Treatment Plan Validation of the Xoft AXXENT™ X-ray Source

Steve Axelrod

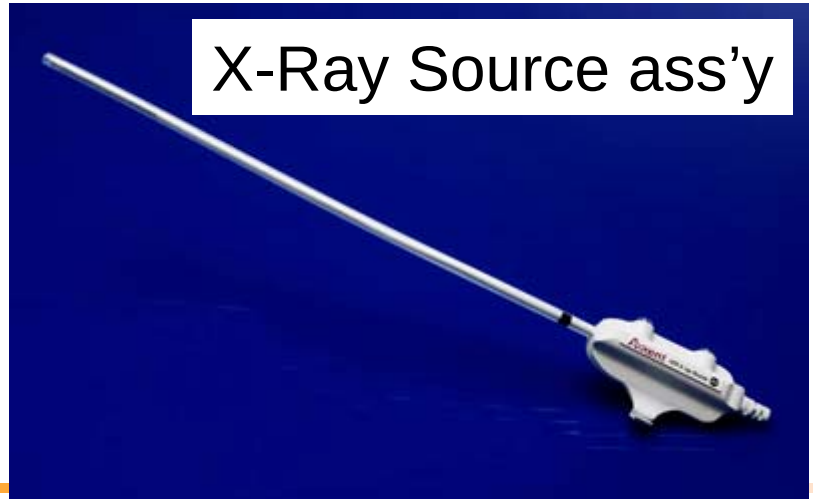
Thomas W. Rusch

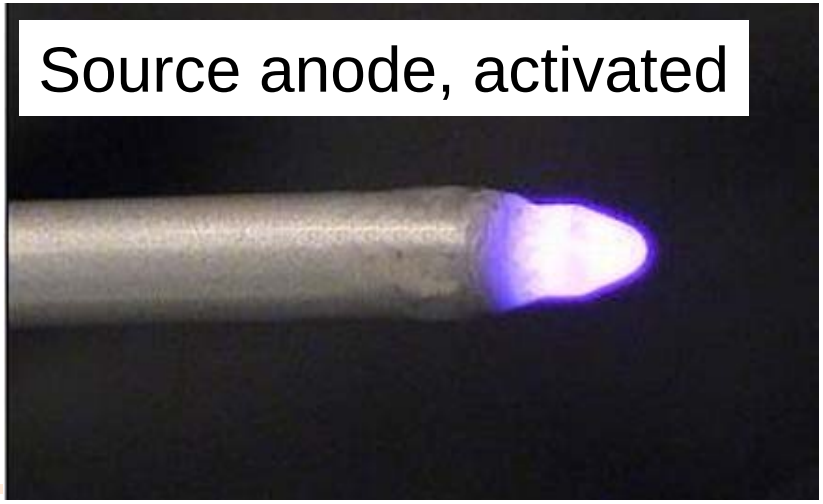
Xoft, Inc. Fremont, CA

AXXENT X-Ray Source

- Miniature X-ray tube for therapeutic radiation treatment
  - 2.2 mm diameter by 10 mm long
- Initial indication is breast brachytherapy
  - Not yet cleared by the FDA
- Operates up to 50 kV at up to 300 µA beam current
  - Up to 1 Gray/minute dose rate at Rx point
  - Inside balloon applicator
- Mobile Controller unit
  - User interface
  - X-Ray power and safety interlocks
  - Steps the source position

Family Photos





Axxent™

Xoft

Source Characterization

- Characterization of X-Ray output via TG-43U1 parameterization for brachytherapy
  - Terms for Source strength, dose ratio air/water, spatial distribution
  - Point source approximation ($1/r^2$) used here

$$\dot{D}(r,\vartheta) = S_k \cdot \Lambda \cdot \left(\frac{r_0}{r}\right)^2 \cdot g_p(r) \cdot F(r,\vartheta)$$

- Key terms for this study are the depth-dose $g_p(r)$, and polar angle distribution $F(r,\theta)$
- Azimuthal distribution is assumed flat (no dependence)

Treatment Planning for HDR Breast

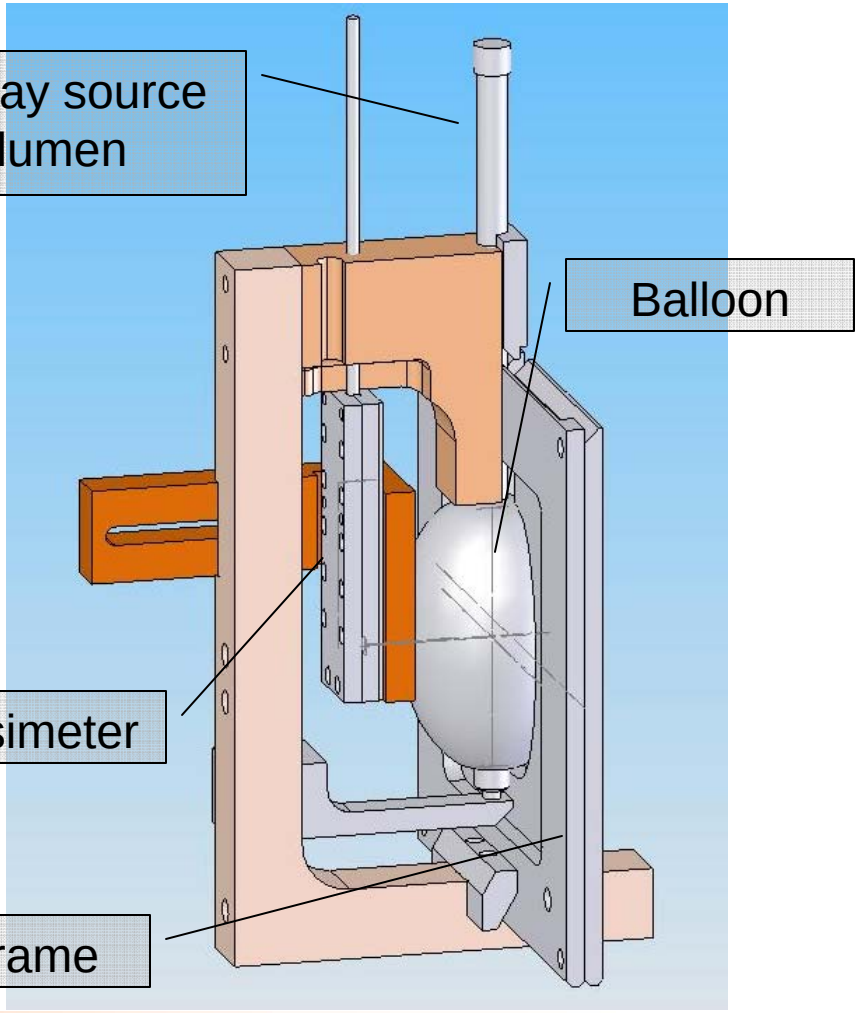
- Any treatment planning system using TG43 is compatible
  - Varian BrachyVision used for this study
- TPS used to calculate dwell times for stepping of source
  - To optimize dose delivery
  - Delivers “dwell file” for controller use
  - Dose info including isodose contour map
- Need to validate accuracy of actual treatment compared to the plan

Dose Plan Validation Technique

- Two methods employed during simulated treatment in a water and Solid Water™ phantom
  - Radiochromic Film measures spatial distribution
    - 5” square films in plane of source
    - 5mm off central axis, cut out to conform to balloon
    - Images digitized and analyzed for conformance to plan
  - Dosimeter determines total dose
    - PTW 34013 air ionization chamber
    - Located at prescription point, 1 cm from balloon at 90°
    - UniDos electrometer read into LabVIEW computer program

Film/Dosimeter Fixture

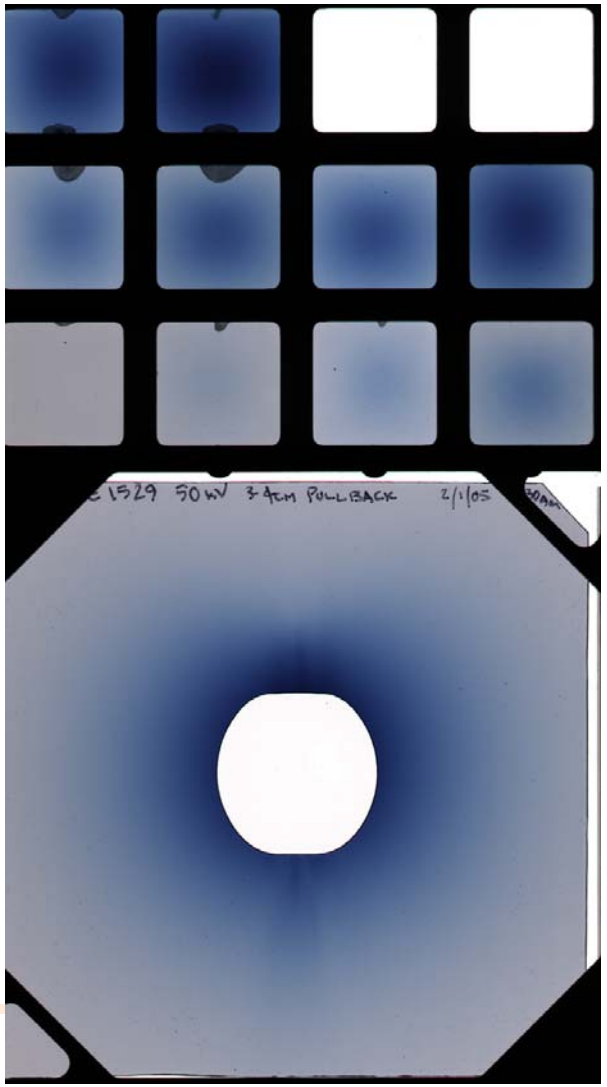
- Fixture built primarily of Solid Water™
  - Immersed in water bath
- Dosimeter encased in solid water™
- X-Ray source enters from top
- Balloon applicator shown is ellipsoidal
- Film frame 5 mm off central axis
  - GAFChromic Type EBT film



Axxent™ Xoft

Film Scanning

- Exposed film and calibration coupons scanned together
  - Metal frame holds films in reproducible positions
  - Films cut by computerized mill
- 48 bit RGB scan to RAW format
  - Epson Perfection 4870 scanner
  - No “color correction” by scanning software
- Analysis done using the 16 bit red component



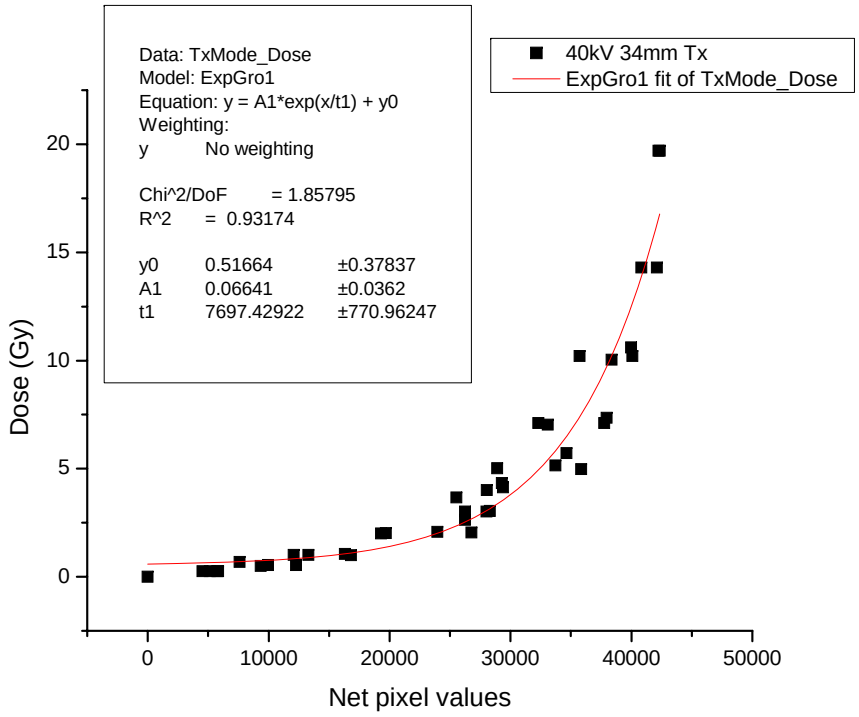
Axxent™ Xoft

Film Calibration

- Film coupons exposed to monitored doses of radiation
- Film and dosimeter continuously rotated around source to average out azimuthal variations in source output
- Pixel values averaged over small area in center of coupons
- Exponential fit of pixel values to total dose
- Pixel value offset (0 dose value) is not small
  - Source of error

Film Calibration Fit

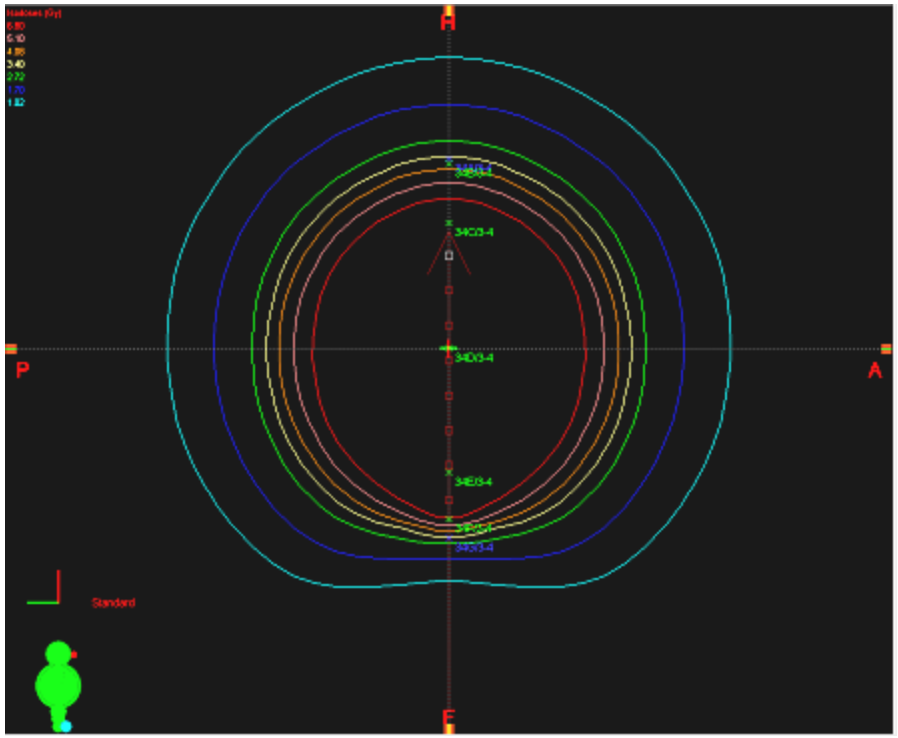
- $Y = Y_0 + A_1 \exp(X/t_1)$
  - Y = Dose
  - X = Net pixel values
    - = Pixel values – offset
- Scatter in data
  - RMS of residuals 23%
  - Room for improvement!
- Calibration function applied to scanned film



Axxent™ Xoft

Comparison of Film to TPS Plan

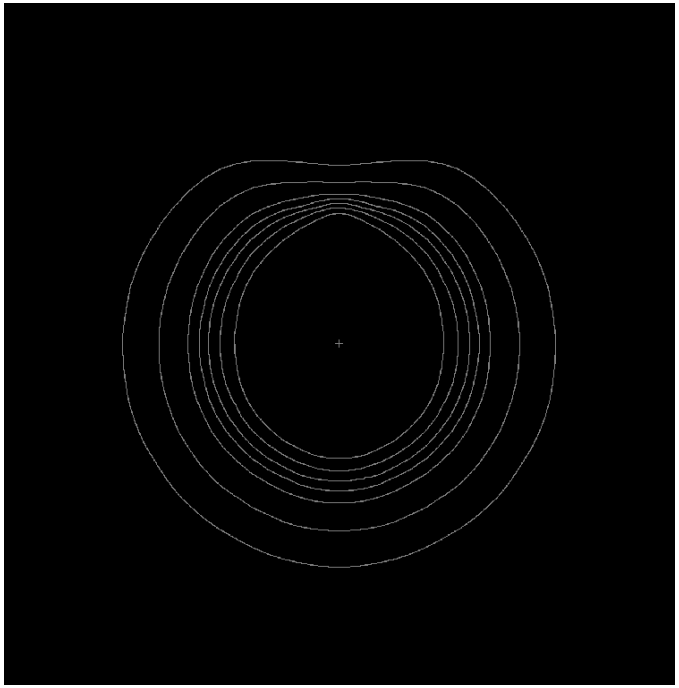
- BrachyVision generates an image of isodose contours
  - Picture at right
- A binary image “mask” is created with only the contours
- This is multiplied by the calibrated film image
- Resulting image has measured values, but only at the location of isodose contours



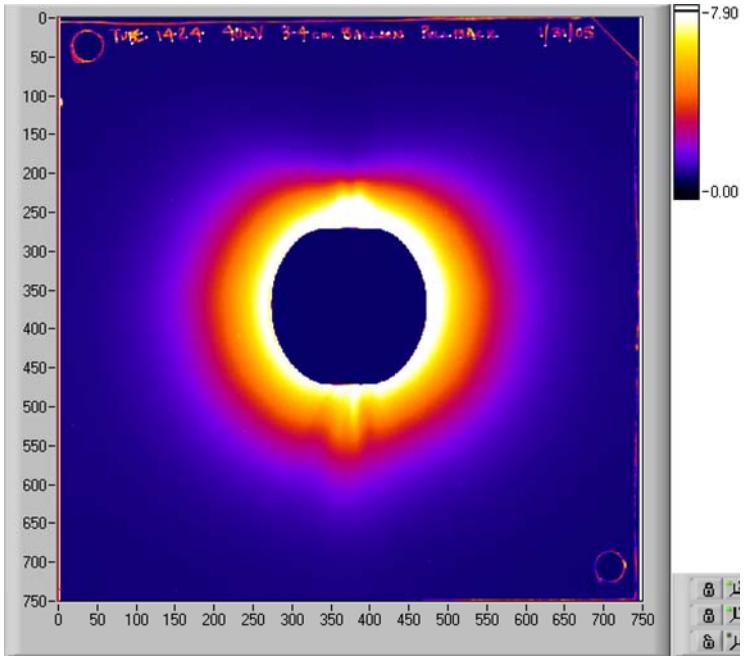
Axxent™ Xoft

Image Math

- BrachyVision originated mask
  - Scaled to pixel and spatial dimensions of film image



- Scanned film of treatment with calibration applied

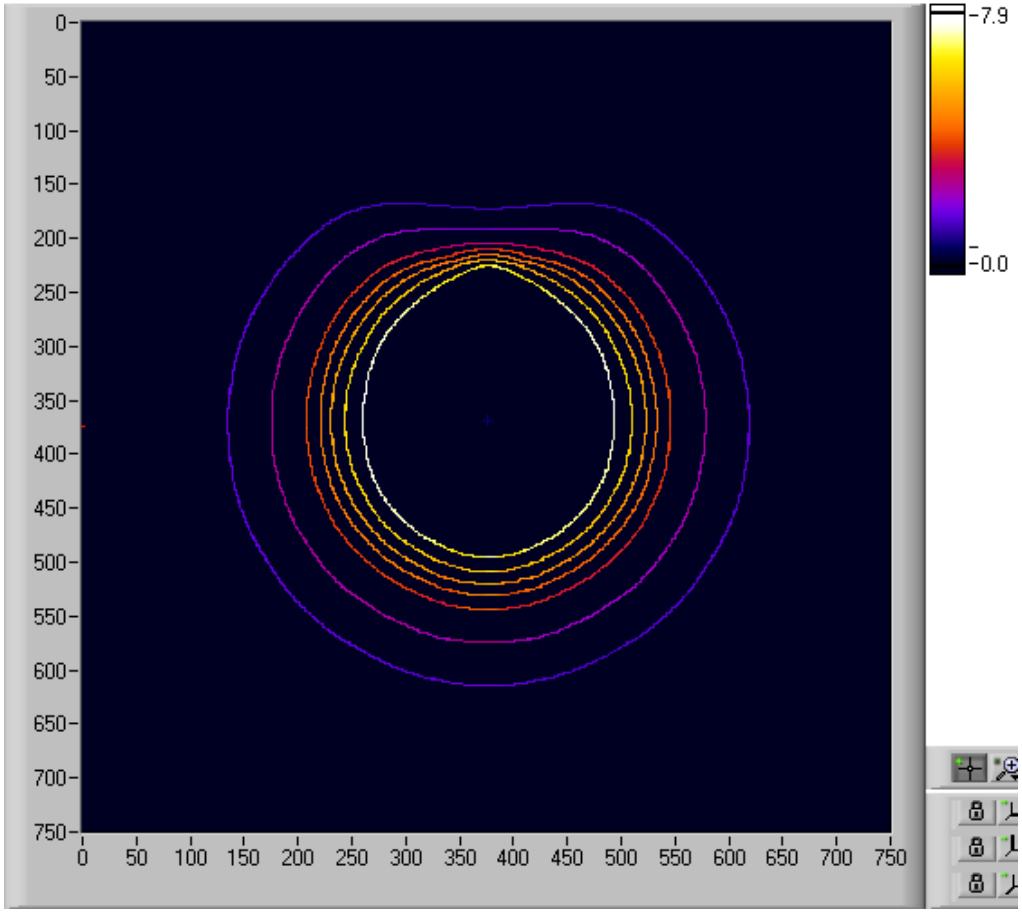


Axxent™

Xoft

Composite Film Image

- Calibrated film image multiplied by isodose contour "mask"
  - Generates new image
  - False color mapping LUT* shown at upper right
- Ideally each contour should be a uniform color
  - Are they?

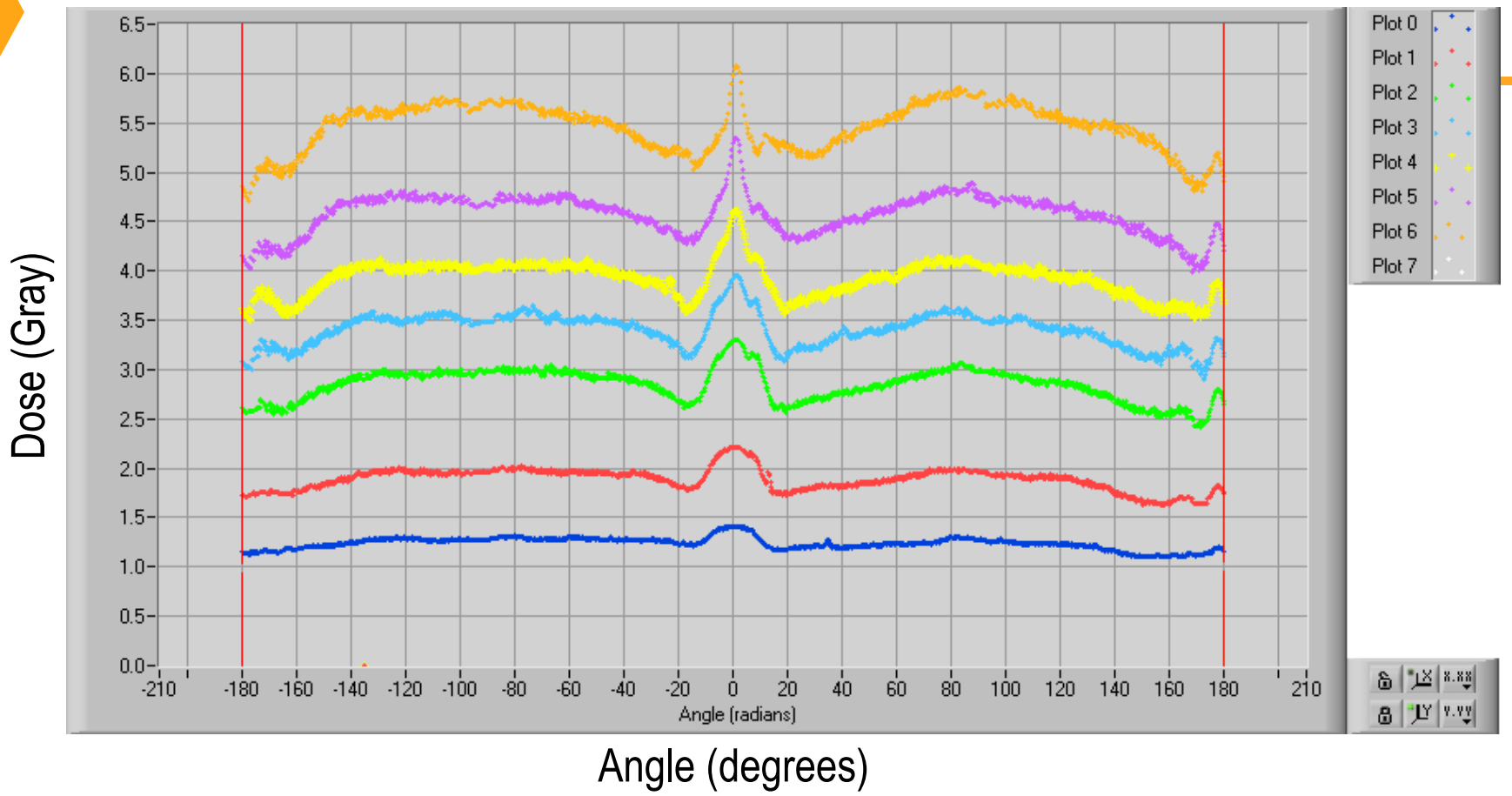


* LUT = Look Up Table

Quantifying the Composite Image

- The non-zero image values which define the contours are identified pixel by pixel
- Angle with respect to the center is calculated
- Values are then plotted versus angle
  - This is the polar angle
  - 0 degrees is the distal end of the source
- Referred to as “unwrapping” the isodose lines

Unwrapped Isodose Contours



- Ideally flat, absolute magnitude equals isodose contour value
- 50 kVp source, 34 mm spherical balloon

Axxent™ Xoft

Film-Based Numeric Results

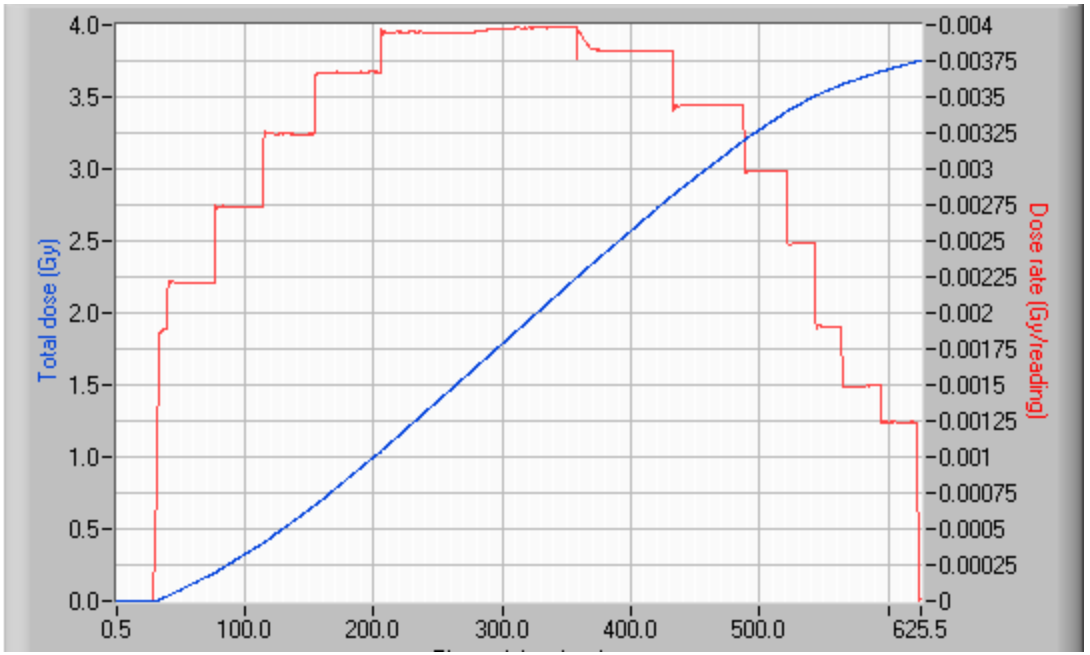
- Results from two runs at 50 kVp, 34 mm diameter balloons
- Averages and standard deviations for each contour are calculated and compared to the target dose
- Difference between target and measured has pattern which suggests it is due to the limitations of the film calibration

Target Gy	Average Gy	Difference (%)	Sigma (Gy)	Sigma (%)
1.02	1.24	21%	0.06	5.0%
1.70	1.89	11%	0.11	6.0%
2.72	2.84	4%	0.17	6.0%
3.40	3.40	0%	0.17	5.0%
4.08	3.91	-4%	0.18	4.6%
5.10	4.57	-10%	0.21	4.6%
6.80	5.44	-20%	0.25	4.6%

Target Gy	Average Gy	Difference (%)	Sigma (Gy)	Sigma (%)
1.02	1.10	8%	0.06	5.6%
1.70	1.70	0%	0.12	7.1%
2.72	2.70	-1%	0.20	7.4%
3.40	3.35	-1%	0.23	6.9%
4.08	4.00	-2%	0.25	6.2%
5.10	4.90	-4%	0.32	6.5%
6.80	6.18	-9%	0.44	7.1%

Dosimeter Results

- Time series (red) and integral (blue) of dosimeter readings
- Source is stepped through multiple dwell positions
- Dose units are in Gray
- Time axis is in terms of 0.5 second readings
  - Elapsed time ~ 5 minutes



- Plan dose at this point was 3.52 Gray, actual measured was 3.75 Gy
  - Within 6.5%
  - Uncertainties include position of dosimeter with respect to balloon surface
- Dosimeter absolute calibration much more accurate and reliable than film

Summary of Several Dosimeter Runs

Source	X-ray energy	Balloon type	Prescription dose	Measured dose	Measured / Prescription
---	*kVp*	---	*Gray*	*Gray*	---
A	40	34 mm spherical	4.0	4.41	1.10
B	40	34 mm spherical	4.0	3.95	0.99
C	40	50 x 70 mm elliptical	4.0	4.02	1.00
D	40	50 x 70 mm elliptical	4.0	4.30	1.07
E	50	34 mm spherical	3.4	3.04	0.89
C	50	50 x 70 mm elliptical	3.4	3.75	1.10
F	50	50 x 70 mm elliptical	3.4	3.15	0.93

- Note that comparisons are to prescription dose, rather than plan dose
- Since planned dose is not exactly the same as the prescription, this makes the comparison appear slightly worse than it actually is

Conclusion

- Film and dosimeter based measurements were carried out to validate treatment planning for the Xoft Axxent™ electronic brachytherapy system
- Dosimeter measurements at 90° at prescription depth show agreement of planned and delivered dose to within ~10%
- Film based measurements showed good agreement of the shape of the actual distribution with predictions of the TPS
- Dosimeter and film measurements together are an effective means of comparing planned dose to delivered