DOSIMETRIC STUDY OF A NEW SURFACE APPLICATOR FOR THE XOFT AXXENT SYSTEM

S. Axelrod, L. Kelley, A. Walawalkar, S. Yao , T.W. Rusch, *Xoft*, Inc., Sunnyvale, CA

BACKGROUND

- Over the past two years, the Axxent® Electronic Brachytherapy (eBx) 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.

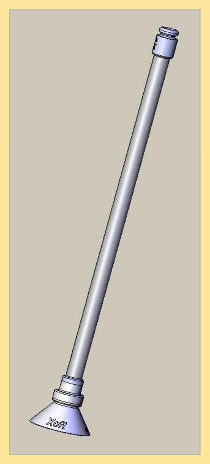


Figure 1. Surface Applicator

- The FDA cleared the Axxent® eBx System for more general treatment of "lesions, tumors and conditions in or on the body where radiation is indicated".
- Xoft has developed a set of surface applicators for use with the Axxent® electronic brachytherapy (eBx) system. The applicators are conically shaped, with a linear channel for introduction of the source catheter, and are made of stainless steel (Figure 1). The set consists of 10, 20, 35 and 50 mm diameter versions.
- These surface applicators were designed for use in treating superficial sites on the head and neck as well as the extremities, especially hands and legs.
- 10 million actinic keratoses and 1 million basal cell carcinoma cases occur each year.
- Radiation oncologists currently see a small percentage of these patients secondary to patterns of referral, inconvenience of treatment, and inefficiency of equipment utilization
- The Axxent® eBx system (**Figure 2**) allows lesions up to 5-10 mm deep to be treated without risk of excessive skin dose and can cover small areas up to nearly 5 cm diameter.
- The Axxent® eBx System has the potential to be equivalent to external beam radiation in its range of applications and sophistication of use.
- Its electronic on/off nature and other unique design features make it ideally suited for superficial radiation therapy.
- The Axxent® eBx System is a self-contained unit that can be wheeled from one operating room (or procedure room) to the next.
- The Axxent® system can be used as an alternative to HDR sources such as Ir-192, with the advantage that the treatment room can be lightly shielded and staff can be in the room with the patient during treatment.

Figure 2. Axxent® System Controller

PURPOSE

- The development of each surface applicator for use with the Axxent® eBx system included an aluminum flattening filter, to create a uniform dose distribution across the output plane. The filter also served to harden the beam to provide a depth dose relationship which is similar to that obtained with HDR systems. Heights of the cones were selected to provide dose delivery rates similar to HDR based systems.
- Owing to the low penetration of 50 kVp radiation in higher Z materials, a wall thickness of 1 mm stainless steel in the cone provides full shielding. This results in lower weight compared to similar units designed for use with seeds such as Ir-192. The channel is compatible with many commercially available fixation systems.
- Dosimetric measurements of these applicators are key to providing guidance for planning treatments. In particular, flattening filters have been incorporated to reduce the variation of dose across the treated area, as occurs with traditional Leipzig style applicators.
- The measurements reported here show the degree to which flatness or uniformity has been achieved, the variation in dose with depth, and the absolute dose rates in Gray per minute.

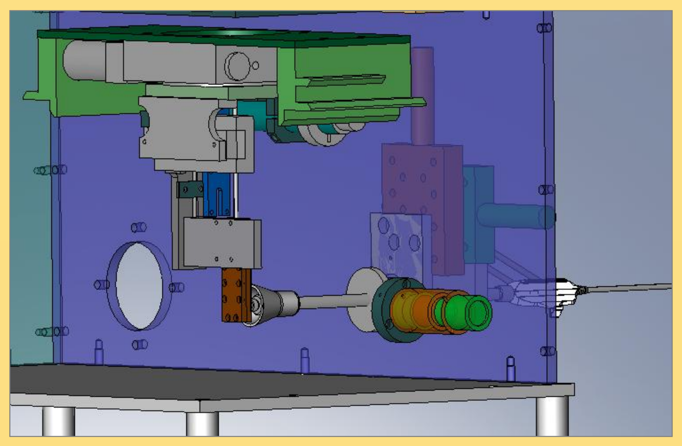
METHODS

- Measurements of dose rate, dose profiles and percent depth dose (PDD) were made using two techniques, ion chamber and radiochromic film, for the 35 mm applicator.
- Laboratory measurements were made using standard Xoft Axxent® sources running at the nominal 50 kVp, 300 µA operating point used in most indications of the system. Data was taken with a 35 mm diameter applicator, the first of four applicator sizes: 10, 20, 35 and 50 mm. Film measurements (type EBT) were made in a water phantom at several distances from the surface, in an orientation parallel to the surface. Film was also exposed in the perpendicular orientation, along the central axis of the applicator.

Ion Chamber:

- Absolute dose rate was measured in a water phantom using a PTW 34013 ion chamber calibrated to dose in water. The ion chamber was encased on a Solid Water™ jacket to make it watertight. It was mounted on a computer-controlled linear stage, allowing transverse scanning for measurement of dose profiles. The applicator was mounted on a linear stage as well, to set the distance from the ion chamber (**Figure 3**).
- Measurements were made at distances of 2, 5, 10 and 15 mm from the face of the applicator to the ion chamber. The applicator comes with disposable sterile end caps to ensure proper positioning of the treated tissue. To prevent water from entering the cone volume, the end cap was held with a watertight bond to the applicator cone. This apparatus thus provides dose profiles, absolute dose and depth dose information.

Figure 3. Water Tank Apparatus. The figure shows a water tank with a PTW model 34013 ion chamber attached to a computer-controlled, precision stepper motor. Stage and motor assembly are at top. The ion chamber is encased in solid water (brown in the figure) and scans from left to right. The applicator under test enters from the rear; its depth is controlled by a micrometer stage.



Radiochromic film

- GafChromic EBT radiochromic film was used to supplement the ion chamber measurements and to emulate what will likely be used in clinical settings for routine QA. Film provides high spatial resolution but must be carefully calibrated to the radiation quality in use. Such calibrations were performed at several distances from the source in water to investigate the effect of a varying spectrum. No dependence on distance was found over the range from 1 to 4 cm. Accuracy of the calibration fits in terms of residual error was below 2% (2 σ) above 0.5 Gy.

ION CHAMBER RESULTS

- Data with a scanning PTW 34103 ion chamber was taken for 10 sources, using a single applicator. Data was also taken with a single source and 3 different applicators, and no significant differences were observed. These measurements were made as part of a formal Design Verification protocol.
- The average profiles of the 10 sources at distances of 2, 5, 10 and 15 mm in water are shown in **Figure 4**. Vertical lines delineate the 80% width boundaries (at 14 mm). Data was taken at 1 mm intervals. Note that the ion chamber has an active diameter of 3 mm, so sharp edges will be convolved with the response function and thus broadened.

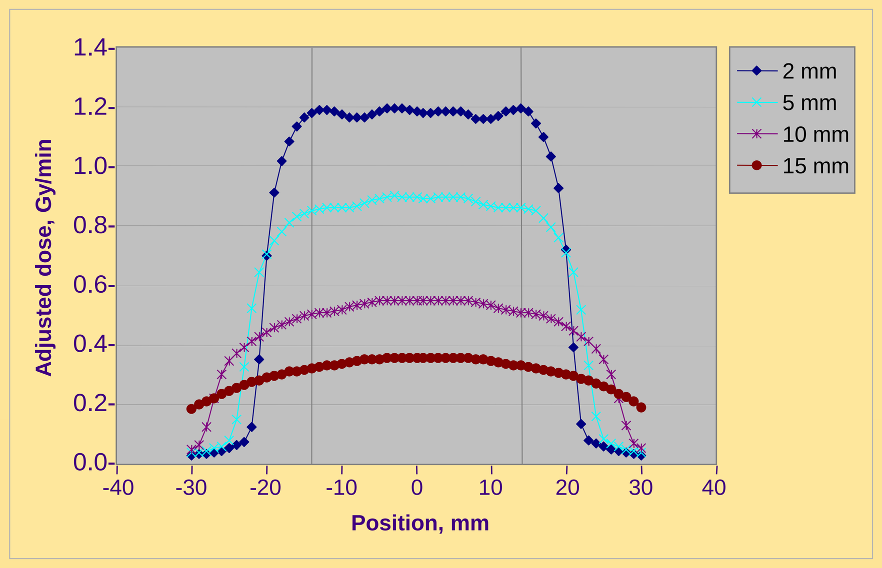


Figure 4. Average Dose Rate vs. Position

- **Table 1** shows maximum and minimum values in the central 80% region for the average profile, in percentage of the average dose rate. Also shown is the standard deviation (σ) across the profile, representing the RMS deviation from flat response.

Table 1

Distance	Max	Min	σ
2	101.3%	98.1%	1.0%
5	102.3%	97.0%	1.9%
10	102.9%	93.7%	3.0%
15	102.7%	92.9%	3.1%

- Individual source runs naturally show greater variation than the average profile, attributable to small differences in source spatial characteristics. **Figure 5** shows individual profiles at 2 mm distance for the 10 sources, normalized to 1.0 over the central 80% region. Comparable amounts of variation are seen at distances of 5, 10 and 15 mm.

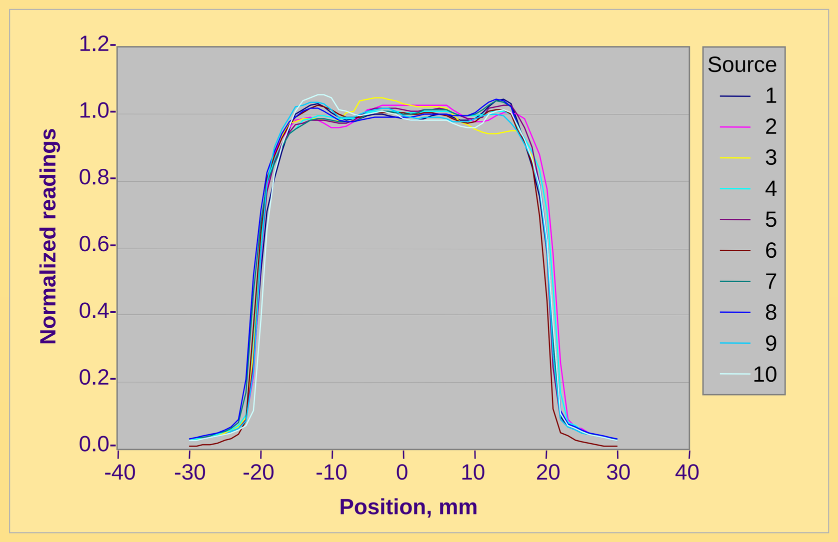


Figure 5. Normalized Profile Readings vs. Position for 10 sources

DEPTH DOSE RESULTS

- Depth dose data was derived from ion chamber measurements taken at distances of 2, 5, 10 and 15 mm in water.
- The average dose over 80% of the defined applicator width was calculated at each distance, and a 4th order polynomial fit was applied. The fit allowed extrapolation to 0 mm, and interpolation of intermediate distances up to 15 mm.
- **Table 2** and **Figure 6** show percent depth dose (PDD) results, derived from the average of measurements with ten sources. Also shown are the standard deviations calculated over the 10 sources.

Table 2

Distance, mm	PDD, %	std dev
0	100	-
5	62	4.9%
10	38	4.3%
15	24	4.3%

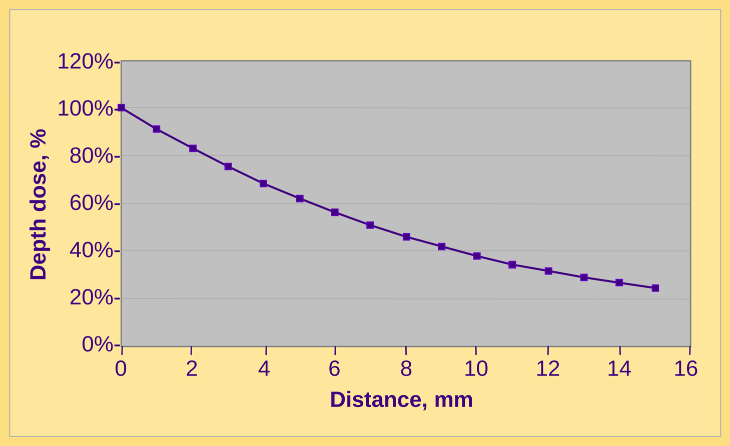


Figure 6. Percent Depth Dose. At the surface the absolute dose rate is approximately 1.45 Gy/min.

FILM STUDY RESULTS

- Film data was taken both in the course of product development and as part of a formal Design Validation protocol. The film's high spatial resolution and complete coverage was a complement to the scanning ion chamber data.
- The exposed film was scanned as a 48 bit RGB image, at 150 DPI. An example is shown in **Figure 7**. Being the most sensitive, the red component was selected for further analysis. The 16 bit pixel values were inverted and had a background image, based on the unexposed film, subtracted. A profile across the center of the image at this stage of processing is shown in **Figure 8**.
- A 5th order polynomial calibration was then applied to get dose values in Gray, and the average dose over 80% of the diameter was calculated.

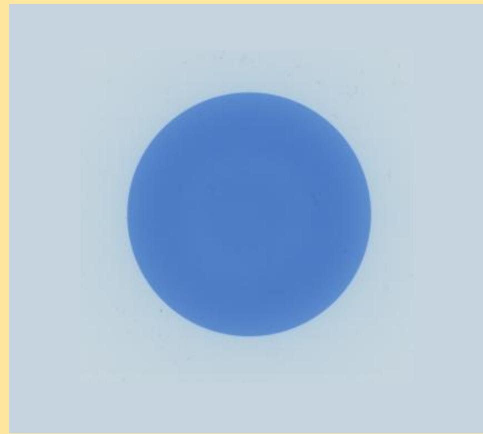


Figure 7. Raw RGB film image

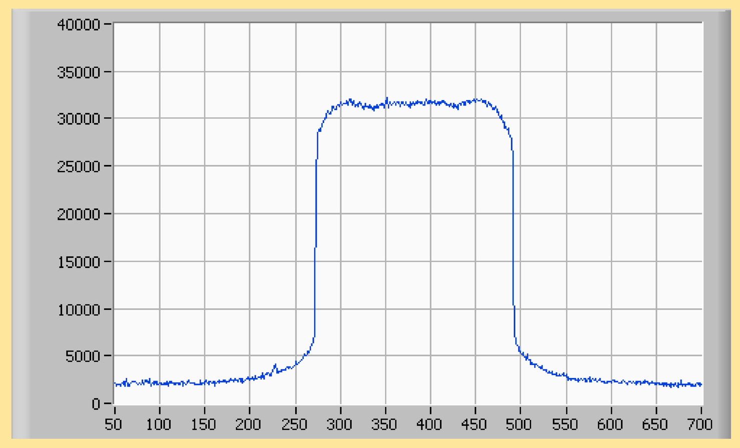


Figure 8. Line plot of red channel intensity across center of Figure 7.

Patient Treatment Simulation

- The Design Validation protocol focused on simulating a patient treatment, including use of an Axxent® controller to run the source to deliver a prescribed dose. A treatment plan consisting of dwell time at a single dwell point was created, based on average dose rate values determined in the 10 source Verification protocol. The Validation protocol specified use of 3 sources, each running the same treatment plan. Actual delivered dose, as determined by the film, was compared to the prescribed dose.
- The image in **Figure 9** represents the dose-calibrated film, with a color table shown in the upper right, ranging from 0 to 10 Gray. The line plot in **Figure 10** is from the center of the image horizontally. A median smoothing filter with rank 2 was applied to the 150 DPI scan data to remove high spatial frequency noise. Target dose was 5.0 Gy, which is in good agreement with the data. Table 3 shows results for the 3 sources used in the Validation protocol.

Table 3

Source	Planned Dose	Measured Dose
1	5.0 Gy	5.10 Gy
2	5.0 Gy	4.90 Gy
3	5.0 Gy	4.94 Gy

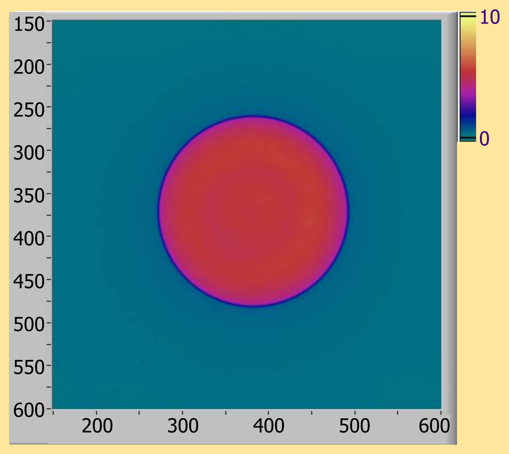


Figure 9. Film image calibrated to dose in Gy.

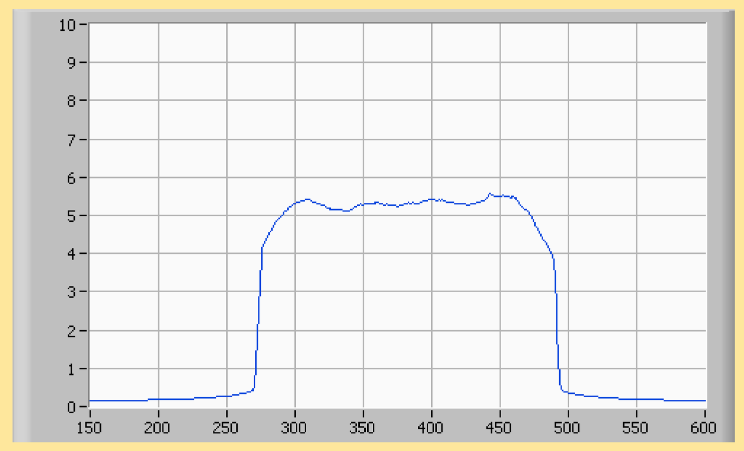


Figure 10. Line Plot across center of calibrated film image. Vertical axis is dose in Gy, horizontal axis is in pixels, where 1 mm = 5.905 pixels.

SUMMARY

- A new set of cone-style applicators has been developed for use in treating surfaces in conjunction with the Axxent® Electronic Brachytherapy System. The applicator described here has a diameter of 35 mm and is one of a set that spans a range from 10 to 50 mm.
- The cone walls are approximately 1 mm thick stainless steel, which provides adequate shielding for the 50 kVp radiation while keeping overall weight low.
- Ion chamber data show good flatness at all depths, with slow changes in the overall shape with depth, attributed to geometry and the hardening effect of the flattening filter. Scans made with the ion chamber provide reliable depth-dose and absolute dose rate data.
- A fit to the dose rate results at each depth allows prediction of percent depth dose values at various distances from the surface.
- Absolute dose rate, normalized to the nominal Axxent® 50 kVp source strength of 110,000 U, is approximately 1.45 Gy/min at the surface. At 5mm depth the dose rate is 62±4.9% of that at the surface.

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