Public Calibration Function for Radiochromic Film

Together with Maria Chan from Sloan Kettering Cancer Center I have successfully tested this concept using EBT3 film and we presented a poster on the subject at the AAPM meeting in Indianapolis in 2013. Now I ask for your help in testing it more broadly. If the effort is successful it could lead us, the manufacturer, to publish the coefficients of a lot-specific calibration function for anyone else to use. So long as they use film from the same production lot and follow a specific protocol for their measurements it would eliminate the need for film calibration. Alternately you could publish a calibration function for others to use subject to the user adhering to the rules of the application protocol.

If you'd like to join in, please adhere to the following directions as you gather calibration data for a specific production lot.

Assumptions:

1. You use an Epson 10000XL or 11000XL scanner
2. You scan film in transmission mode
3. You use EBT3 film manufactured in November 2013, or later, and you tell me the lot number. The first six numerals in the lot number tell the date of manufacture – ddmmyy
4. You use FilmQAPro software
5. You adhere to the protocol that follows and send me your calibration function, i.e. the coefficients of calibration function.
6. I acquire a set of calibration films for the specified film lot using the following protocol.
7. Using the 'One-scan' Measurement Protocol (attached) I will apply your calibration function to the response data from my films on an Epson 10000XL scanner and report the doses calculated for all the films in my set.

Calibration Protocol

I. PURPOSE

To define a protocol for acquiring calibration data to test the concept of a public calibration function.

II. SCOPE

The calibration protocol applies to Gafchromic EBT3 film exposed at doses up to about 10 Gy and for film lots manufactured in November 2013, or after. The calibration protocol requires a minimum/maximum time to elapse between exposure of the films and scanning. The calibration exposures are to be made on film strips about 4 cm wide.

Note: A calibration is only valid when it is applied to application films from the same production lot as the calibration films.

III. INTRODUCTION

The efficiency of this protocol stems from the use of fitting functions that behave similarly to film. For example, consider the rational function X(D,n) = a + b/(D-c) where X(D,n) is the scanner response in the nth color channel measured for film exposed to dose D and a, b and c are constants. Figure 1 shows an example for calibration data (seven dose points) from EBT3 film fit to this function. The function behaves as film is expected to behave, i.e. as dose increases the response values decrease because the film gets darker. The values asymptote to almost constant values at very high dose.

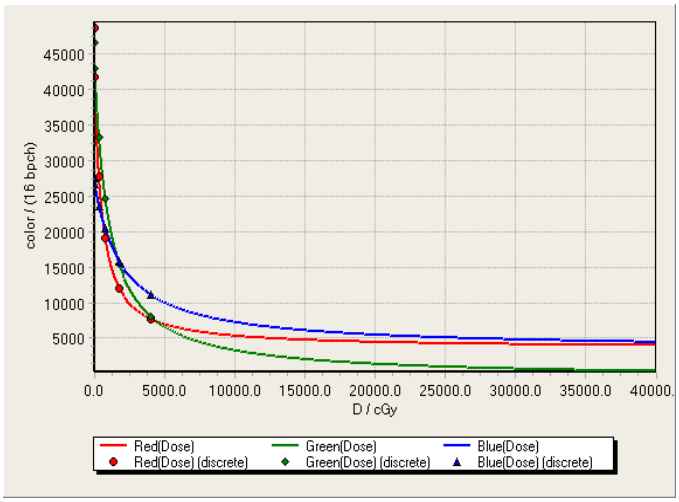

Figure 1

Contrast this to the behavior when the same data is fitted to polynomial functions (in this case 4th order) as shown in Figure 2. Obviously the polynomial functions don't behave like film – film doesn't get lighter in color and more transparent at high doses. Also, polynomial functions are unacceptable because they oscillate between dose values. The fit with the polynomial function could be improved with additional dose points, but it takes more time and doesn't address the fundamental problem.

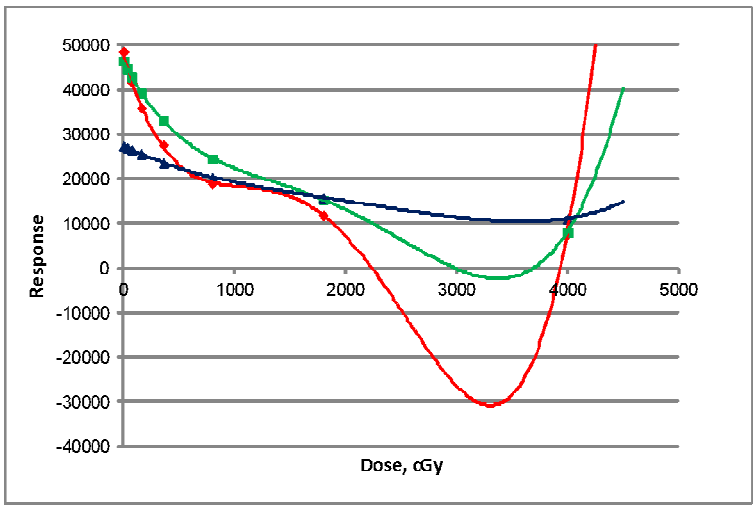

Figure 2

The benefit of using the type of rational function described above is that you can actually ***reduce*** the number of dose points required for calibration. Figure 3 shows the fit when four of the data points were removed. It is almost identical to the fit in Figure 1 with seven data points. The function has three constants a, b and c and is fully defined with three data points – two films exposed to known doses plus one unexposed film.

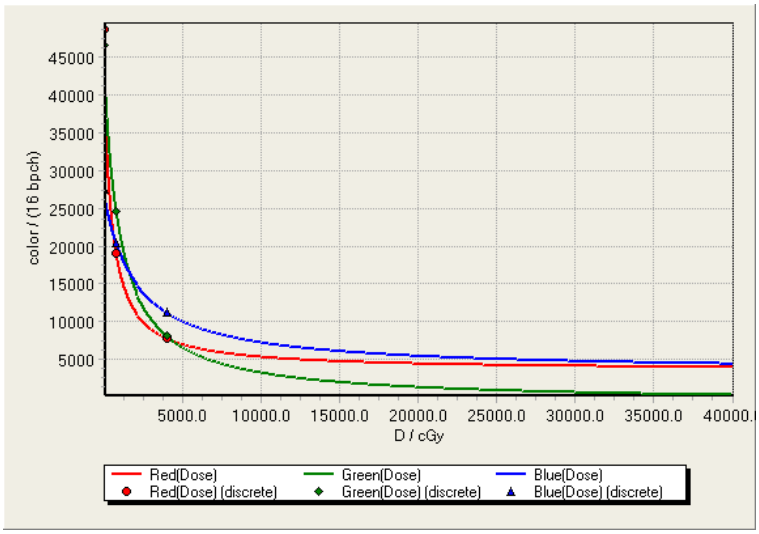

Figure 3

IV. EQUIPMENT AND MATERIALS

Gafchromic EBT3 radiochromic films
Adhesive tape
Radiation source – usually a linear accelerator, but it could be a source delivering photons between about 10kV and 25MV
Epson model 10000XL or 11000XL flatbed scanner with transparency adapter
Epson Scan software and Twain driver
FilmQA Pro software application

Microsoft Excel
The use of a phantom to provide electron equilibrium (e.g. water equivalent plastic blocks) is optional.

V. PROCEDURE

Obtain two sheets of 8"x10" EBT3 film from the same production lot. You will cut the film into strips approximately 4 cm wide. The strips could be cut parallel to either the 8" or 10" dimension of the sheet, but don't mix the sizes. You will need to specify the way in which you have cut the films. You will need seven (7) film strips

For calibration exposure it is assumed most people will deliver a 10x10 cm^2 exposure field at 6MV and expose the films to accurately known doses. However, other exposure sources are acceptable as long as they produce a known dose and it is uniform over an area of at least 20 cm^2

The protocol requires six exposure doses, plus a dose of zero. A greater number of exposure doses is not necessary. The calibration will be valid for doses between zero and the highest exposure dose for the calibration.

The protocol requires the calibration films be scanned together in a single scan with the exposed areas all located along the central axis of the scanner (see Figure 7).

The protocol requires a minimum time to elapse between exposure and scanning. It is most efficient if the exposures are made within a relatively small time window, say about 30 minutes, or less. Assuming all exposures were made within a time window of T hours, the elapsed time between the last film exposure and start of film scanning must be a minimum of 4T hours. This keeps dose measurement error due to post-exposure timing differences to 0.5%, or less. An explanation is given in the Appendix.

Step 1: Position a calibration film strip in the center of the radiation field delivered by the exposure source with the plane of the film perpendicular to the beam. Frequently the film will be exposed in a phantom or between slabs of plastic to achieve electron equilibrium, but this is not mandatory. The essential requirement is that the user knows the exposure doses delivered in the plane of the film.

Step 2: Using a 10x10 cm^2 open field expose the calibration film to a known dose of about 1000 cGy. The goal is to create a large area of uniform exposure on the film. Note the time of the exposure. Remove the film and keep it where it is not exposed to light.

Step 3: Repeat Step 1 using new film strips and known doses of about 700, 400, 200, 100 and 50 cGy. Note the time of each exposure and place the exposed film where it is not exposed to light. The time window within which the calibration films are exposed is related to the speed with which the scanning can be completed. Efficiency increases by minimizing the time window. If the first and last exposures are T hours apart, film scanning can be done 4T hours later, or any time thereafter. An explanation is given in the Appendix.

Step4: Turn on the scanner, connect a computer and open the FilmQA Pro application. From the drop-down menu (Figure 4) under "Case Object Management" select "Film Calibration (ordinary)".

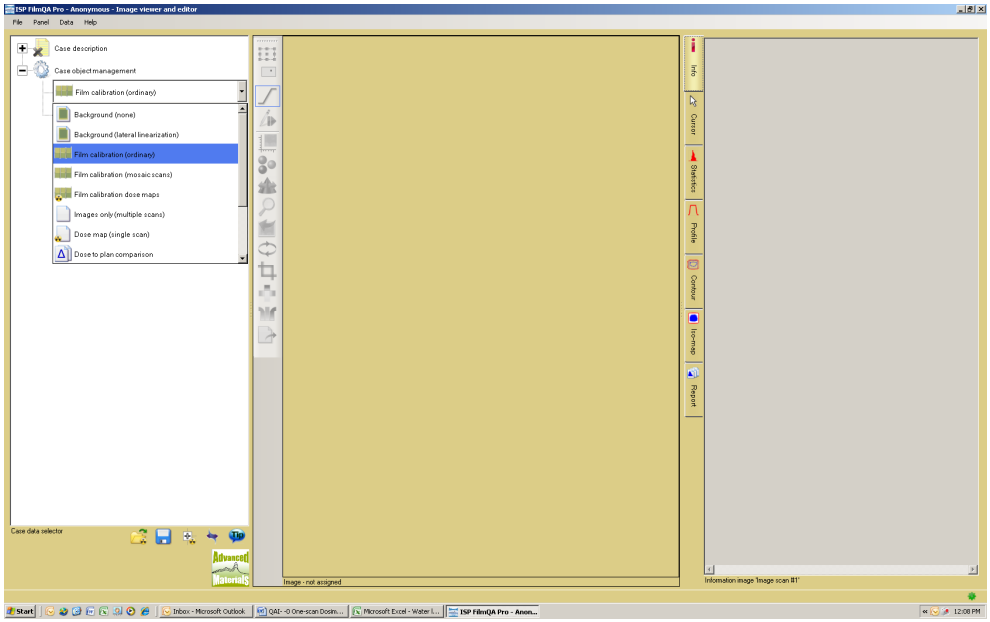

Figure 4

Step 5: Expand the Film Calibration case object, right click on “Data Calibration Film (empty)” and select and click “Scan Image Calibration Film” (Figure 5). The Epson Driver Window will appear. Choose the settings shown in Figure 6C. If the color correction icons are active (red arrow in Figure 6A) they must be de-activated. Open the Configuration window (Figure 6B) and check “No Color Correction”. The icons should appear gray (green arrow below, right). Then run six (6) preview scans to warm up the light source in the scanner.

Note: It is suggested that you scan using image resolution of 50 or 72 dpi.

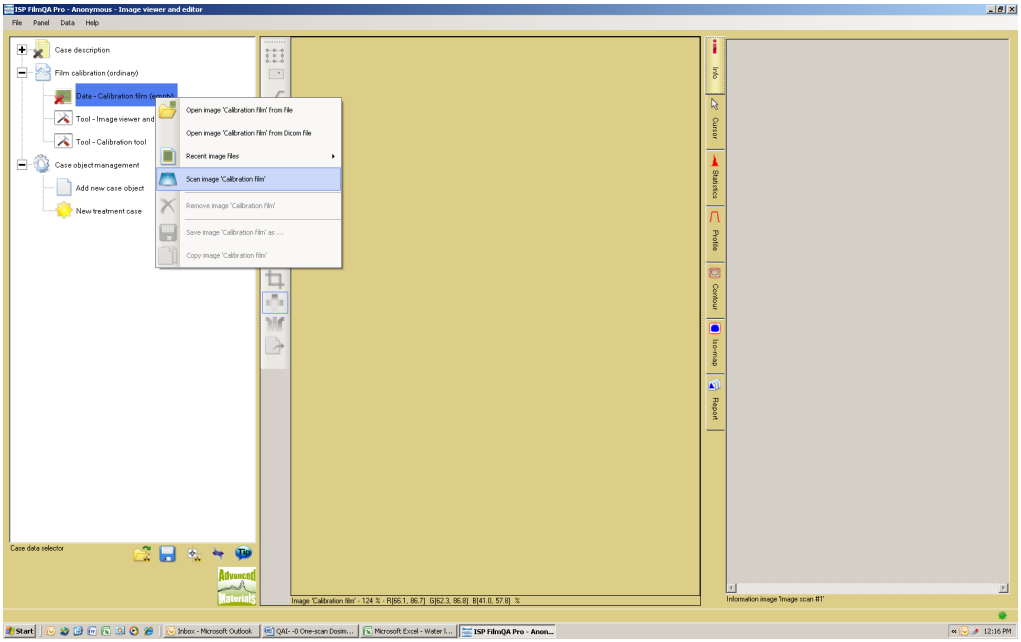

Figure 5

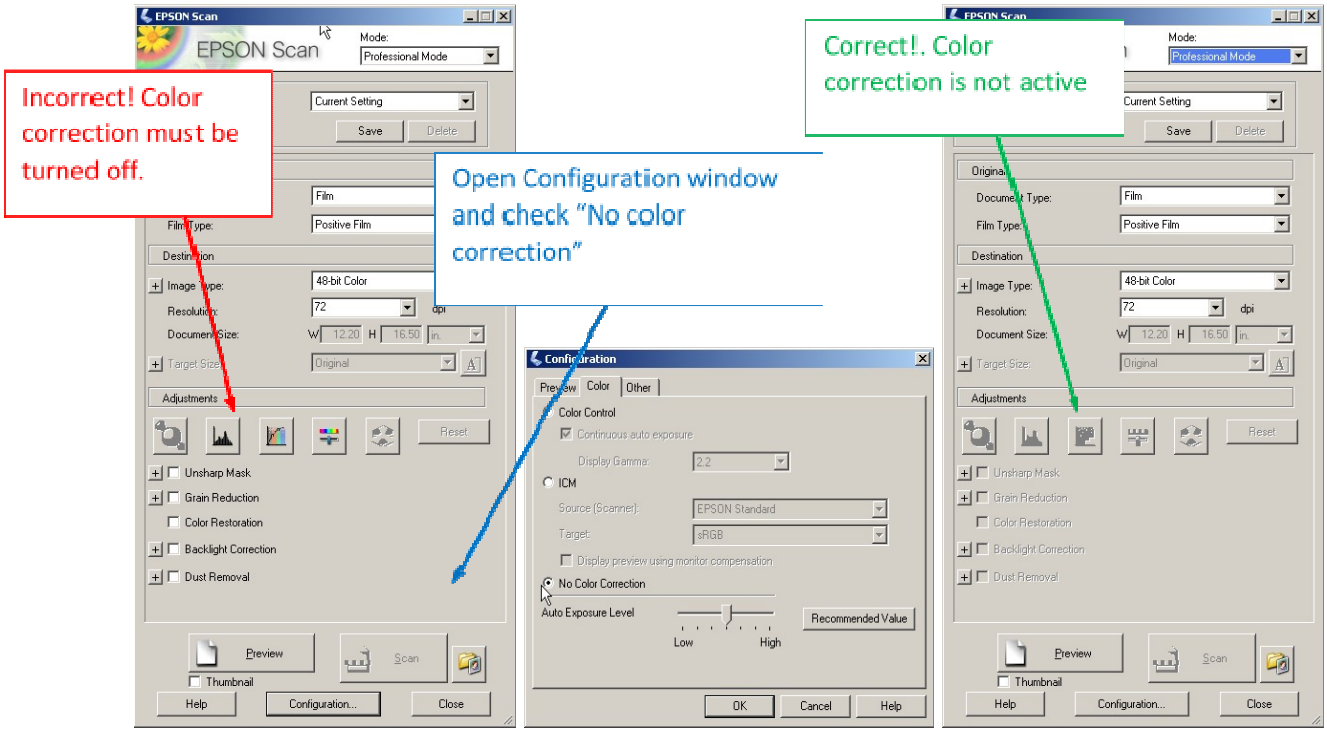

Figure 6A Figure 6B Figure 6C

Step 6: Place the calibration film strips and an unexposed film strip from the same lot on the scanner. Figure 7 shows four (4) strips, but you will have seven (7) – six exposed and one unexposed. The time between film exposure and scanning is related to the time window within the strips were exposed. If the time from first to last exposure was T hours, film scanning can be done 4T hours later, or any time thereafter. An explanation is given in the Appendix.

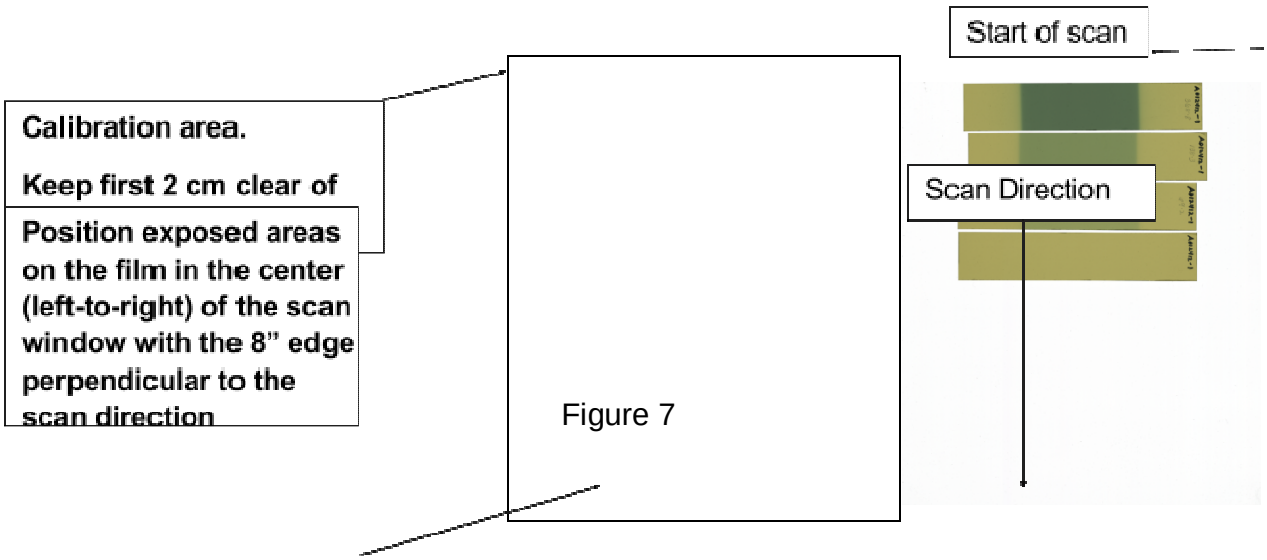

Figure 7

Figure 7

Step 7: Use the Frame Tool to mark areas of interest in the center of each calibration strip (Figure 8).

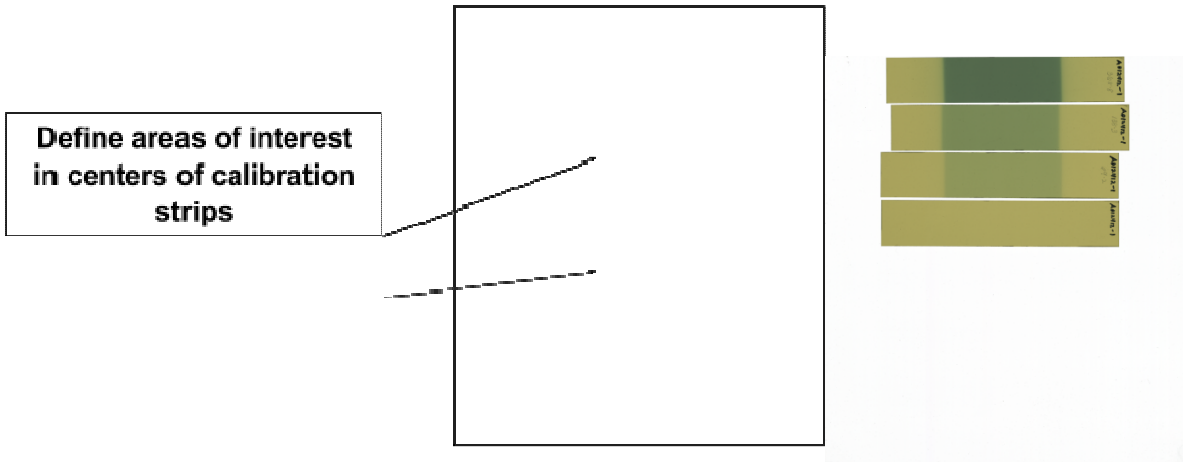

Figure 8

Step 8: Click the “123” icon on the bottom right corner (Figure 9A). The table will fill with the response values of the calibration films. Type in the dose values in the “Absorbed dose” column.

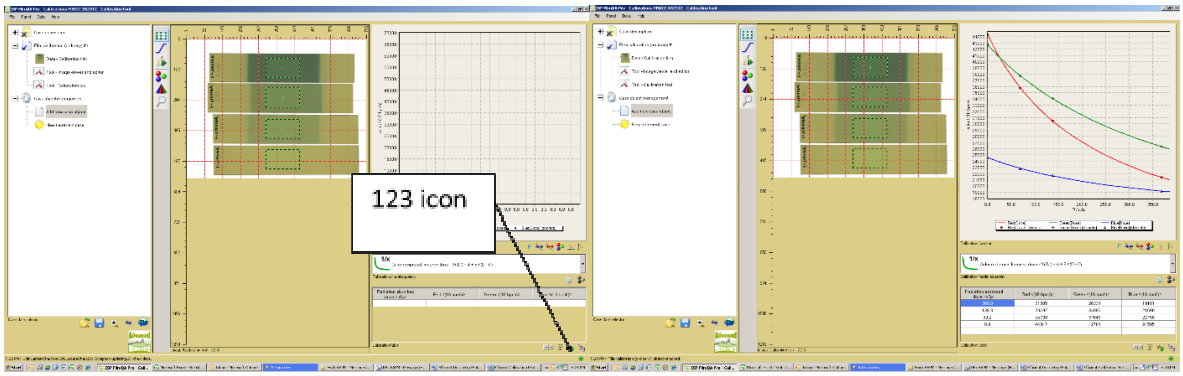

Figure 9A Figure 9B

Step 9: Click the “Calibration function” panel and select the Color rational (linear) vs dose function as the fitting function – Figure 10. X(D) = (a +b.D)/(c+D) where X(D) is response at dose D and a, b and c are the coefficients to be determined.

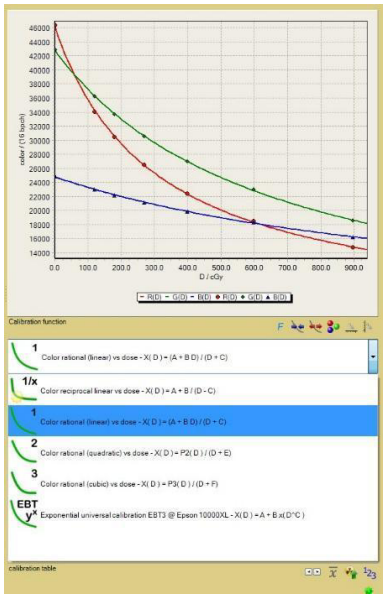

Figure 10

Step 10: Click the  icon under the calibration chart and select “Copy calibration function parameters” (Figure 11). Open an Excel spreadsheet and paste the tables with the calibration coefficients.

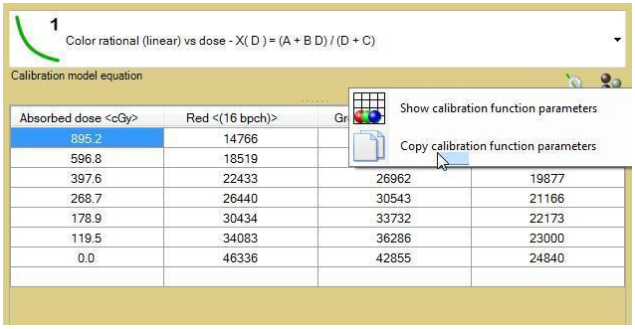

Figure 11

Step 10: Save all the calibration information in a Case file – click “File” and “Save treatment case as ….” and save it in your chosen folder. Do not send me the Case file unless I request it.

Step 11: Save the Excel file with calibration coefficients and mail a copy to me at dlewis@ashland.com Include in your e-mail the lot number of the film you used as well as the information on the size of your film strips, i.e. were the strips cut parallel to the 8” or 10” edge of the film.

Appendix

Post-Exposure Change

Exposure of radiochromic film to ionizing radiation starts a solid-state polymerization in crystals of the active component. Polymer grows within the crystal matrix of the monomer. Interatomic distances in the polymer are shorter than in the monomer causing the gap between the end of the growing polymer chain and the next monomer molecule to increase as polymerization progresses. Consequently the rate of polymerization decreases with time. Based on measurement, the response is linear with log(time-after-exposure) as shown in Figure A-1. This means that an error in the dose-response function could result if calibration films are scanned at different times-after-exposure. Since the calibration protocol requires exposed films to be scanned together at the same time the time-after-exposure for the films will be different. However, if the timing difference is small, i.e. the films are exposed within a narrow time window, any error caused by the timing difference will diminish rapidly as the ratio of the timing difference to the time-after-exposure decreases.

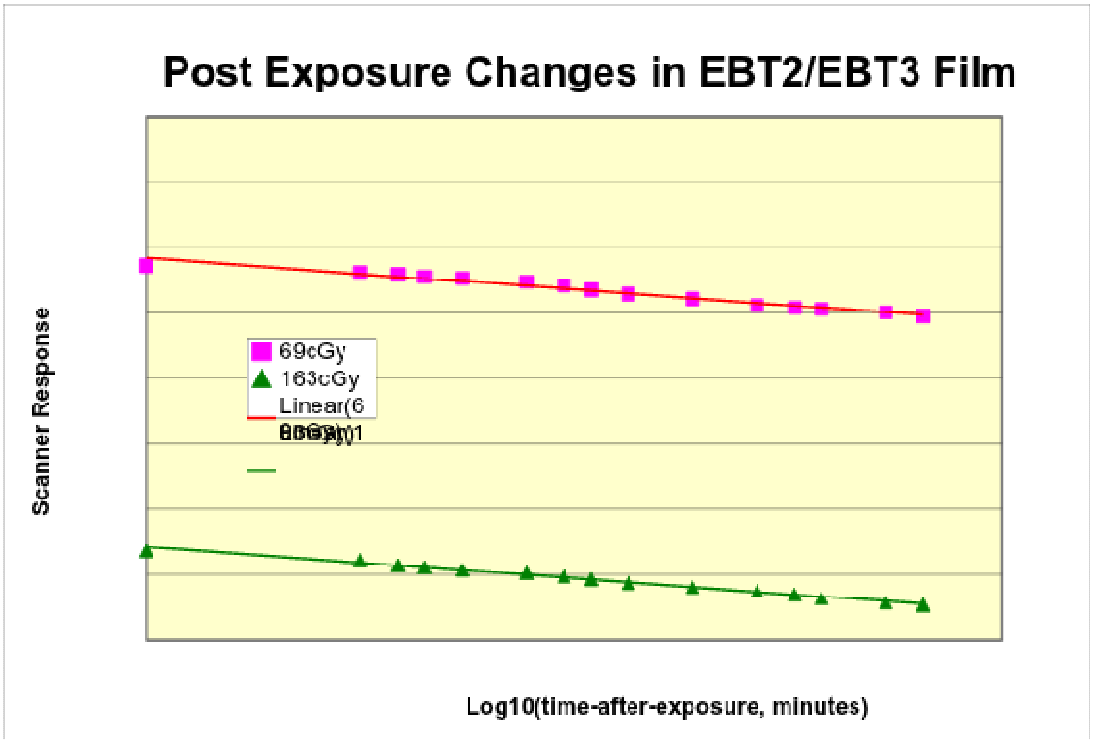

Figure A-1

From the data in Figure A-1, it is calculated that at time-after-exposure of 30 minutes, a 5-minute timing difference could contribute to a dose error of about 0.3%, while a 10 minute timing difference

could contribute to a dose error about 0.6%. As time-after-exposure increases from 30 to 60 minutes the dose error contributed by a given timing difference decreases by a factor of two. To ensure that time-after-exposure differences have a small contribution to dose error i.e. (<0.5%), film scanning should be delayed for a time period at least 4X longer than the interval between exposure of the first and last calibration films. For example, if exposures are within a 5 minute time window, scanning should be delayed for 20 minutes, or done at any time thereafter.