Dosimetric characterization of surface applicators for use with an electronic brachytherapy source

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Introduction

- Skin cancer is the most common form of cancer in the United States, despite being virtually preventable
- Over one million cases are diagnosed each year
- If detected early, non-melanoma skin cancers can often be controlled with radiation therapy and/or surgical intervention
- Basal cell carcinoma (BCC) accounts for 80% of diagnosed skin cancers

Introduction

- Role of radiation therapy in the treatment of skin cancers has included:
  - Linear accelerator based electron beams
  - Superficial x-ray beams
- Specialized surface applicators developed for use with the Xoft Axxent ® electronic brachytherapy (eBx^{TM}) system and high dose rate ^{192}Ir sources

Introduction

- Traditional uses of photon brachytherapy sources governed by the American Association of Physicists in Medicine (AAPM) Task Group 43
- Surface applicators of interest have not been well characterized
- Geometric characteristics of the surface applicators
  - Some constraints of the AAPM low- energy external beam dosimetry protocol (TG-61) may apply

Introduction

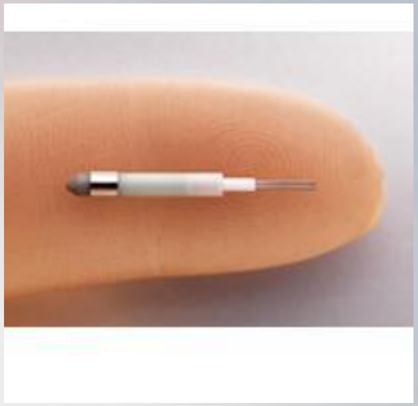
- Significant uncertainty in the applicability of current dosimetry protocols

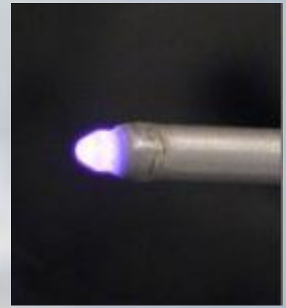
- No standardized method of output verification exists for these types of applicators

- Create a rigorous method of output verification that is applicable to surface applicators used with miniature electronic and ^{192}Ir HDR brachytherapy sources

Background – Source description

- Axxent eBx source originally developed for treatment of early stage breast cancer
- Miniature x-ray source with a peak voltage of 50 kVp, and mean energy of 30 keV
- Source diameter is 2.25 mm, positioned within a 5.4 mm diameter water cooling catheter
- Lightly-filtered bremsstrahlung spectrum is produced at the distal end of the source





Images courtesy of Xoft Inc.

Background – Axxent applicators

- Stainless steel applicators with removable cones ranging in diameter
  - 1 cm to 5 cm
- Aluminum filter at apex of cone
- Disposable polycarbonate disc at exit window
- Treatment times calculated with Axxent Controller based on S_K of bare source

Image courtesy of Xoft Inc.

Background – TG-61

- Dosimetry protocol for low- and medium- energy beam x-ray systems
- Descriptors of beam quality include tube potential and half-value layer (HVL)
- HVL measurements performed before dosimetry measurements

Background – TG-61

$$D_{w,z=0} = M \cdot N_K \cdot B_w \cdot P_{stem,air} \cdot \left[\left(\frac{\bar{\mu}_{en}}{\rho}\right)^{w}_{air}\right]_{air}$$

Dose to water at the surface

- Chamber reading with center placed at reference point
  - P_{tp}, P_{ion}, P_{pol} applied
- Parallel plate chambers recommended

- Chamber Calibration coefficient

- Backscatter factor
- Ratio of water kerma at the surface of a semi-infinite phantom, to water kerma at that point in the absence of the phantom
- Tabulated in TG-61 for a various SSDs and field sizes

Chamber-stem correction factor

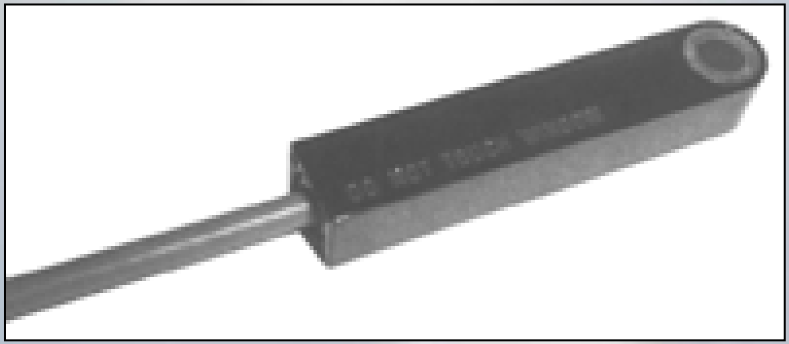
- Accounts for differences in scatter from the stem between the calibration and users beam
- Measured by the user

- Ratio of water-to-air of the mean mass energy-absorption coefficients averaged over the incident photon spectrum
- Tabulated in TG-61 from a global fit of data from various studies

Limitations of current dosimetry protocols Axxent eBx and TG-61

- Manufacturer recommends a modified version of TG-61, described in an operator's manual

- Air-kerma rate, beam quality, and depth dose measurements for each applicator completed with PTW 34013



PTW 34013 photo courtesy of PTW. Freiburg, Germany.

Limitations of current dosimetry protocols Axxent eBx and TG-61

- Air-kerma rate measurements
  - Chamber placed flush to exit window
  - Measurements corrected by the factors described in TG-61 to get a dose to water
  - Listed values of B_w and μ_{en}/ρ generated under ideal conditions
    - Surface applicators are not limited by the same geometry, energy, and scatter conditions

Materials and Methods

- Initial beam quality and output measurements for the Axxent surface applicator set
  - Attix free-air chamber (FAC)
  - Two models of miniature parallel plate ionization chambers
    - PTW 34013
    - Exradin A20
- Monte Carlo simulations with MCNP5 of kerma in-air and in-water
- Radiochromic film measurements of the dose distributions at the exit window in air

Beam quality measurements

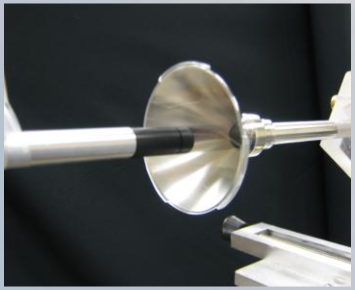
- Beam quality measurements performed with an Attix FAC
- Source to detector distance of 80 cm with high-purity aluminum attenuators placed 30 cm from the source
- Agreement with operator's manual to within 6.1%

Table 1: HVL measurements for Axxent surface applicators

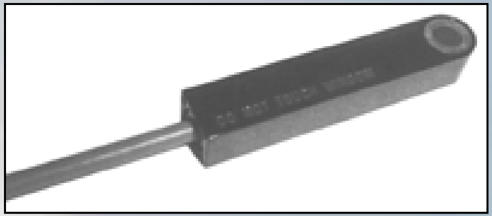
	HVL1		HVL2		HC	
Applicator / Beam Quality	UW	Xoft	UW	Xoft	UW	Xoft
1 cm	1.46	1.39	2.19	2.20	0.67	0.63
2 cm	1.63	1.53	2.45	2.45	0.67	0.62
3.5 cm	1.60	1.57	2.46	2.60	0.65	0.61
5 cm	1.64	1.56	2.43	2.57	0.68	0.61
UW50-M	1.02	–	1.54	–	0.66	–
UW60-M	1.68	–	2.55	–	0.66	–

Air-kerma rate measurements

- FAC placed at 15, 25, 60, 80, and 100 cm from the source
- Miniature chambers were positioned flush to applicator exit window
- Each miniature chamber was calibrated at the UWADCL at the UW50-M and UW60-M points



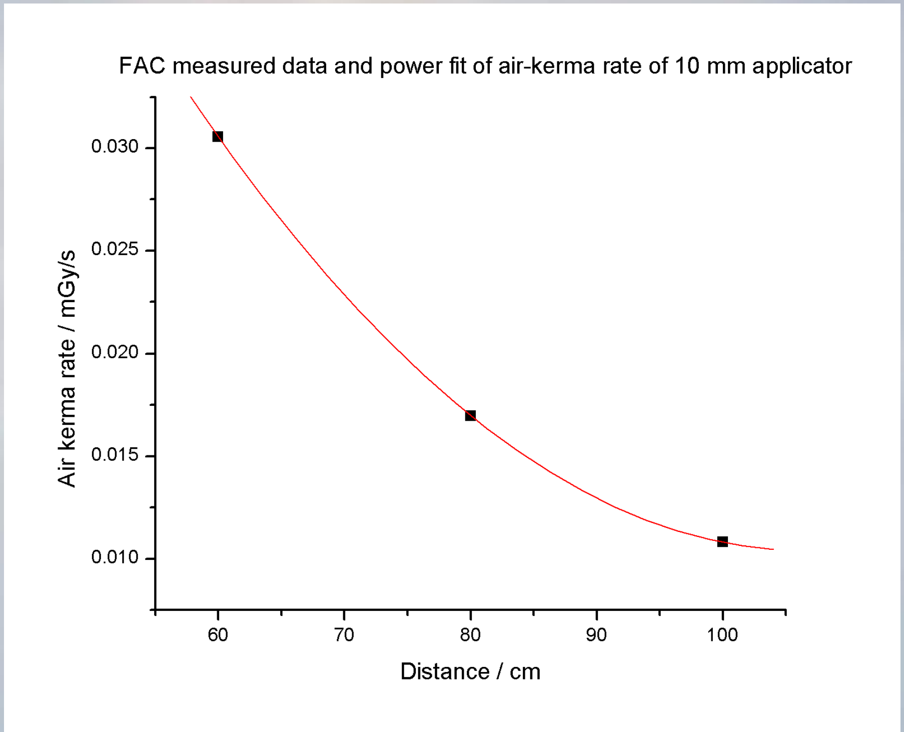
Standard Imaging end-window parallel plate A20 chamber and 5 cm applicator.



PTW 34013 photo courtesy of PTW. Freiburg, Germany.

Air-kerma rate measurements

- Data analysis
  - Power function of FAC data - extrapolating back to exit window



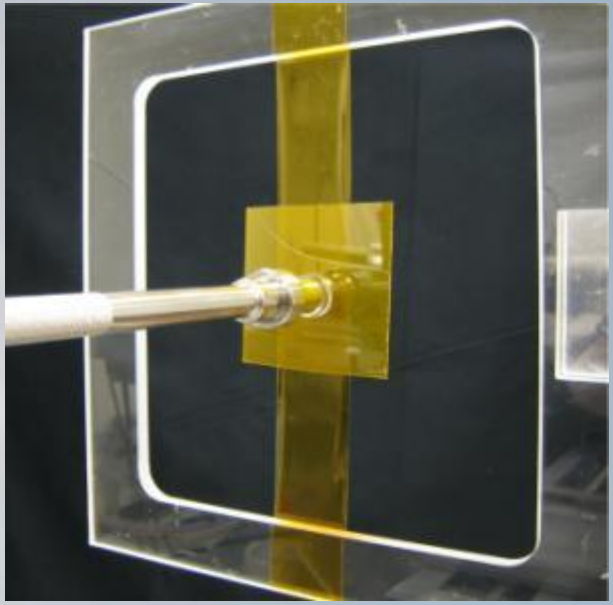
  - HVL interpolation using known N_K and HVL for UW-50M and UW-60M combined with measured HVL of Axxent applicators

Air-kerma rate measurements

Applicator diameter [cm]	Chamber type	Output [mGy/s]	% difference from FAC
1.0	FAC	28.45	-
	PTW 34013	26.10	-8.3%
	Exradin A20	26.77	-5.9%
2.0	FAC	24.74	-
	PTW 34013	22.80	-7.8%
	Exradin A20	23.33	-5.7%
3.5	FAC	25.52	-
	PTW 34013	22.44	-12.1%
	Exradin A20	23.34	-8.6%
5.0	FAC	11.71	-
	PTW 34013	10.40	11.2%
	Exradin A20	11.16	-4.7%

Radiochromic film measurements

- Gafcromic ® EBT2 (ISP Inc) film used for all measurements
- Calibration films irradiated using UW60-M at air-kerma levels from 100 mGy to 1500 mGy
- Experimental films placed flush to exit window
- Epson 10000XL scanner
- Analysis of films was completed with MATLAB®



1 cm applicator placed flush against film

Results – radiochromic film

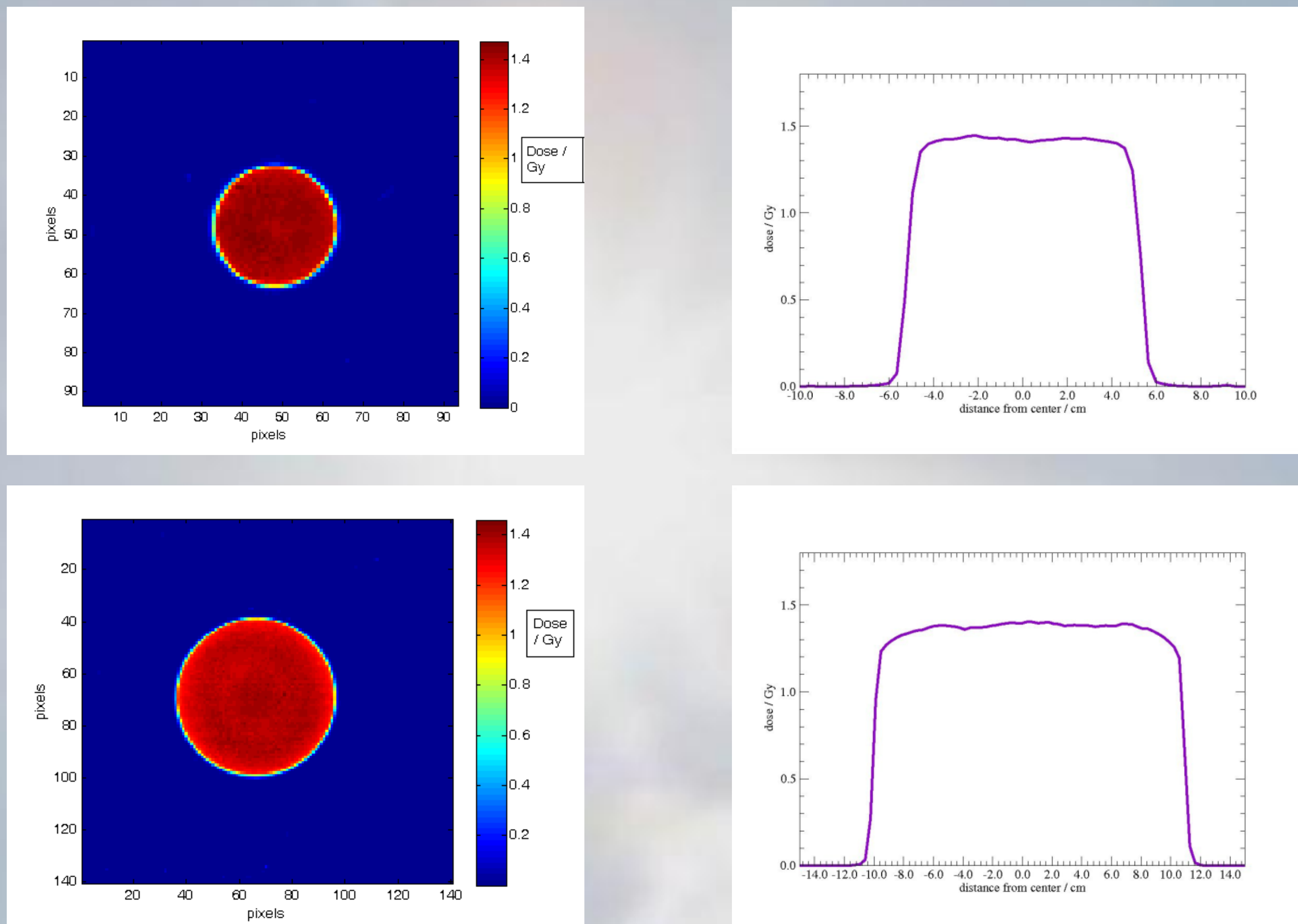


Figure 1: Surface dose distributions and profiles for the 1 cm and 2 cm applicators

Results – radiochromic film

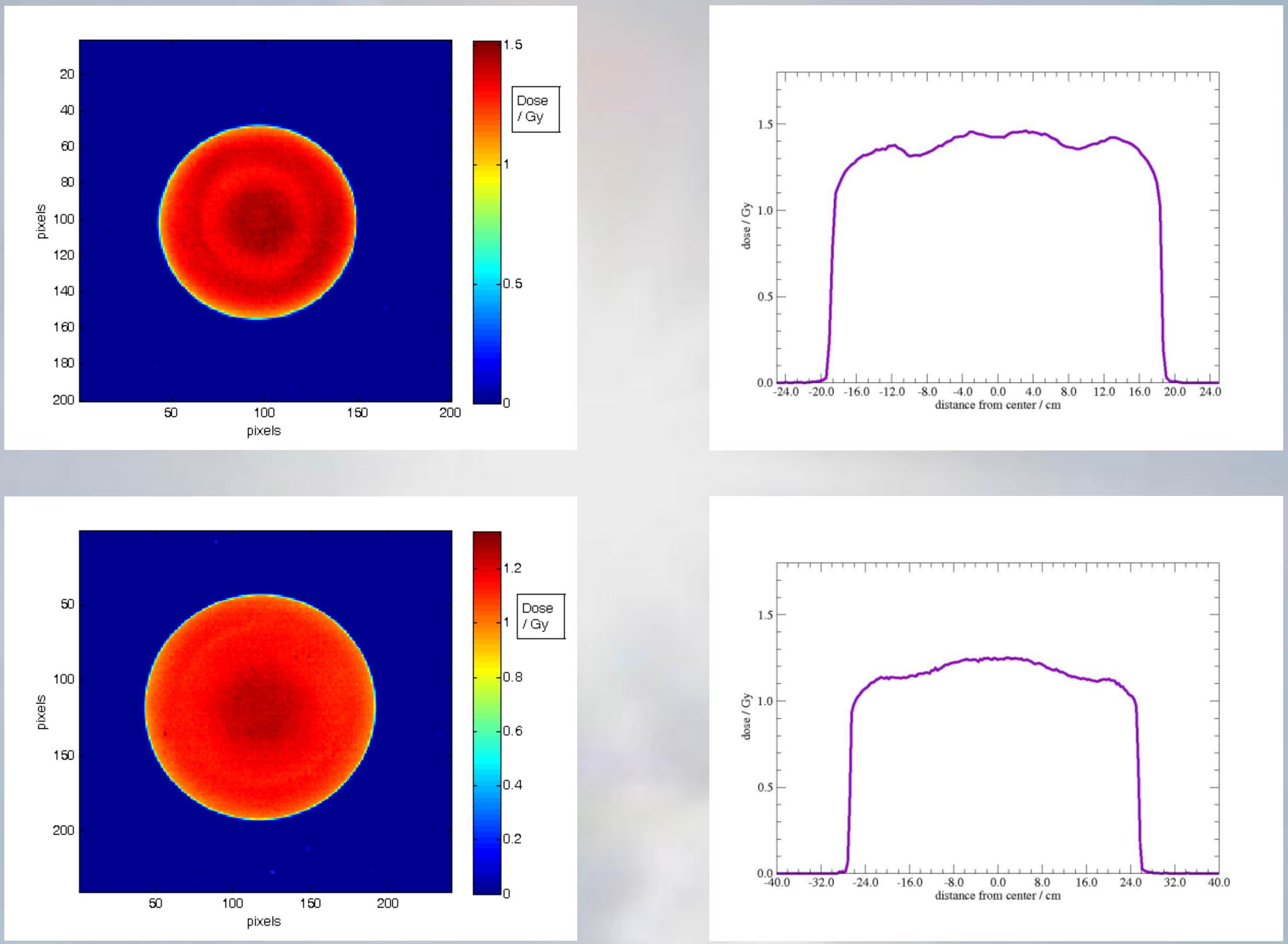
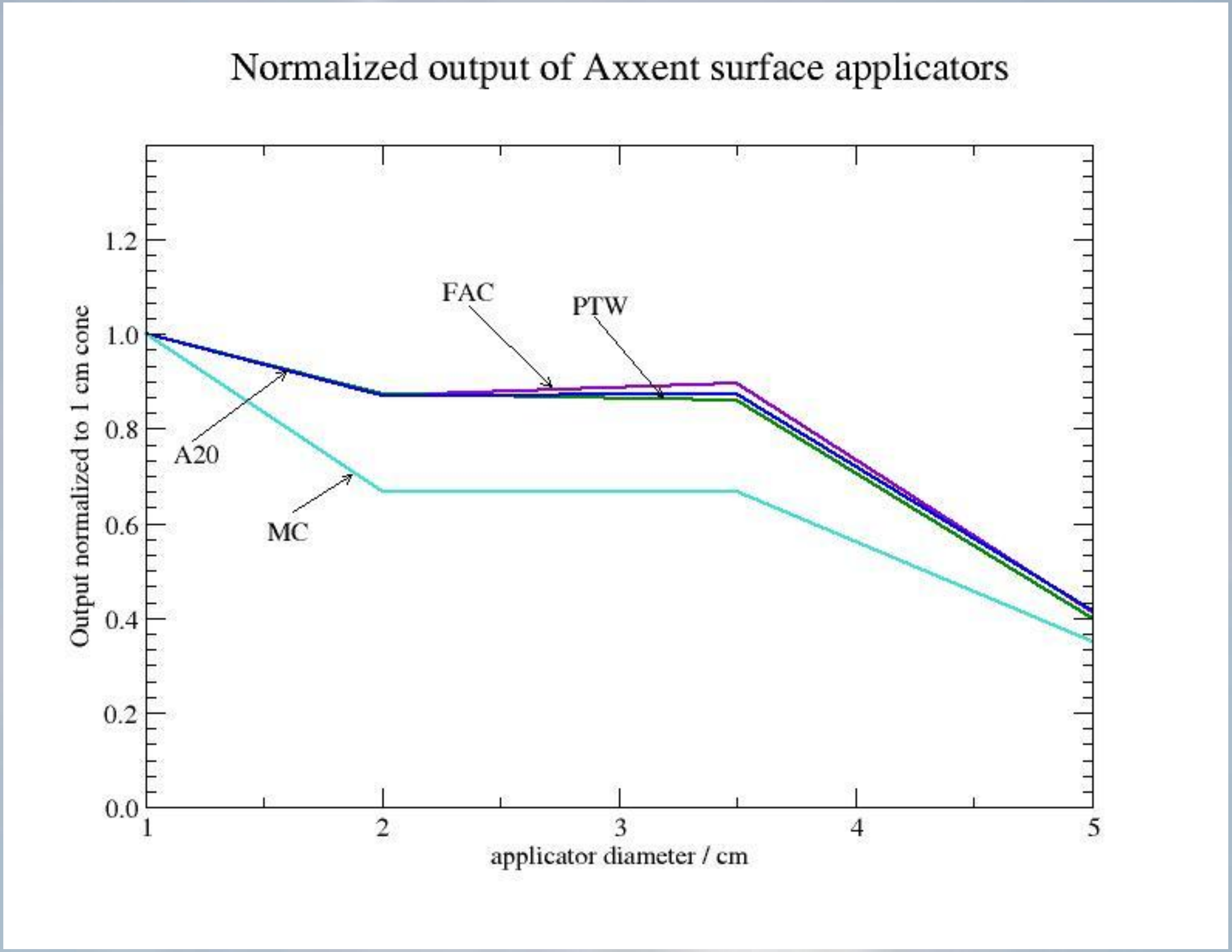


Figure 2: Surface dose distributions and profiles for the 3.5 cm and 5 cm applicators

Monte Carlo simulations



Conclusions and Future work

- Initial work characterizing the output and relative dose distributions of the Axxent applicators has been completed
- Create a universal method of output verification for brachytherapy surface applicators
- Future work includes:
  - Air-kerma rate measurements with small volume ionization chambers
  - Monte Carlo simulations of relevant quantities
  - Dose distribution measurements with TLDs and radiochromic film

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