An Efficient Calibration Protocol for Radiochromic Film

I. PURPOSE

To define an efficient protocol for calibration of radiochromic dosimetry film.

II. SCOPE

The calibration protocol applies to Gafchromic EBT2 and EBT3 films at doses up to about 10 Gy. The resulting calibration is intended for use with a radiochromic film dosimetry protocol. The calibration protocol requires a minimum time to elapse between exposure of the films and scanning. The time is shortest and the protocol is most efficient when the calibration films are exposed within a narrow time window. An explanation is given in the Appendix. The calibration exposures may be done on a single film or multiple films. In either case it is assumed that the doses delivered in the film plane are known.

Note: The calibration is only valid when 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.

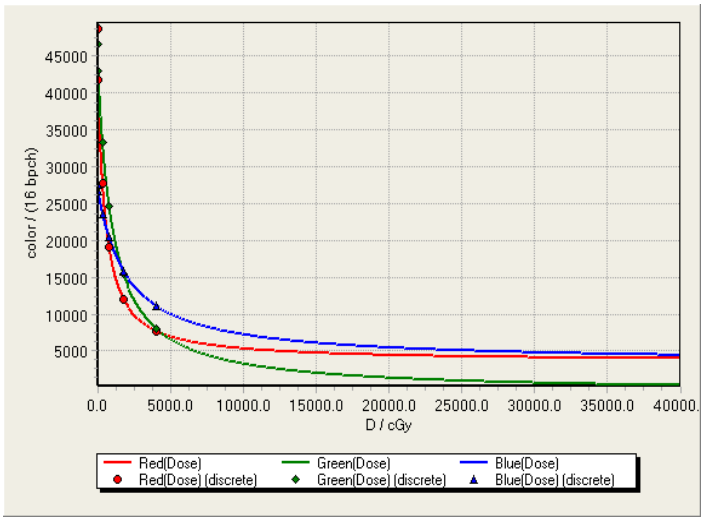

Figure 1

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.

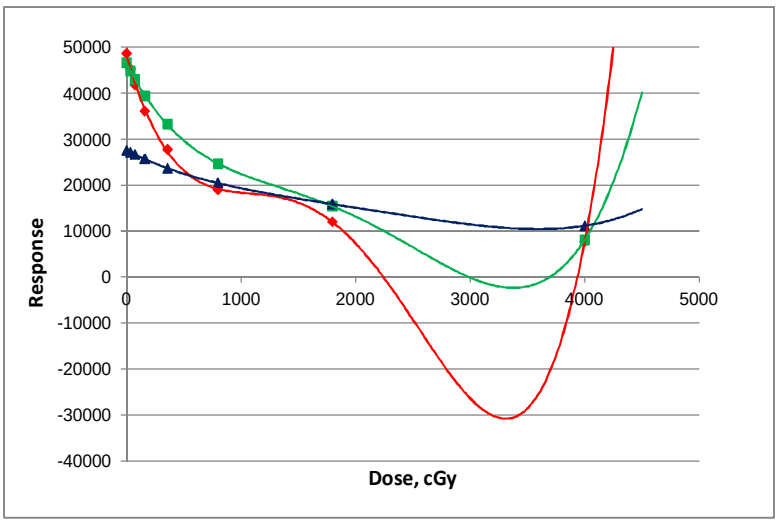

Figure 2

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.

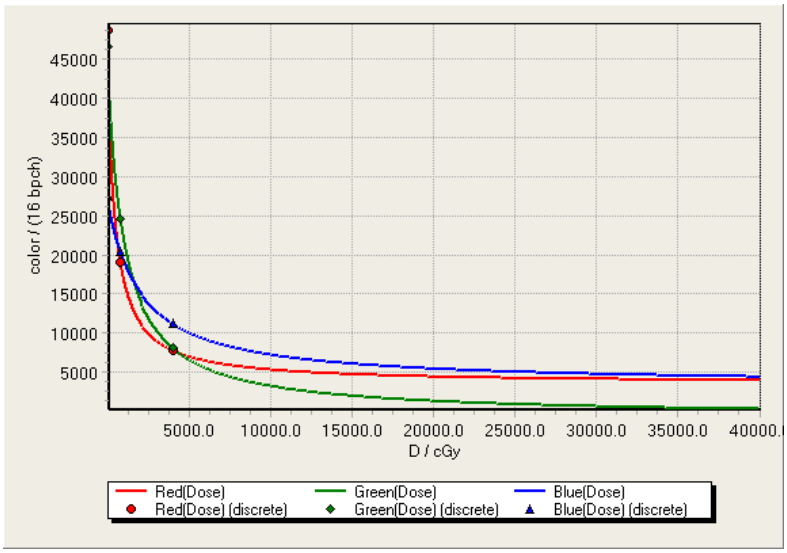

Figure 3

IV. EQUIPMENT AND MATERIALS

Gafchromic EBT2 or EBT3 radiochromic films
Adhesive tape
Radiation source – usually a linear accelerator, but it could be a source delivering photons between about 10kV and 25MV
48-bit rgb Epson flatbed scanner, preferably model 10000XL with transparency adapter
Epson Scan software and Twain driver
FilmQA Pro software application

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

V. PROCEDURE

The film sizes could be 1.5” x 8” strips, or 8” x 10” sheets or anything between. If multiple films are used they must have the same lot number. When cutting strips be certain that the orientation is known with respect to the sheet from which they were obtained.

The radiation source is provided as the means for delivering known exposure doses to the calibration and application films. For calibration exposure, it is assumed the user can control the source to deliver the known doses to the film.

The protocol requires a minimum of two non-zero exposure doses, plus a dose of zero. A greater number of exposure doses could be used, but this is not necessary. The calibration will be valid for doses between zero and the highest exposure dose for the calibration. The calibration will be valid for other EBT2 or EBT3 film from the same production lot scanned on the same scanner as the calibration films.

The protocol requires the calibration films to be scanned together in a single scan with the exposed areas all located along the central axis of the scanner (see Figure 7). The exposures could be made on a single film, or on separate films. In any event, the films should be sized to fit together on the scanner. One recommendation is to cut an 8”x10” sheet into pieces 8” long and at least 1.5” wide.

The protocol requires a minimum time to elapse between exposure and scanning. It is most efficient if the exposures are made within a narrow time window, t. The elapsed time between the last film and film scanning must be a minimum of 4t. An explanation is given in the Appendix.

Step 1: Position a calibration film in the center of the radiation field to be 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: Expose the calibration film to a known dose about 30% greater than the highest dose expected for an application film. One way is to use a linear accelerator to expose a 10 cm x 10 cm, but the choice is up to the user. 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 another film from the same production lot. Using the same exposure source and exposure conditions and setup, expose the film to a known dose about 20% of that used for the first film. Note the time of exposure. The time window within which the calibration films are exposed is related to the speed with which the scanning and calculations can be completed. Your efficiency increases by minimizing the time window. If the exposures are T min. apart, film scanning can be done 4T min. later, or any time thereafter. An explanation is given in the Appendix. Remove the film and keep it where it is not exposed to light.

Step 4: While unnecessary, additional calibration films could be generated by repeating Step 3 with different exposure doses.

Step5: 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)”. Note: The calibration will be valid for other films from the same production lot scanned on the same scanner.

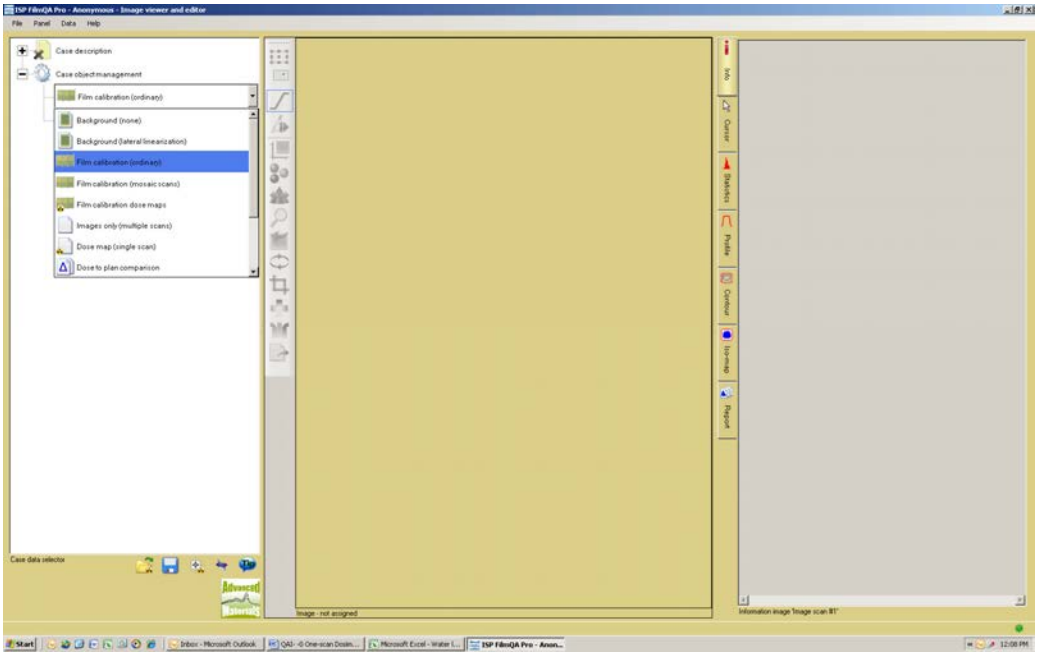

Figure 4

Step 6: 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). Note: Resolution of 72 dpi is suggested.

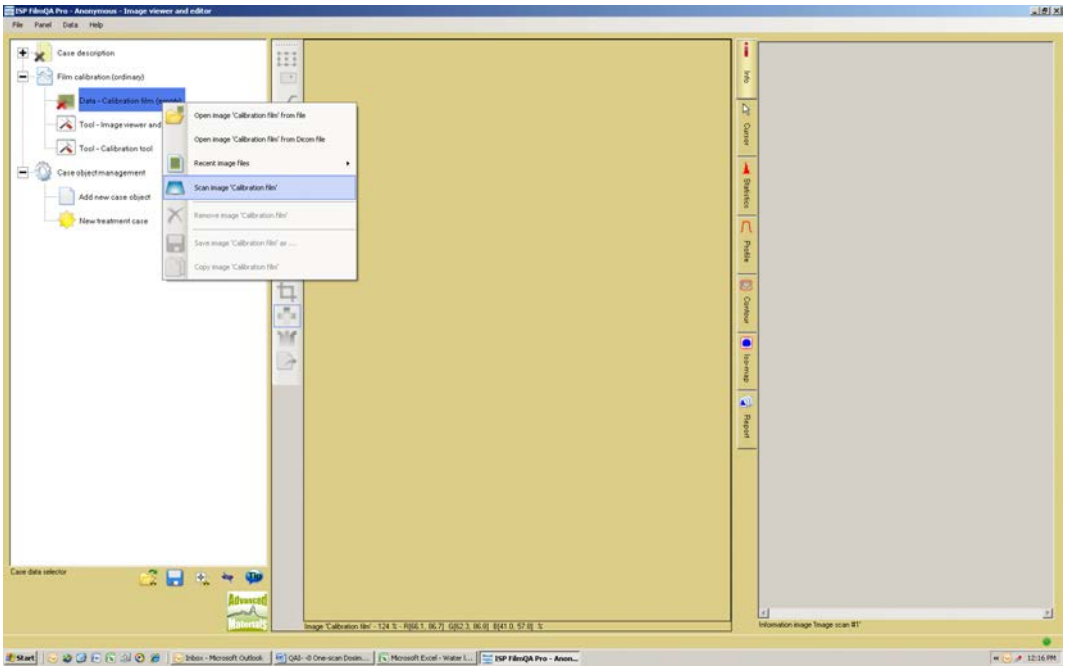

Figure 5

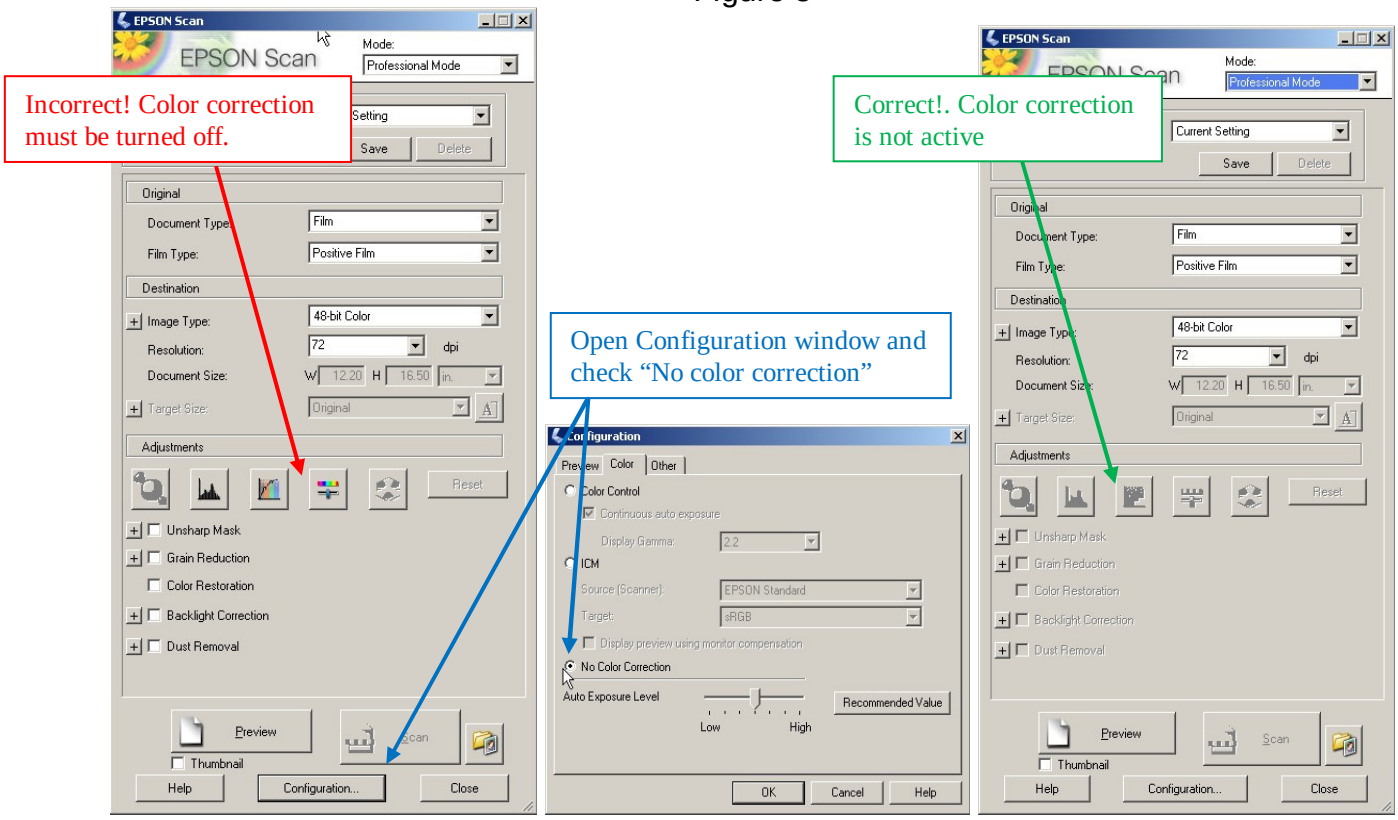

Figure 6A Figure 6B Figure 6C

Step 7: Place the calibration films and an unexposed film from the same lot on the scanner as shown in Figure 7. The time between film exposure and scanning is related to the time window within which the calibration strip and application film were exposed. Your efficiency increases when you minimize the time window. For exposures t min. apart, film scanning can be done 4t min. later, or any time thereafter. An explanation is given in the Appendix.

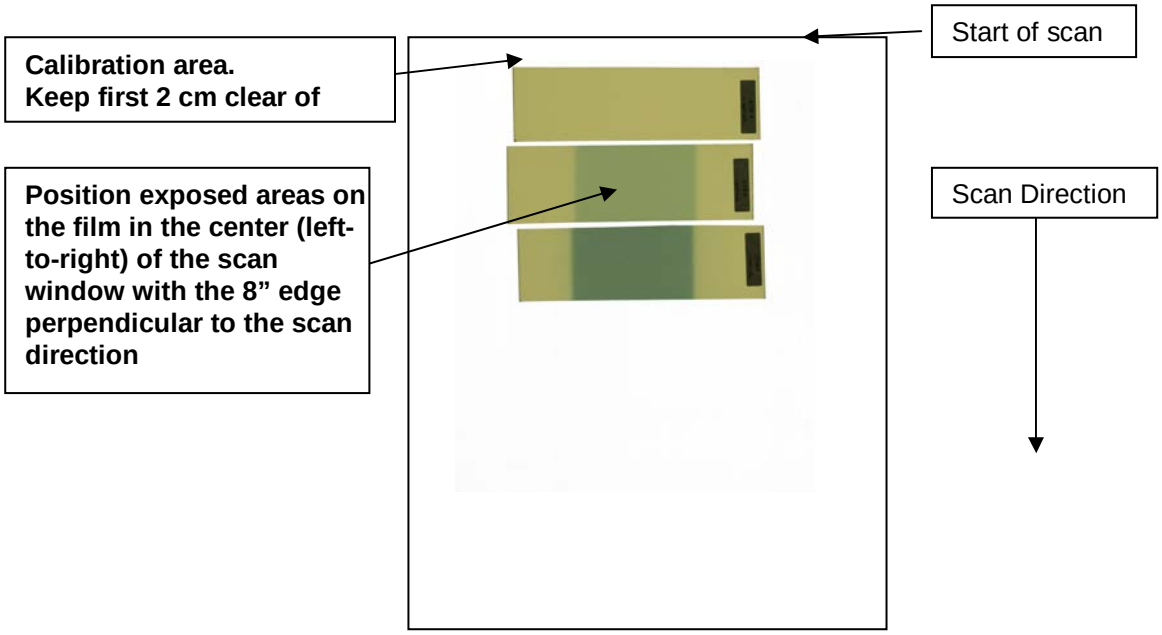

Figure 7

Step 8: Use the Frame Tool to mark areas of interest in the centers of the calibration strips (Figure 8).

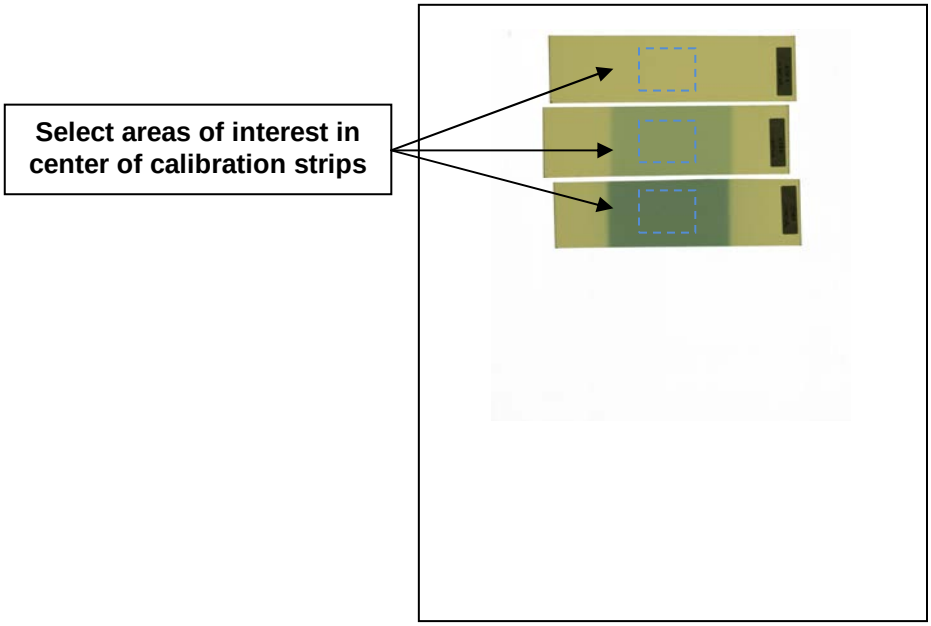

Figure 8

Step 9: Click the "123" icon on the bottom right corner (Figure 9A). Select the "Color reciprocal linear vs. dose" fitting function (Figure 9B) and type in the dose values into the calibration table.

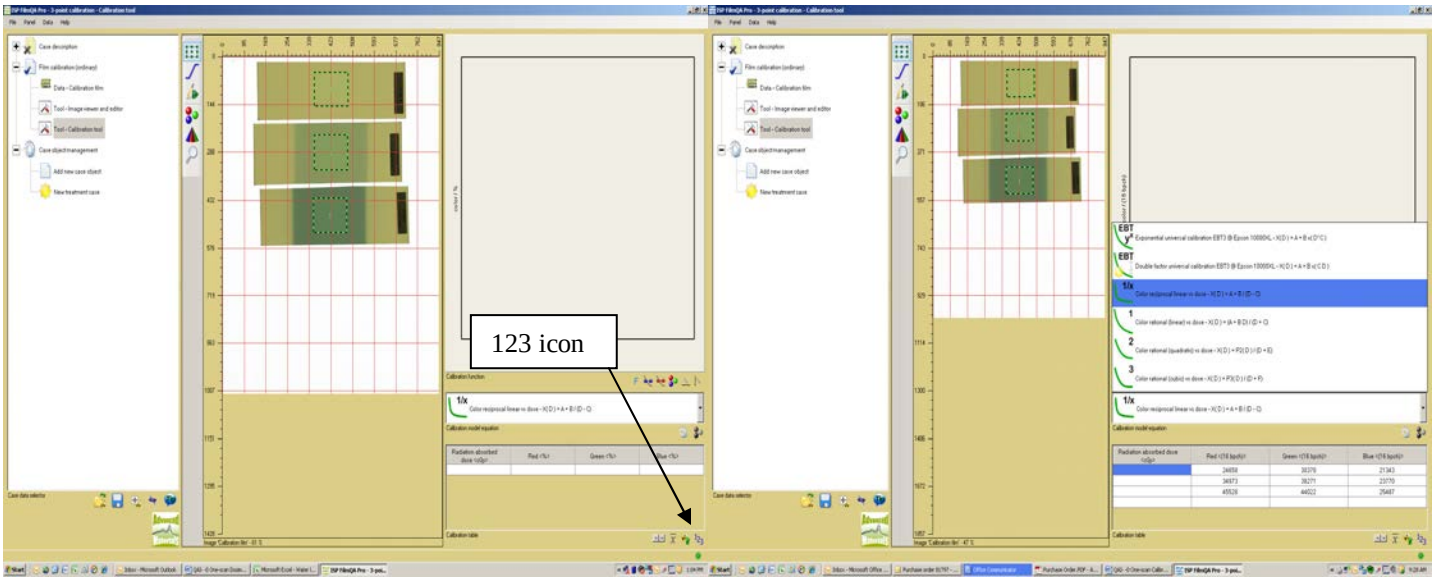

Figure 9A Figure 9B

Step 10: Right click the “Film Calibration (ordinary)” data object, select “Save as fixed calibration” from the dropdown menu (Figure 10) and save the calibration. The fit of the dose-scanner response function is valid and usable between zero dose and the highest dose exposed on the calibration films. It is applicable to other films from the same production lot scanned on the same scanner.

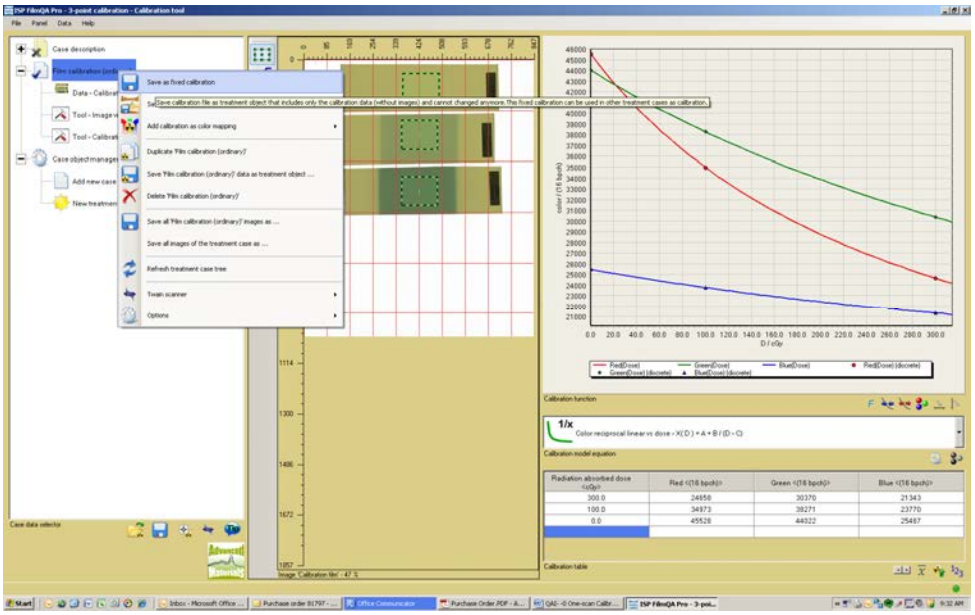

Figure 10

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.

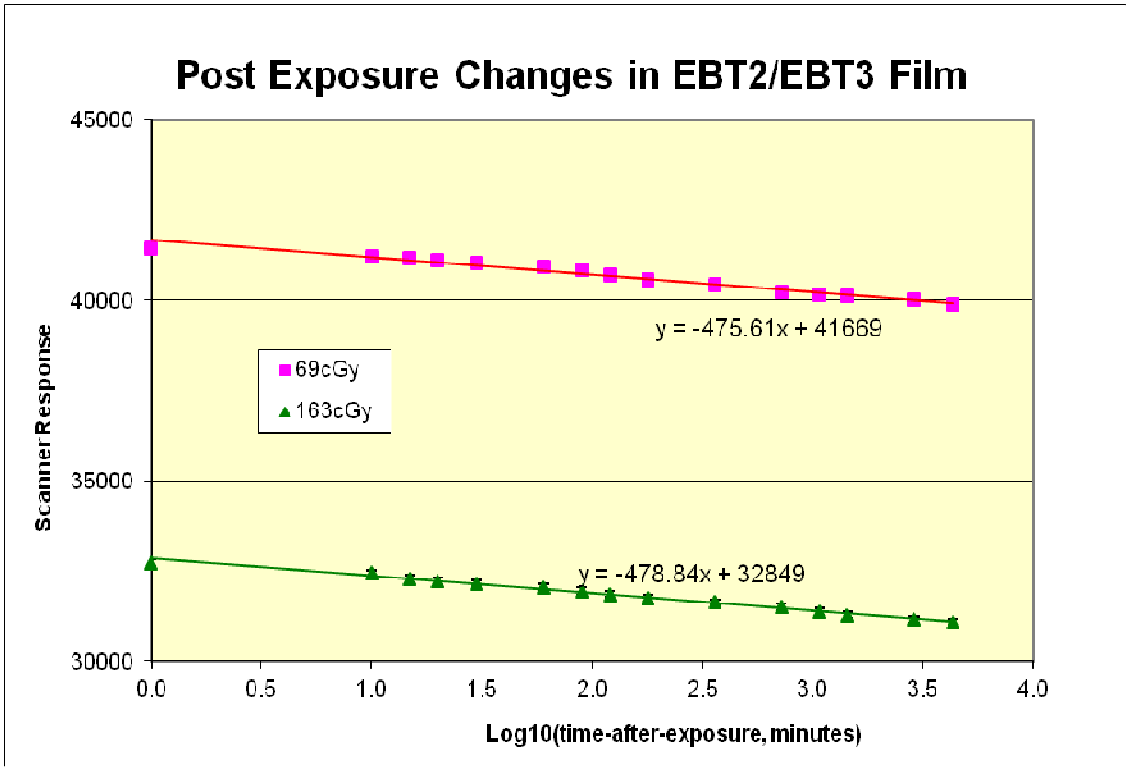

Figure A-1

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.