that holds the lamp in place. Do not tighten it too tight or it will crush the lamp.
10. Replace the front panel and the 4 screws in the corners.
11. Plug in the power cord.
12. Turn the instrument on and adjust the high and low for both wavelengths. If there is a great adjustment difference between the two you may want to readjust the gain for both wavelengths. (See Setting the Gain at 510 nm and at 600 nm.)
13. If you have a set of neutral density filters, read their OD. The 0.3 OD (nominal) filter will read lower than normal if the lamp is inserted too far into the well housing.

8.2. To Access All Adjustments

The adjustments are all inside the enclosure. To gain access to the adjustments:

1. Remove the front panel by removing the 4 screws in the corners.
2. ***Be cautious of the line voltages that are present on the power supply and input plate***.
3. After the adjustments have been made, replace the front panel and screws.

8.3. Setting The Gain At 510 nm

1. Switch to the 510 nm filter.
2. Place an empty dosimeter holder in the well. Lift the dosimeter holder slightly from the standard index position, rotate it 45 degrees to block the light path and simulate an infinite OD.
3. Adjust the 0%T knob until the meter reads 0%T.
4. Rotate the dosimeter holder until the standard index falls into the standard position.
5. Turn the 100%T knob counter clockwise until it stops.
6. Then turn it 3 turns clockwise.
7. Adjust trimmer R5 until the meter reads 100%T.
8. Repeat step 2 thru 7 several times since the controls are interactive.

8.4. Setting The Gain At 600 nm

1. Switch to the 510 nm filter.
2. Place an empty dosimeter holder in the well. Lift the dosimeter holder slightly from the standard index position, rotate it 45 degrees to block the light path and simulate an infinite OD.
3. Adjust the 0%T knob until the meter reads 0%T.
4. Rotate the dosimeter holder until the standard index falls into the standard position.
5. Adjust the 100%T knob until the meter reads 100%T. This sets 100% transmission.
6. Repeat steps 2 thru 6 until both the HI and LO gain adjust settings are correct.
7. For steps 9 and 10 do not change the settings of the HI or LO gain adjust controls.
8. Switch to the 600 nm filter.
9. Rotate the dosimeter holder until the standard index falls into the standard position.
10. Adjust trimmer R3 until the meter reads 0%T.

APPENDIX SCHEMATICS