CALIBRATION OF LOT 47207-01I GAFCHROMIC EBT FILM USING THE XOFT AXXENT® X-RAY SOURCE

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ABSTRACT

- **Purpose**: To determine the absolute dose delivered for a given exposed optical density of GAFCHROMIC® EBT film over a range of 0.25 to 14 Gy and over a range of distances from 1 cm to 4 cm in water for a Xoft Axxent® Model S700 X-ray Source.
- **Method and Materials:** GAFCHROMIC film is used for dose delivery validation for the Xoft X-ray source and associated applicators used to deliver prescription dose distributions. Custom Gammex RMI 457 Solid Water™ film fixtures were designed to locate both a PTW34013 ionization chamber and a film coupon at precise distances from the X-ray source. The fixtures complete integral rotations around the X-ray source during exposures to minimize azimuthal effects. Three sets of 12 exposures were performed for the dose range at each distance. Film coupons were scanned with an Epson® Expression® 10000XL scanner and the maximum pixel value was determined for each coupon corresponding to the calibrated ionization chamber measured dose.
- **Results:** The measured maximum pixel values for each data set were fit to a 5th order polynomial. Calibration coefficients were determined at different distances from the X-ray source to investigate spectral differences. All fits were well behaved with residuals within 4%. Differences between the fitted dose as a function of distance were small, indicating little sensitivity of the film to the range of source spectra. This calibration was applied to Xoft Axxent Vaginal Applicator validation study films, producing good agreement with the isodose contours predicted by BrachyVision™ treatment planning software.
- **Conclusion:** A precise calibration of GAFCHROMIC EBT film was performed for the Xoft X-ray source using a PTW 34013 ionization chamber. It showed no significant difference in the measured optical density for a given measured dose over a distance range of 1 cm to 4 cm.

BACKGROUND

- The Axxent® Electronic Brachytherapy (eBx) System utilizes a proprietary miniaturized X-ray source to deliver radiation directly to a tumor bed within the body. The Axxent X-ray Source delivers high-dose rate, low energy radiation without the use of radioactive isotopes. The Axxent Source mimics certain characteristics of the most common HDR brachytherapy isotope, ^{192}Ir, but the low energy of the Axxent Source enables the procedure to be done in a minimally shielded setting under the supervision of a radiation oncologist.
- The Axxent® System has been used to deliver accelerated partial breast irradiation (APBI) using an inflated balloon placed into the patient's resection cavity one to two weeks post-lumpectomy.
- Recently FDA-clearance was granted for the Axxent® eBx System in the general treatment of "lesions, tumors and conditions in or on the body where radiation is indicated".

Figure 1. Controller for the Axxent® Electronic Brachytherapy (eBx) System

- Unique attributes of the Axxent® System:
  - No radioactive materials handling and safety issues
  - Creates greater access to treatment facilities by requiring a minimally shielded room for use.
  - Medical personnel can be present in room during treatment, improving patient comfort and well being.
  - Self-contained unit can be wheeled from room to room (**Figure 1**).
  - Radiation is attenuated beyond the area under the Axxent® FlexiShield® protecting other parts of the body.
  - Radiation is emitted during treatment only when the X-ray source is turned on.
  - Radiation is emitted at a low energy and high-dose rate, providing coverage to the target area and sharper dose fall-off than conventional HDR isotopes.
  - Source voltage and current can be modulated, permitting Intensity Modulated Brachytherapy (Xoft IMBT™) in future applications.

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METHODS

PURPOSE

- Radiochromic film is used for dose delivery validation of the Xoft Axxent® Model S700 X-ray Source and the applicators used to deliver prescription dose distributions. We have performed a calibration of the exposed film optical density as a function of the dose delivered over the range from 0.25 to 14 Gy at distances of 1 cm, 2 cm and 4 cm from the source.

APPARATUS

- Custom Gammex RMI 457 Solid Water™ film fixtures were designed to place the active surfaces of the GAFCHROMIC® EBT film and the PTW type 34013 soft X-ray ionization chamber at the same distance from the source. The film was cut into 1.125" square coupons to fit into the film fixture, with the orientation of the film coupons preserved.
- The 1cm solid water fixture is shown in brown in **Figure 2**. On the right side of this fixture, the white frame is the film coupon holder and on the left side is the ionization chamber, also in white, sealed into a water-tight solid water case but vented to atmosphere.
- The X-ray source is inserted into the source tube from the top of the fixture and aligned to the entrance window of the ionization chamber. The fixture is mounted onto a Newport® M-485ACC rotary stage assembly to allow the film and ionization chamber to rotate around the X-ray source to average over any source azimuthal anisotropy. The entire solid water portion of the fixture is submerged in a water tank.
- Three solid water film fixtures were used to make these measurements, placing the center of the two active layers of the film at 1 cm, 2 cm or 4 cm from the source. The film fixture was rotated around the source by an integral number of rotations while exposures were taking place. A custom LabVIEW program was used to control the rotary stage and acquire the data using a PTW Unidos® E Electrometer.
- During a measurement, a shutter covering the source was closed, and the source was brought up to full voltage (50kV) and the desired beam current for the exposure. The shutter was opened at the same time the stage rotation and data acquisition program was started. The shutter was closed after the desired number of rotations was complete and the acquisition program had stopped. To reduce variability, a single source (S/N 105762) was used for all the film exposures. This study did not address source to source variability in dose as a function of distance. For nearly all exposures, an integral number of rotations were performed to minimize azimuthal effects. The lowest dose and closest distance exposure required that only a half rotation be used.

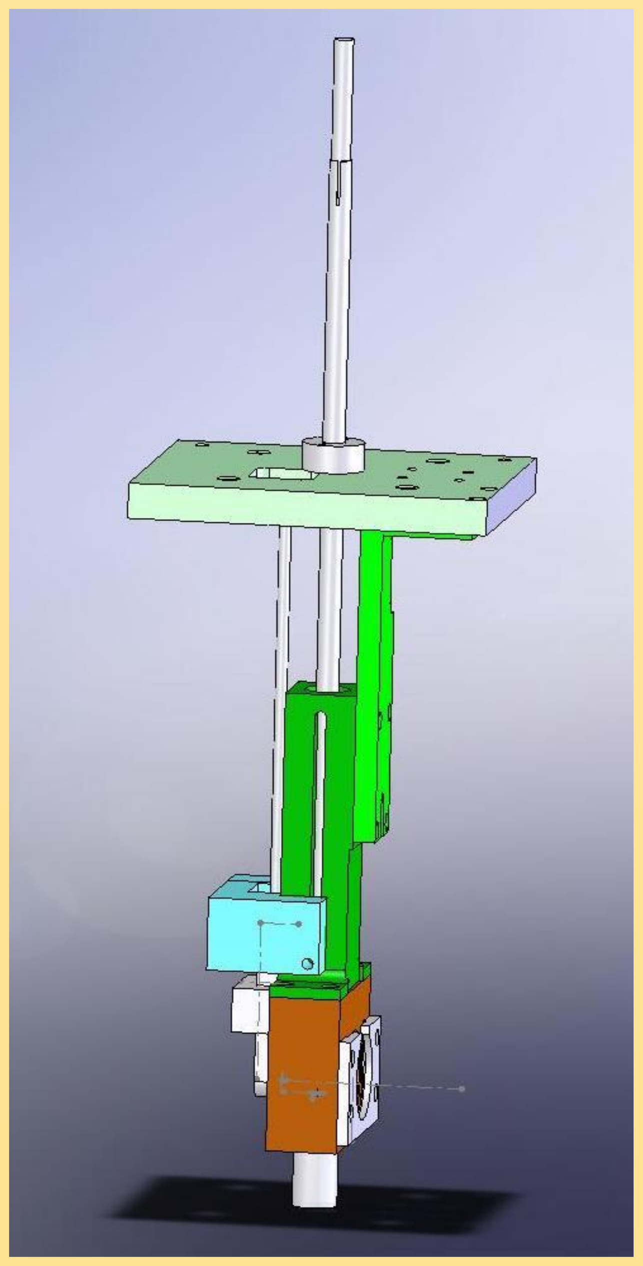

Figure 2. Diagram of the test apparatus

ANALYSIS SCANNING AND IMAGE PROCESSING

- As recommended by the film manufacturer, an Epson® Expression® 10000XL was used to scan the radiochromic film. A film scan locator fixture was used to position the coupons at a fixed location near the center of the scanner bed. The film scan locator fixture can hold 12 calibration coupons and a 5-inch square of film.
- A sample post-exposure film scan is shown in **Figure 3**. The red channel of the RGB scan was used for analysis since the film is most sensitive in the red portion of the spectrum. The Epson Scan program was set to transmission scanning mode with 48 bit color depth and 150 dpi. All adjustments and corrections were turned off. The calibration coupons were inserted into the fixture and scanned prior to exposure. The pre- and post-exposure position and orientation of each film coupon was kept fixed in the scan locator fixture.
- ImageJ was used to select the red channel and convert the file into a text image to be read into a custom LabVIEW analysis program. Within this analysis program, the 16 bit grayscale image was inverted so that white (65535) became 0. The image was background subtracted using the initial pre-exposure scan and smoothed by averaging 2 pixels (0.34 mm) to reduce noise. A small amount of realignment, by 1-2 pixel values, was typically required to line up the edges of the fixture for the pre- and post-exposure scans.

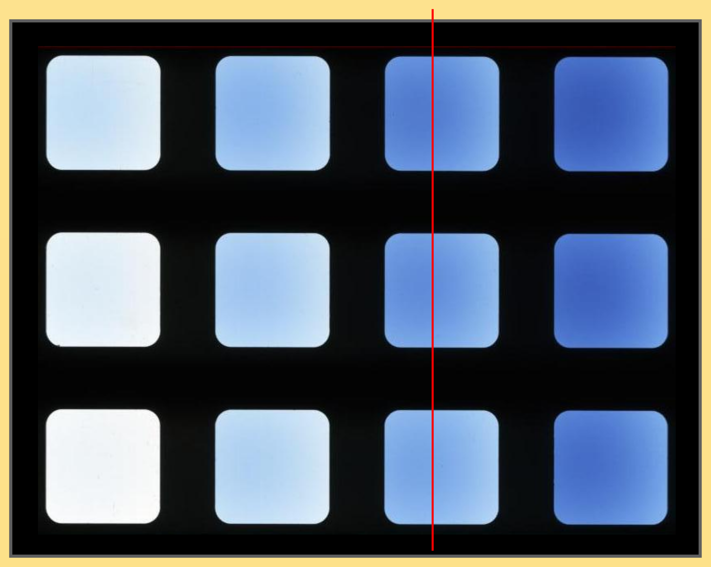

Figure 3. Post exposure raw film scan

- The maximum intensity pixel value for each film coupon was determined as shown in **Figure 4**. The measured dose corresponding to this pixel value was obtained from the calibrated ionization chamber reading for that film exposure.

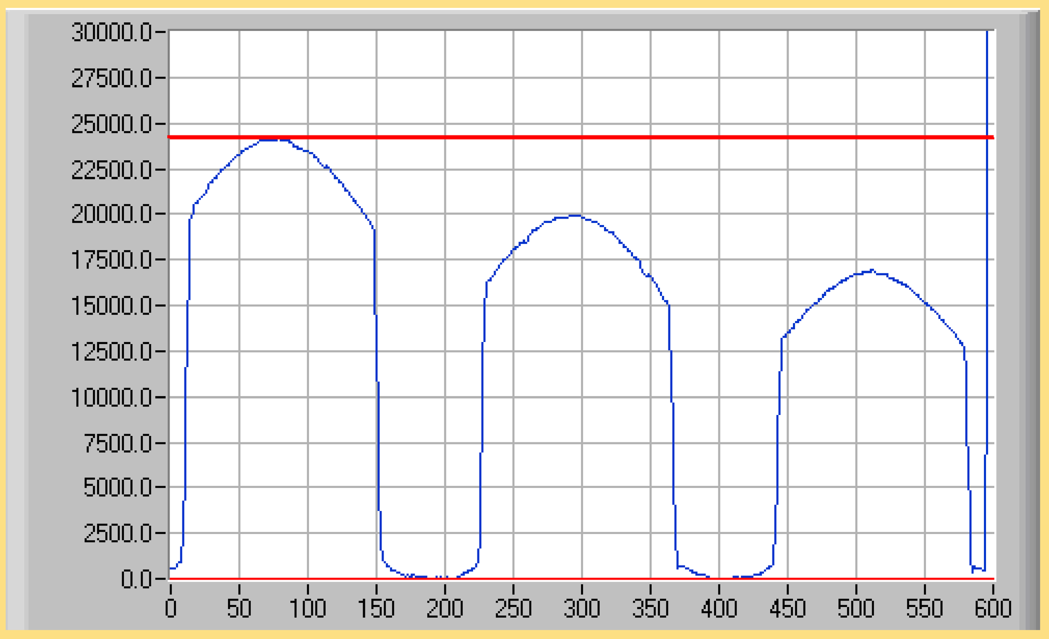

Figure 4. Line plot along a line such as the red line in Figure 3 depicting maximum pixel values for the 3 film coupons

FITTING

- After the red channel pixel value was determined at each measured dose, Origin 8 software from OriginLab© was used to fit these values to a 5th order polynomial:

$$D = A_0 + A_1x + A_2x^2 + A_3x^3 + A_4x^4 + A_5x^5$$

where D is the fitted dose, x is the measured pixel value and the constant term, A_0=0.

- The dose for each pixel value was determined from the average polynomial fits at each distance.

RESULTS

FITTING

- The dose for each pixel value, determined from the average polynomial fits at 1, 2 and 4 cm, is shown in **Figure 5**.
  - The individual fits are all well behaved without any anomalous outlying points and with fit residuals within 4%.
  - Fits were also performed combining the data at each distance. When using the combined fit, all residuals were within 6%.

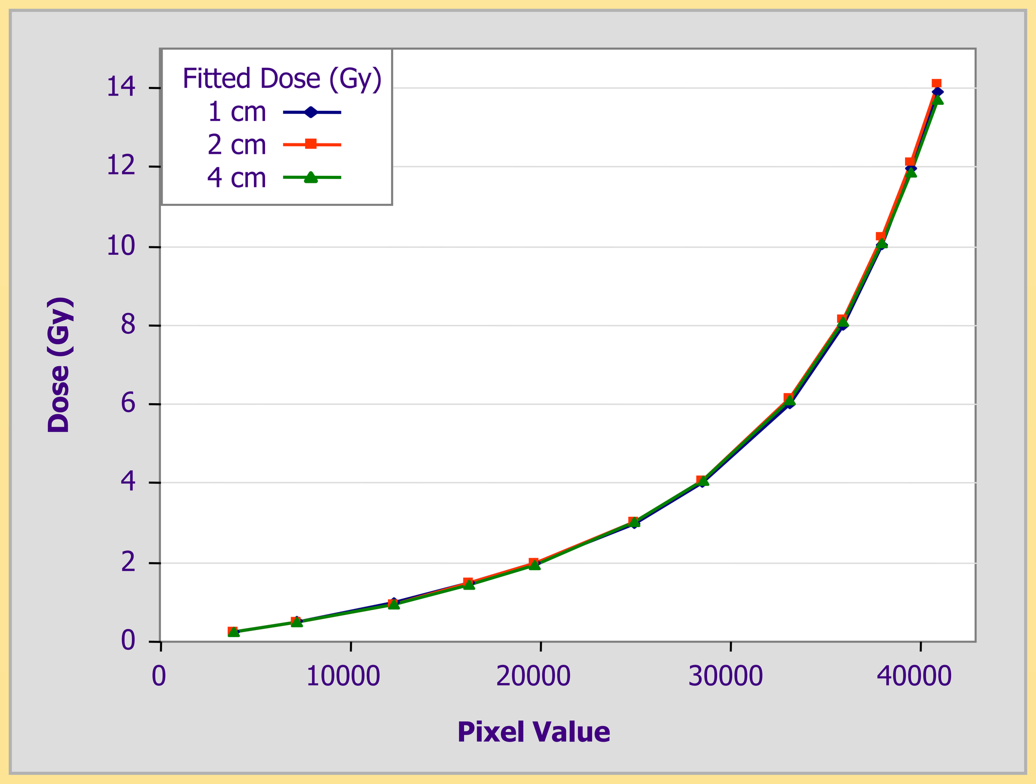

Figure 5: Dose (Gy) determined from the polynomial fits

- At greater distances from the X-ray source in water, the softer portion of the source spectrum is attenuated so that a harder energy spectrum will be seen by the film. If the film exposure response is a strong function of the source spectrum, then a shift in the calibration constants may be observed between the 1 cm and 4 cm exposures due to the hardening of the spectrum with depth in water.
- **Figure 6** presents the percent difference of the 4 cm and 1 cm fitted dose as compared to the 2 cm fitted dose.
  - Here, it can be seen that the 4 cm dose fit does diverge at the lowest, 0.25 Gy target, dose by nearly 10%. This corresponds to a difference in absolute dose of only 0.024 Gy.
  - All other differences are within 4% indicating that no overall difference in measured pixel value for a given detected dose was observed as a function of distance (or as a function of the source spectral range) from 1 cm to 4 cm distance in water.

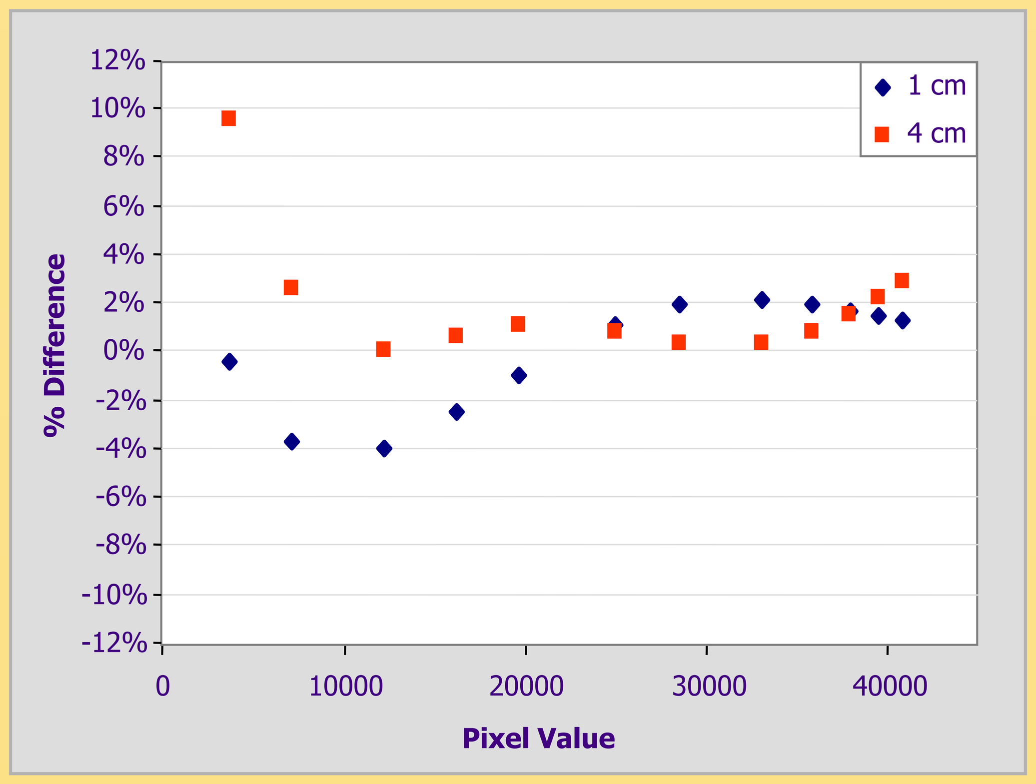

Figure 6: Percent difference in calculated dose of the 1 cm and 4 cm combined fits compared to the 2 cm fit

- The calibration coefficients determined from these fits were applied to radiochromic films exposed as part of a validation study of the dose delivered with the Xoft Axxent® Vaginal Applicators.
  - Good agreement was seen between the isodose contours determined employing the film calibration and those predicted using BrachyVision™ treatment planning software.

CONCLUSION

- A calibration of Lot 47207-01I GAFCHROMIC EBT film was performed at distances of 1 cm, 2 cm and 4 cm using the Xoft Axxent® X-ray source.
- No significant differences in the measured pixel value were observed for a given dose over this distance range.
- At 4 cm distance, the difference in calculated dose at the lowest pixel value, corresponding to about 0.25 Gy, was higher than that for the 1 cm and 2 cm distances by about 10%. This difference is small in absolute dose.

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