Two-dimensional Dosimetry For an Electronic Brachytherapy Source Using Radiochromic EBT Film: Determination of TG43 Parameters

Sou-Tung Chiu-Tsao, PhD[1]; Stephen Davis, MSc[2]; Tina Pike, BS[2]; Larry DeWerd, PhD[2]; Thomas Rusch, PhD[3]; Robert Burnside, MSEE[3]; Manjeet Chadha, MD[4] and Louis B Harrison, MD[4].

[1]Quality MediPhys LLC, Denville, NJ; [2]Medical Radiation Research Center, University of Wisconsin, Madison, WI; [3]Xoft, Inc., Fremont, CA; and [4]Radiation Oncology, Beth Israel Medical Center, New York, NY

ABSTRACT

Purpose: To measure 2-dimensional dose distribution for Xoft Axxent® electronic brachytherapy source using radiochromic EBT films in solid water phantom and to determine TG43 parameters.

Materials and Methods: We measured 2-dimensional dose distribution for Model S700 Xoft Axxent® X-ray Source out to 5 cm in solid water phantom (RMI457, 30cmx30cmx24cm) using radiochromic (GAFCHROMIC EBT lot #35076) films. A source catheter was vertically positioned in the central channel of a solid water slab (30cmx30cmx2cm) originally designed to accommodate a Farmer 0.6cc thimble chamber. A multiple film technique was employed. For each experiment, a pair of experimental films of the same size was vertically positioned at 1cm from the source at opposite sides. The film emulsion layer was at 1.012cm from the source center. Totally 20 pairs of films were separately exposed with different exposure times, 20s, 40s, 80s, 120s, 240s, 300s, 500s. Three sources operated at 50 kVp were used in the experiments. The source air kerma strength was determined before each film exposure using an HDR1000 Plus well chamber. 15 calibration films (of the same lot) were exposed to 50kV x-ray (M50) in air at 100cm SSD at UW with doses ranging from 0.2 to 20 Gy. All experimental, calibration and background films were scanned (512 x 512 pixels, 0.2mm resolution) using a PeC CCD100 densitometer, with red, green and blue light sources. Conversion from net optical densities to doses was done using the calibration curve established for each light source used in scanning. The values of 2-d dose rate per unit air kerma strength in cylindrical coordinates were converted to spherical coordinates and the TG43 parameters were generated.

Results: The radial dose function and anisotropy function obtained with red, green and blue light sources were plotted and compared with one another. Dose rate constant (at 1 cm) was determined by extrapolation from the dose rate per unit air kerma strength at 1.012 cm and beyond.

Conclusions: Dosimetry for an electronic brachytherapy 50kV source using radiochromic EBT films has been presented and TG43 parameters were obtained.

PURPOSE

- To study the two-dimensional dose distributions around a new electronic brachytherapy source, the Axxent® Electronic Brachytherapy System, using radiochromic EBT film in solid water for distances from 1.012 cm out to 5 cm.
- To monitor the reproducibility of the radial and angular distributions of the doses.
- To determine the TG-43 dosimetric parameters for this X-ray source.

METHODS

- The X-ray Source for the Axxent® Electronic Brachytherapy System comprises an X-ray tube in a multi-lumen catheter that allows cooling fluid to circulate over the tube. The X-ray tube is ~2.25 mm in diameter x 15mm long and is attached to a high voltage cable and encapsulated within an electrical ground. Monoenergetic, 50 keV electrons originate from the hot cathode, and travel from left to right in the above diagram.

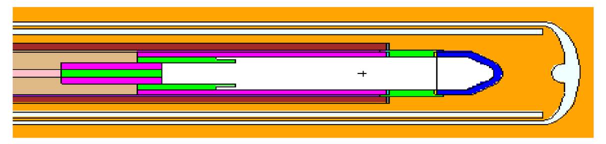


Figure 1. Xoft Axxent® model S700 Electronic Brachytherapy Source.

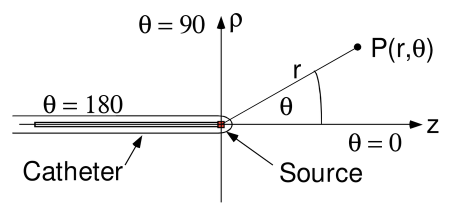


Figure 2. Diagram of coordinate systems

METHODS

- A multiple film technique was employed.
- Each film (EBT lot #35076) was at 1 cm distance from the source center, which was at the center of a solid water phantom, 30 x 30 x 24 cm.
- Totally 40 experimental films (in 20 pairs) were separately exposed to 4 sources, with the exposure times of 20, 40, 80, 120, 240, 300 and 500 sec.
- The source air kerma strengths ranged from 94,929 U to 132,069 U during the experimental runs.
- 20 background films were kept with the experimental films exposed in Beth Israel Medical Center.

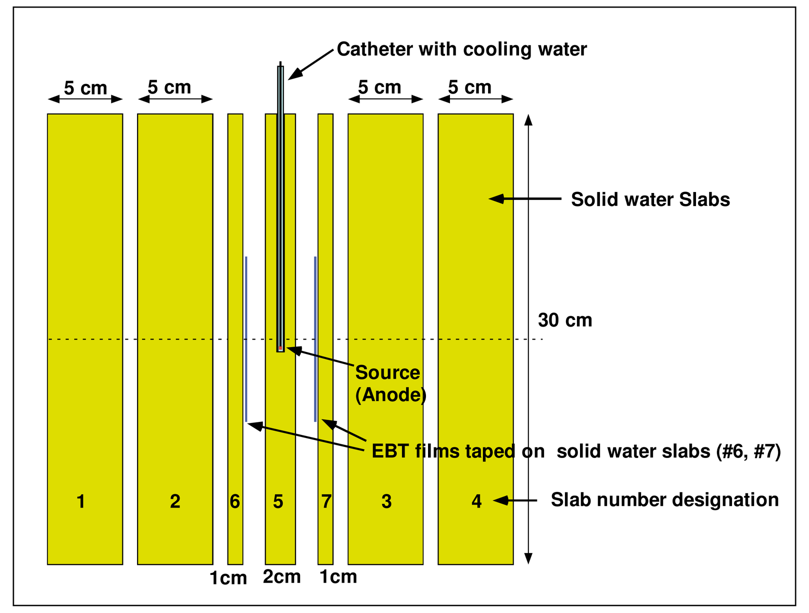
Radiochromic EBT film

- Lot #35076 from International Specialty Products, Wayne, NJ
- Film thickness: 0.25 mm
- Active emulsion layer at the center of the film
- The film surface was at 1 cm from the source center
- The active emulsion layer was at 1.012 cm from the source center.

Phantom Assembly

- The central slab (#5) was 2 cm thick, with a central channel designed for Farmer 0.6 cc ion chamber, with inner diameter of about 0.8 cm.
- The source catheter (outer diameter about 0.6 cm) was inserted into the vertical central channel. There was small air space between the catheter outer surface and the channel wall.
- Two films were exposed simultaneously, at opposite sides of the source.
- Each EBT film was taped on a solid water slab (#6, #7), 1 cm thick.
- All Solid water slabs were of RMI model 457 CTG, 30cm x 30cm.
- After the films were taped, all slabs were pushed against one another to form a phantom block of 24 cm (left to right) in width.

Figure 3. Side view of solid water phantom assembly



Air Kerma Strength Calibration

- The source air kerma strength was determined before each film exposure using a Standard Imaging HDR1000 Plus well chamber.

Calibration Films

- Two sets of 15 calibration films were exposed to M50 and M40 x-ray beams, respectively, at 100 cm SSD in air to air kerma levels from 0.2 Gy to 20 Gy at the University of Wisconsin. The air kerma levels were converted to dose to water in free space using Monte Carlo simulations performed with MCNP5. The conversion coefficients were within 0.1% of values obtained using the AAPM TG-61 protocol for those beams. The photon spectrum from the Axxent® sources at depth in the Solid Water phantom was expected to be similar to the M50 x-ray beam.
- 20 background films were sent together to University of Wisconsin, as control for the environmental factors in the shipping process.

METHODS

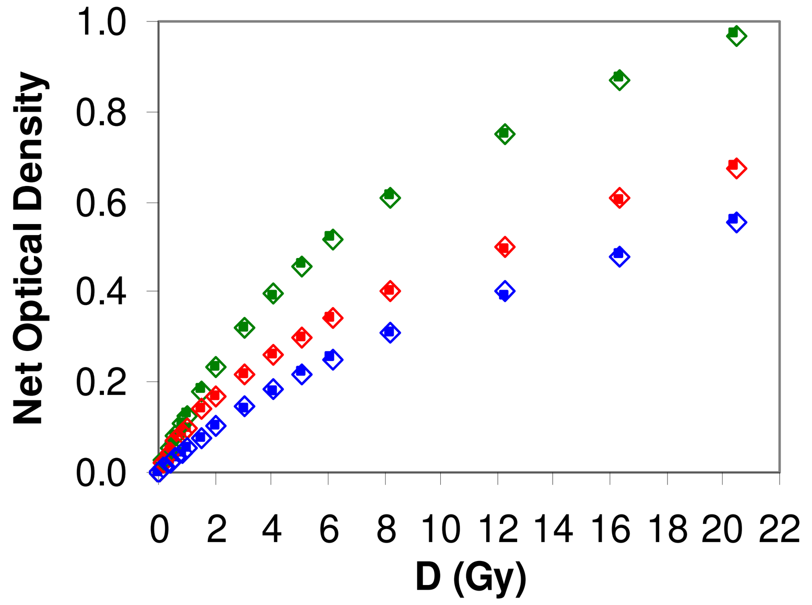
Film scanning

- All experimental, calibration and background films were scanned (pixel resolution 0.2 mm) using a PeC CCD100 densitometer, with red, green and blue light sources at least one day after exposures.
- Background film readings were subtracted from those of calibration films and experimental films to yield Net Optical Density (NOD) values.

Film data analysis

- The calibration and background film data were analyzed using the LabView based program in PeC system. Average optical density reading in a central area of 5 mm x 5 mm of each film was obtained.
- The average reading of the background films sent to UW was subtracted from each calibration film to yield the NOD values.
- Calibration curves were plotted, NOD vs. dose, for M50 and M40 x-ray beams. See Figure 4.
- The calibration curves for M40 and M50 are almost identical.

Figure 4. Calibration curves for M50 and M40 X-ray beams. Red, green and blue symbols are for data obtained using red, green and blue light sources. Closed square symbols are for M50, open diamond symbols for M40.



- The experimental film data in fit format were first analyzed using FV v 4.1.2 (from NASA) to identify the pixel number reflecting the source location near the film center.
- Using IDL v 6.0,
  - The average reading of the background films kept locally was subtracted from the readings of the experimental films to yield the NOD values.
  - The 2-dimensional NOD data in the film plane were converted to dose values in the plane containing the source axis.
  - The dose values in cylindrical coordinates were converted to spherical coordinates.
- Conversion from NOD to dose was achieved based on the M50 calibration curve established for each light source used in scanning.
- Time correction for the ramp up time of 2 sec was applied, in obtaining the dose rate values.
- The dose rate per unit air kerma strength was then determined, based on the air kerma strength from the well chamber measurement.
- Further data analysis and plotting were performed using Excel.

TG-43 Parameters

- The values of 2-d dose rate per unit air kerma strength in cylindrical coordinates were converted to polar coordinates for radial distances of 2, 3, 4 and 5 cm.
- The TG-43 parameters were generated, using the active length of 0.1 cm.

RESULTS

- The radial dose variation and anisotropy functions are plotted in Figures 5-8.
- Dose rate (cGy / U h) at 1.012 cm:
  - Red 0.835 +/- 0.023
  - Green 0.833 +/- 0.020
  - Blue 0.848 +/- 0.020

Figure 5. Radial Dose Variation, Red Light

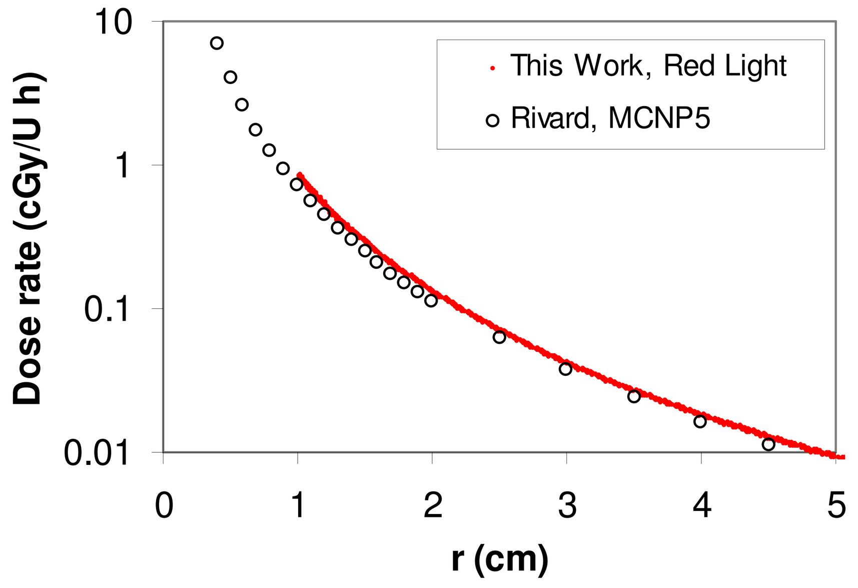


Figure 6. Radial Dose Variation, Green Light

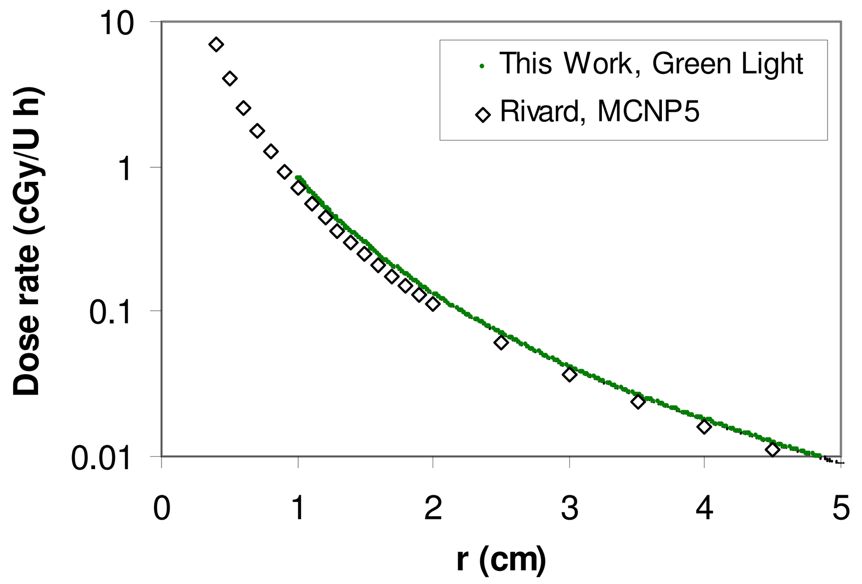
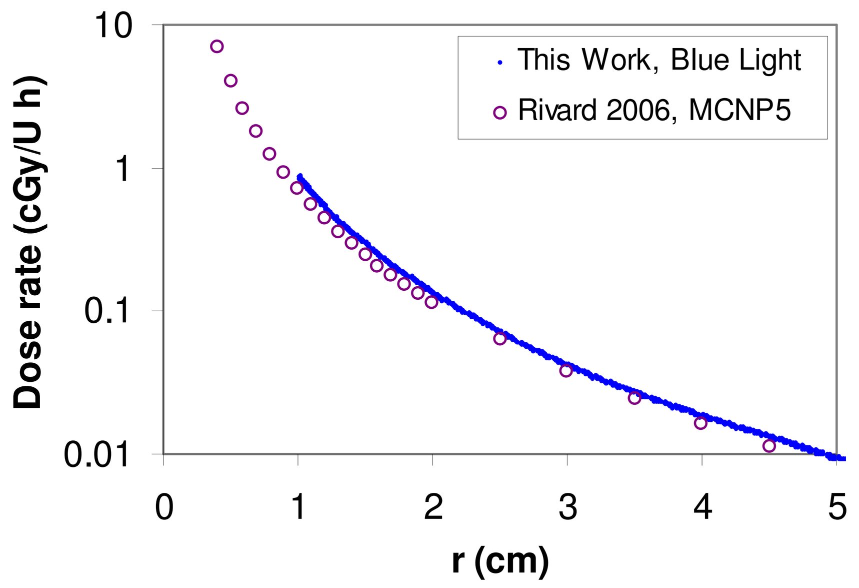
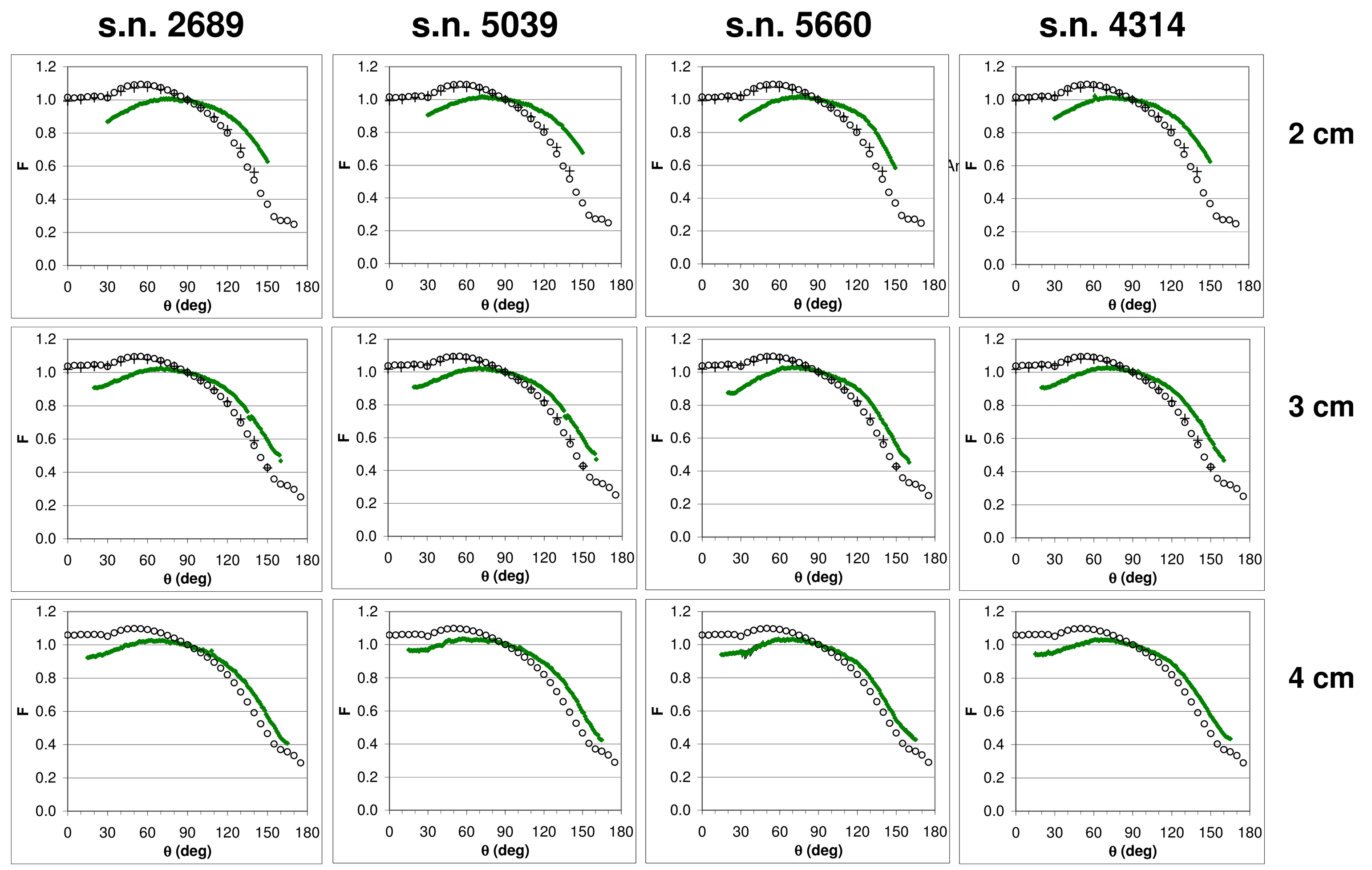


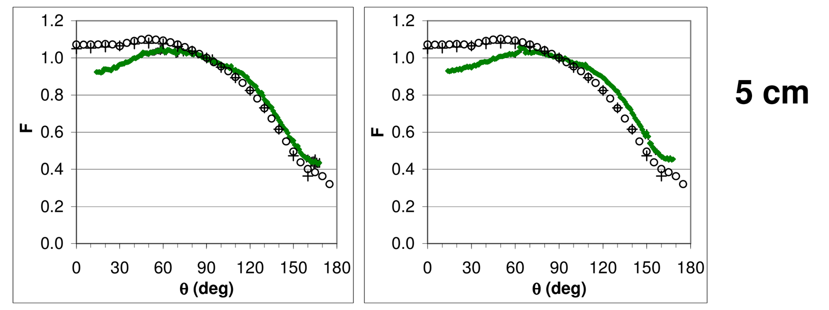
Figure 7. Radial Dose Variation, Blue Light



RESULTS

Figure 8. Anisotropy functions, F(r, θ), at radial distances of 2, 3, 4 and 5 cm for four different electronic brachytherapy sources obtained using green light source for film scanning. Source serial numbers (s.n.) are shown at the top.





- This demonstrates the reproducibility of the anisotropy functions for different electronic brachytherapy sources of the same design.
- For comparison, the open circle symbols are for results of MCNP5 calculations and the plus symbols are for PTW ion chamber data from Rivard et al, Med. Phys. 33, 4020 (2006).
- The anisotropy functions obtained using red and blue light sources are similar, and are not shown here.
- The results from the film scans using three different light sources are similar and corroborate one another.
- The anisotropy functions obtained in this work are similar, but not identical, to those from MCNP5 calculations and PTW ion chamber measurement. The differences are diminishing for increasing radial distances.
- The radial doses from this work are higher than those from the MCNP5 calculations. The difference is to be resolved further.

CONCLUSIONS

- The radial and angular distributions of the doses from the Axxent® X-ray source were found to be reproducible.
- TG-43 parameters were obtained using radiochromic EBT film for distances from 1.012 cm to 5 cm in solid water phantom.
- The TG-43 parameters are compared with those obtained from MCNP5 calculations.
- The radiochromic film dosimetry with model EBT film allowed us to determine 2-dimensional dose distributions with high spatial resolution within reasonably achievable time frame.

Funding provided by Xoft

Poster PO-32 presented at the 28th Annual American Brachytherapy Society Meeting, April 2007, Chicago, IL