RADIOCHROMIC FILM DOSIMETRY FOR A NEW ELECTRONIC BRACHYTHERAPY SOURCE

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ABSTRACT

Purpose: Radiochromic film measurements have been made of the dose distribution around a new miniature x-ray source designed for electronic brachytherapy.

Method and Materials: GAFCHROMIC model XR-T films, lot #30189-2 and #M02C21XRT, were exposed to x-rays emitted from a new flexible x-ray probe with 40 kVp and 100 μA setting in a RMI457 solid water phantom and a liquid water phantom, respectively. The experimental films were positioned parallel to the tube axis at a distance of 9mm and 5 mm, respectively. To establish the calibration curve, a series of calibration films individually received 1 to 60 Gy at the film center with a dose rate based on miniature ion chamber measurements. All films were scanned using red (665 nm) and green (520 nm) lights in a CCD100 microdensitometer with spatial resolution of 0.2mm. The average optical density (OD) over 1 mm x 1 mm area at the center of each calibration film was obtained. After subtracting the background film reading, separate calibration curves (Net OD vs. dose) were plotted for red and green lights. A simple geometric transform was used to convert the measured OD values to dose in the plane containing the probe axis.

Results: Incorporating the exposure time, 2-d dose rate distributions were obtained for distances up to 4 cm, and depth-dose curves were plotted. Dose anisotropy in polar angles and dose variation with radial distances were extracted and evaluated. Measurements agreed favorably with Monte Carlo calculations of x-ray probe output.

Conclusion: GAFCHROMIC XR-T film is a promising tool for new electronic brachytherapy dosimetry.

INTRODUCTION

- Xoft has developed an electronic high dose rate brachytherapy device. The Xoft microTube Flexible X-ray Probe delivers tight, conformal doses of x-radiation to the inner surface of a body cavity such as an excised tumor bed. See Device Description and Figures 3-4.
- This poster describes the measurement of dose distributions using GAFCHROMIC® XR-T film exposed to the Xoft microTube X-ray Probe.
- The initial application of the Xoft microTube Flexible X-ray Probe has been to the conservative treatment of breast cancer utilizing a balloon-based Partial Breast Irradiation System.
- The Xoft Treatment System is designed to shorten radiation treatment time while significantly reducing complications to the skin and surrounding healthy tissue. The Xoft Treatment System does not require a heavily shielded environment, making treatment potentially available for women without access to a facility with an HDR afterloader. This technology eliminates handling and disposal of radionuclide sources.

METHODS

- **Objective**: To study the dose distribution characteristics of a new electronic brachytherapy source based on a miniature x-ray source using GAFCHROMIC XR-T film dosimetry method.
- **Instrument:** Xoft microTube Flexible X-ray Probe operated at 40 kVp and 100 μA
- **Films:** GAFCHROMIC® Model XR-T films (Lots #30189-2 and #M02C21XRT from International Specialty Products Corporation). [1] Film thickness: 0.21 mm
- **Calibration films:** A series of calibration films (Lot #30189-2, about 2 cm x 2.5 cm) were irradiated at a distance of 9.055 mm from the x-ray tube axis in an RMI 457 certified grade solid water phantom (10 x 10 x 15 cm). Lot #M02C21XRT films were irradiated at 1 cm distance in a liquid water phantom (30 cm diameter x 30 cm high). Irradiation times ranged from 0.2 to 12 minutes.
- **Experimental films:** For dose measurements, large film sheets (8.4 x 8.4 cm and 12.5 x 12.5 cm) were irradiated at a distance of 9.055 cm and 0.5 cm, in solid water and liquid water phantom, respectively.
- **Dose Values:** The dose values were based on the dose rate generated from MCNP-5 Monte Carlo calculations and verified by miniature ion chamber measurements (PTW 34013). Dose values ranged from 1 to 60 Gy.
- **Data Collection:** The films were scanned using a CCD100 microdensitometer from Photoelectron Corp. (PeC):
  - PeC-Red: Red LED light box (665 nm)
  - PeC-Green: Green LED light box (520 nm)
  - Spatial resolution: 0.2 mm per pixel

Phantom Setup for Calibration Film

Figure 1. Side view

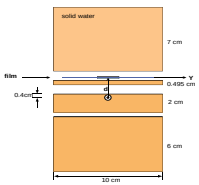
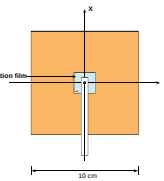


Figure 2. Top view



DEVICE DESCRIPTION

- The Xoft microTube Flexible X-ray Probe consists of a disposable, micro-miniature X-ray source integrated into a cooled, flexible, disposable probe.
- X-rays of 40-50 keV maximum energy are produced at the tip of the directable probe, which otherwise closely resembles current remote afterloading units.

Figure 3.
X-Ray Source –
Scaled to Size

Figure 4. Xoft Treatment System with Flexible X-ray Probe

- The X-ray source can be intensity modulated to mimic penetration and/or dose rate characteristics of many different isotopes, including HDR ^{192}Ir, ^{125}I and ^{103}Pd.
- Control variables are source operating voltage (penetration depth), beam current (dose rate), dwell time and dwell position.
- The Xoft microTube Flexible X-ray Probe can be inserted directly into tissue or into one or more lumens of an intracavitary or interstitial brachytherapy applicator, which is inserted during surgery (lumpectomy) or as an outpatient procedure up to five weeks later.
- This X-ray source is potentially appropriate for any accessible body cavity or excised tumor bed such as with breast cancer or gynecological cancers.

RESULTS

- The average optical density (OD) over a 1 mm x 1 mm area at the film center was obtained for each calibration film.
- The background OD was determined to be the average OD over a 5 x 5 mm area for the background film kept in this set.
- The net OD (NOD) values were obtained by subtracting the background OD from the average OD.
- Dose response curves (NOD vs. dose) were plotted for both red and green lights.

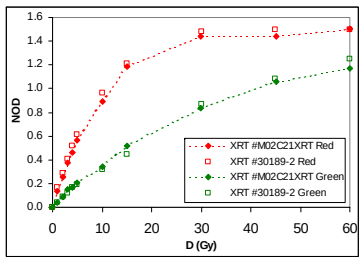


Figure 5. Calibration curves for GafChromic XR-T film

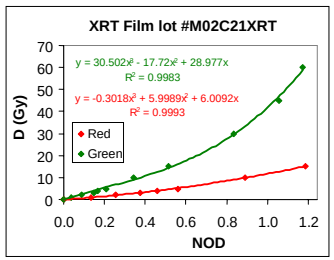


Figure 6. Polynomial fits of the plots of D (Gy) vs. NOD.

- Figure 5 presents the calibration curves for two different lots of GAFCHROMIC® XR-T film exposed to 40 kv x-rays, scanned using red and green lights.
- Figure 6 shows the polynomial fits of the plots of D (Gy) vs. NOD, obtained using red and green lights.
- The polynomial was used for conversion of NOD to dose for each film lot and light box.
- Figures 7 and 8 present the raw microdensitometer images as measured with the red LED. The image in Figure 6 is shifted to include the two films at the right edge.
- The calibration films are arranged with dose increasing from left to right, with higher doses in the upper row.

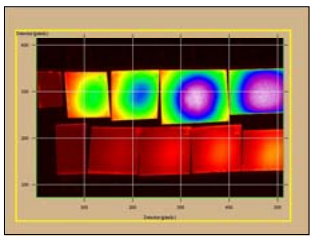


Figure 7. Image A of calibration films

Higher doses

Lower doses

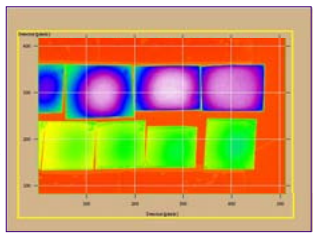


Figure 8. Image B of calibration films

RESULTS

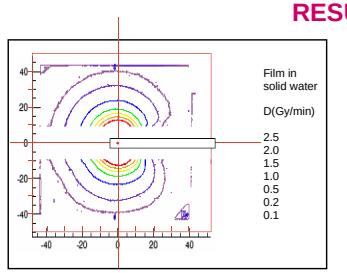


Figure 9. Isodose rate curves from a film in solid water phantom

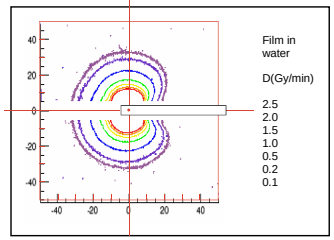


Figure 10. Isodose rate curves from a film in liquid water phantom

- Measured isodose rate curves in the film plane were projected into the plane including the probe axis using a simple geometric transform.
- The transformed isodose rate curves obtained in solid water and liquid water phantoms are displayed in Figures 9 and 10, respectively.
- The dose rate D(Gy/min) values corresponding to the curves are shown on the right side of the isodose curves.
- The depth-dose curves determined from the film for solid water and liquid water media begin to show some difference for distance of 20 mm and greater.
- Film in Figure 11 was exposed for 8 minutes to approach optical density saturation near the source thereby maximizing the range for dose determination.

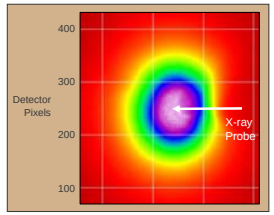


Figure 11. Film exposed for 8 minutes at a distance of 9 mm from the x-ray probe axis using 40 kVp and 100 μA

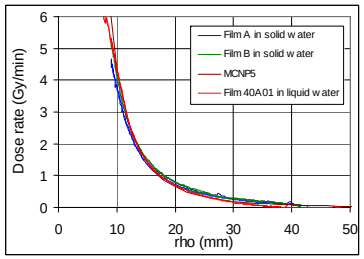


Figure 12. Plot of dose rate vs. radial distance with a linear scale.

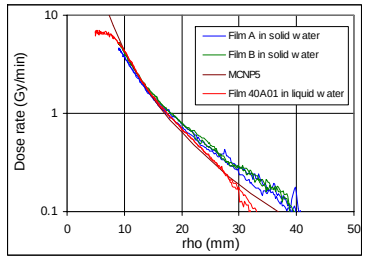


Figure 13. Plot of dose rate vs. radial distance with a semi-log scale.

- Radial dose variation with distance is plotted with a linear scale (Figure 12) and semi-logarithmic scale (Figure 13).
- Dose rate values derived from MCNP5 simulations agree well with the measurements in the liquid water phantom out to a 3 cm radius. Deviations beyond 3 cm may be due to details of the background subtraction.

REFERENCES

[1] S-T Chiu-Tsao, T. Duckworth, C. Zhang, N.S. Pate, C-Y Hsiung, L. Wang, J.A. Shih, and L.B. Harrison. "Dose response characteristics of new models of GafChromic films: Dependence on densitometer light source and radiation energy," Medical Physics, in press (August), 2004; Volume 31.

SUMMARY

- GAFCHROMIC® XR-T film was irradiated in an RMI 457 solid water phantom and a liquid water phantom using a Xoft microTube Flexible X-ray Probe.
- Calibration films were irradiated for 0.2 to 12 minutes with the x-ray probe operating at 40 kVp. Optical density was measured using a Photoelectron Corporation CCD100 microdensitometer with red (665 nm) and green (520 nm) LEDs.
- Net optical density was related to dose using miniature ionization chamber measurements and MCNP-5 Monte Carlo simulations.
- The x-ray probe dose distribution was then evaluated using the calibration curve.

CONCLUSIONS

- GAFCHROMIC XR-T film is a promising tool with acceptable optical density range for new electronic brachytherapy dosimetry.

Study Funded by *Xoft* microTube