Dose distribution measurements of a new directional Pd-103 low-dose rate brachytherapy source

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Introduction
CivaSheet™

- A new directional ^{103}Pd planar source array developed by CivaTech Oncology Inc. (Durham, NC) called CivaSheet™

- Potential use in low-dose-rate (LDR) brachytherapy treatments[1]:
  - Non-small-cell lung cancer
  - Pancreatic cancer
  - Pelvic sidewall treatment
  - Head and neck cancer, colorectal cancer
  - Ocular melanoma, soft tissue sarcoma and skin cancer

- Variable array size, scalable to the treatment area size

[1]http://www.civatechoncology.com/civasheet.htm

Introduction
CivaSheet™

- Array of discrete ^{103}Pd sources called "CivaDots"
- Each CivaDot has a gold shield on one side:
  - Defining a "hot" and a "cold" side of the device
- Maximum CivaSheet size - 5 cm x 15 cm:
  - 8 mm dot spacing
  - 108 dots in 18 rows of 6

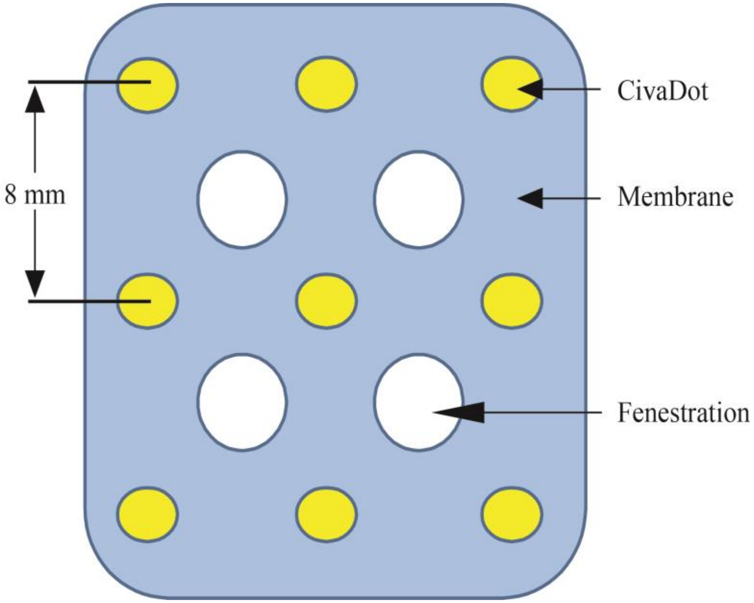
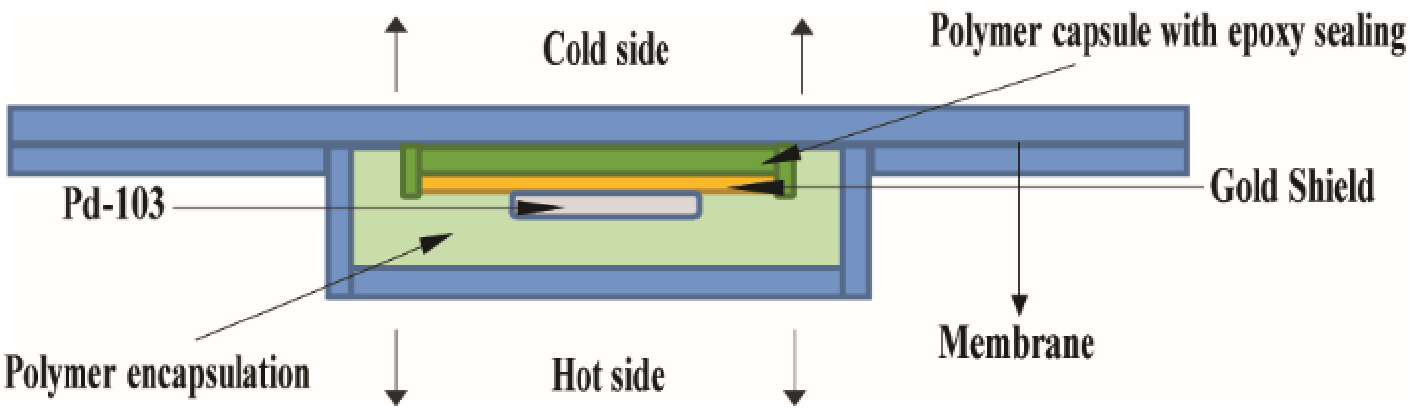


Fig: An example of a CivaSheet having 9 dots[1].

[1]M. Aima *et al.*, "Air-kerma strength determination of a new directional ^{103}Pd source", Med. Phys. 42 (12), 7144-7152 (2015).

Introduction
CivaDots

- A CivaDot consists of:
  - A small cylindrical ^{103}Pd source
  - Gold shield
  - Organic polymer capsule with epoxy sealing
  - Bioabsorbable membrane



[1]

[1]M. Aima *et al*., "Air-kerma strength determination of a new directional ^{103}Pd source", Med. Phys. 42 (12), 7144-7152 (2015).

Motivation

- Source geometry, and design for the CivaDot different than conventional LDR cylindrically-symmetric sources:
  - Planar and directional
  - Fluorescence from the gold shield

- Guidelines and dosimetric formalisms recommended by the AAPM for conventional LDR sources[1-4]:
  - No standard protocol for planar or directional LDR sources
  - AAPM Task Group No. 43 proposed formalism[1] – traditional definition of various parameters precludes the use of this source

[1]M. J. Rivard *et al.* , "Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations," Med. Phys. 31, 2004.
[2]R. Nath *et al.*, "Code of practice for brachytherapy physics: Report of the AAPM Radiation Therapy Committee Task Group No. 56," Med. Phys., 24, 1997.
[3]W. M. Butler *et al.*, "Third-party brachytherapy source calibrations and physicist responsibilities: Report of AAPM Low Energy Brachytherapy Source Calibration Working Group," Med. Phys., 35, 2008.
[4]L.A. DeWerd *et al.*, "Calibration of multiple LDR brachytherapy sources," Med. Phys., 33, 2006.

Goal

- Develop a clinically-viable source strength framework and an adapted dosimetric formalism for the CivaDot
  - Dose distribution measurements of the CivaDot

Establishment of a source strength standard

$$\dot{D}(r,\theta) = \boxed{S_{\mathrm{K}}}$$

Source strength primary standard

- <u>CivaDot Spectrum</u>:
  - Measured at NIST – high-purity germanium spectrometer
  - Predicted at UW – MCNP6 v1.0 simulations
  - Gold fluorescence observed
  - Agreement between the relative intensity of all the photo-peaks within 2% for the spectra

Source strength primary standard

- Source strength measurements:
  - Air-kerma strength (S_K) adapted to a static on-axis measurement
  - Measurement performed at UW using the Variable-Aperture Free-Air Chamber[1] and at NIST using the Wide-Angle Free-Air Chamber[2]
  - An inter-comparison of the S_K determination for eight CivaDot sources
    - Average agreement of 0.3% (σ=0.4%)
    - Maximum difference of 1.1%

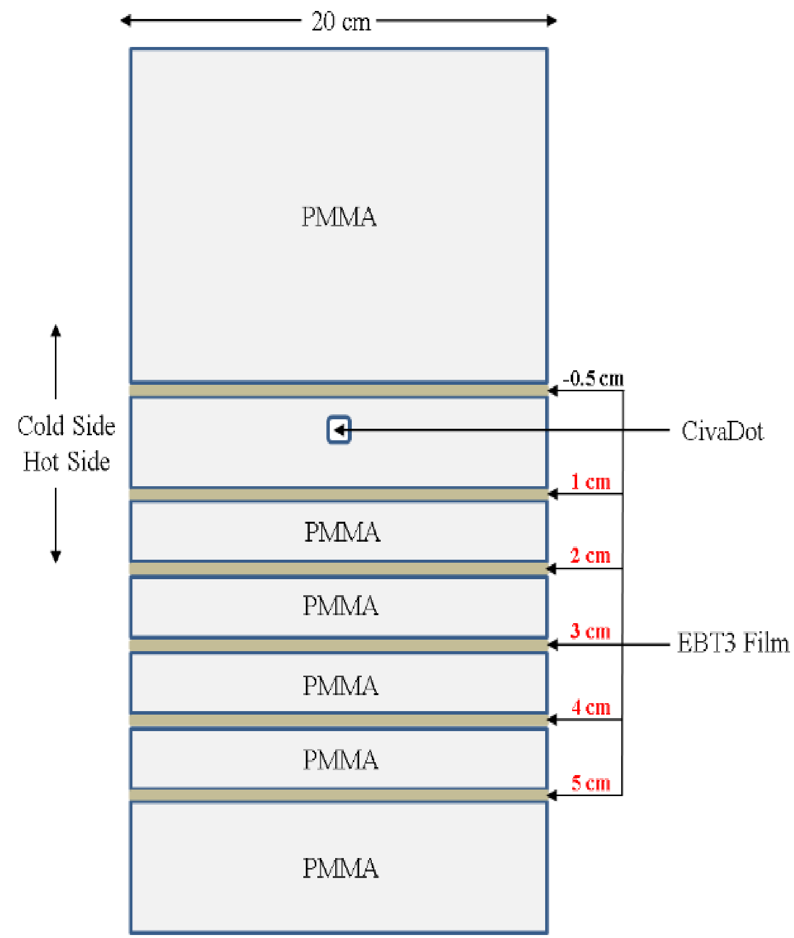
[1]Culberson *et al.*, "Large-volume ionization chamber with variable apertures for air-kerma measurements of low-energy radiation sources", Rev. Sci. Instrum. 77, (2006).
[2]S. M. Seltzer *et al.*, "New national air-kerma-strength standards for ^{125}I and ^{103}Pd brachytherapy seeds," J. Res. Natl. Inst. Stand. Technol. 108, 337-357 (2003).
[3]M. Aima *et al*., "Air-kerma strength determination of a new directional ^{103}Pd source", Med. Phys. 42 (12), 7144-7152 (2015).

CivaDot dose distribution measurements

$$\dot{D}(r,\theta) = \quad \Lambda \quad g_L(r)\,.\,F(r,\theta)$$

PMMA film stack phantom

- PMMA phantom (20x20x12 cm^3)
- Orientation adapted to an on-axis measurement
- 12x12 cm^2 Gafchromic™ EBT3 films placed on the source central axis at:
  - 1 cm, 2 cm, 3 cm, 4 cm, 5 cm – hot side
  - 0.5 cm – cold side
- The films were read out using an Epson 10000XL flatbed scanner



Methods

Dose determination

- Dose-rate to water determination using EBT3 film:

$$\left(\dot{D}_{\text{water}}\right)^{\text{CivaDot}}_{\text{water}} = \frac{\lambda}{\left(e^{-\lambda t_1} - e^{-\lambda t_2}\right)} \times$$

$$\left(netOD_{\text{EBT3}}\right)^{\text{CivaDot}}_{\text{phantom}} \times f\left(\left(D_{\text{water}}\right)^{\text{M40}}_{\text{cal}}, \left(netOD_{\text{EBT3}}\right)^{\text{M40}}_{\text{cal}}\right) \times \left(\frac{\left(D_{\text{EBT3}}\right)^{\text{CivaDot}}_{\text{phantom}}}{\left(netOD_{\text{EBT3}}\right)^{\text{CivaDot}}_{\text{phantom}}} \times \frac{\left(netOD_{\text{EBT3}}\right)^{M40}_{\text{cal}}}{\left(D_{\text{EBT3}}\right)^{\text{M40}}_{\text{cal}}}\right) \times \left(\frac{\left(D_{\text{water}}\right)^{\text{CivaDot}}_{\text{water}}}{\left(D_{\text{EBT3}}\right)^{\text{CivaDot}}_{\text{phantom}}} \times \frac{\left(D_{\text{EBT3}}\right)^{\text{M40}}_{\text{cal}}}{\left(D_{\text{water}}\right)^{\text{M40}}_{\text{cal}}}\right)$$

Measurement | Calibration | Intrinsic-energy correction | Phantom/Detector correction

- Intrinsic energy correction factor assumed to be unity[1,2]
- Phantom/detector correction factors calculated using Monte Carlo (MCNP6) simulations

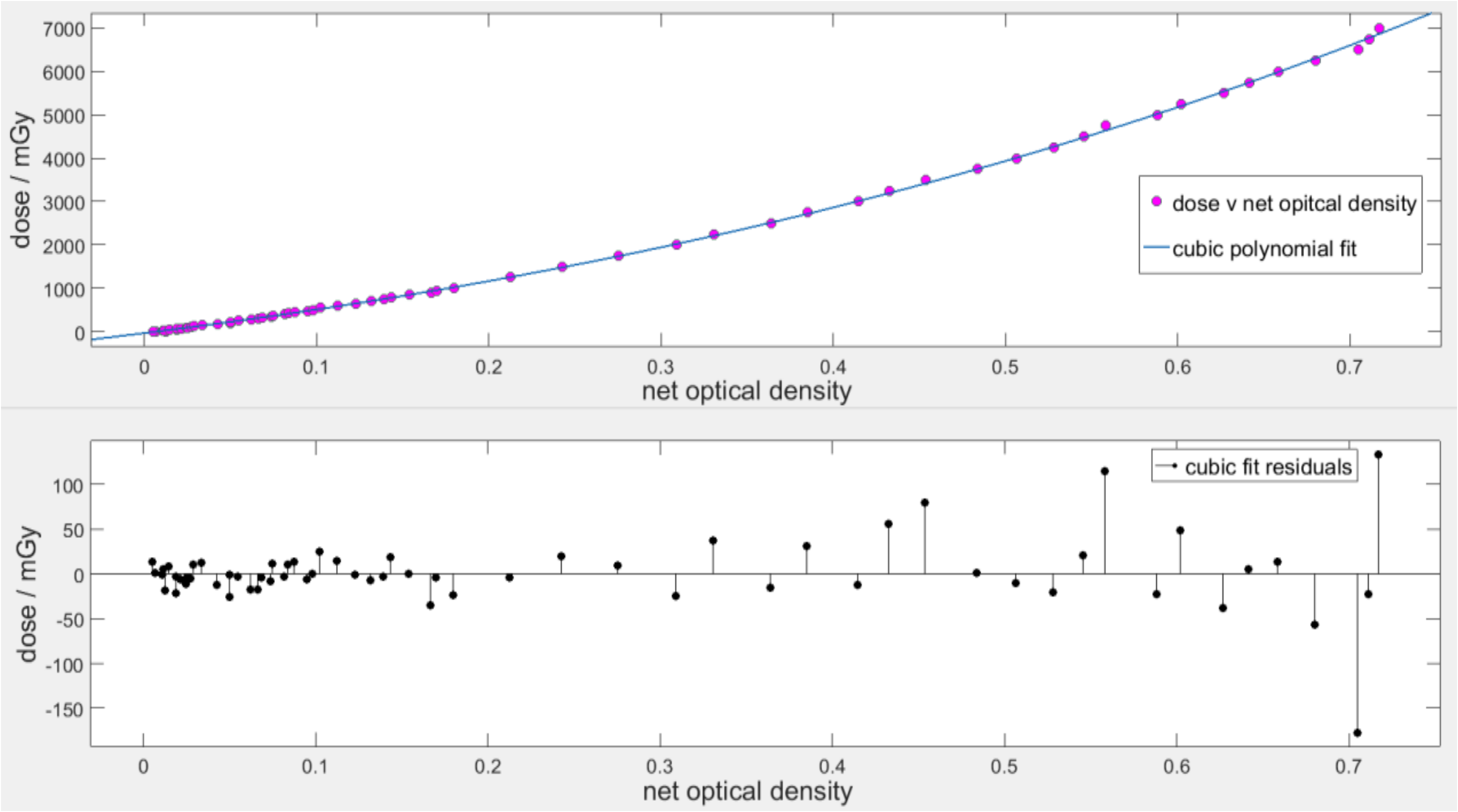
[1]H. Morrison *et al*., "Radiochromic film calibration for low-energy seed brachytherapy dose measurement", Med. Phys. 41, 072101 (2014).

[2]Chiu-Tsao *et al., "*Dosimetry for ^{131}Cs and ^{125}I seeds in solid water phantom using radiochromic EBT film", App. Rad. Iso., 92 102-114 (2014).

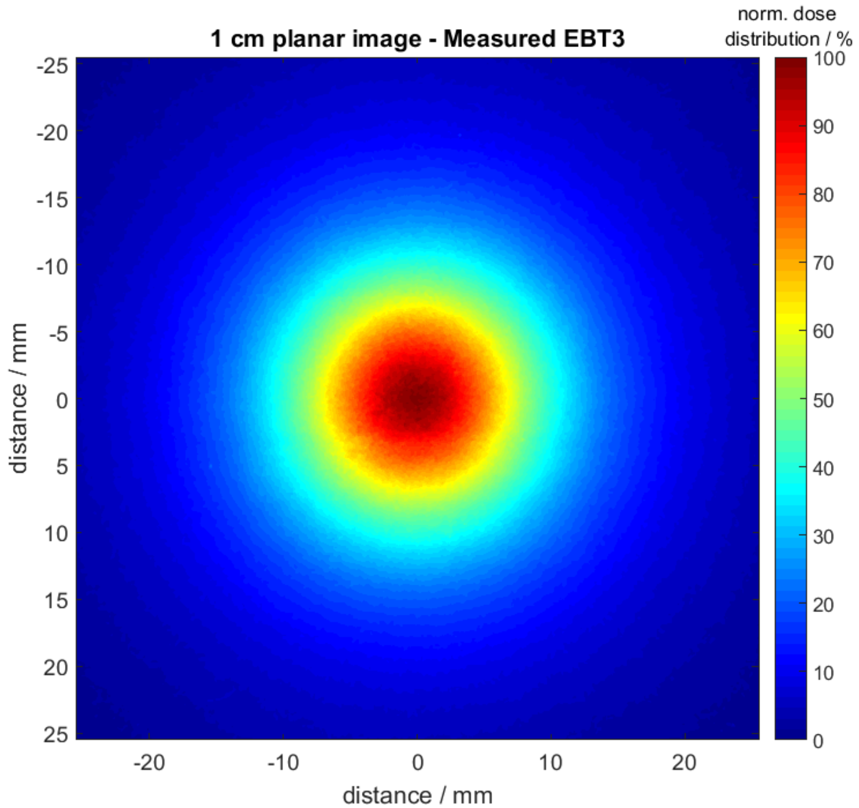
Methods

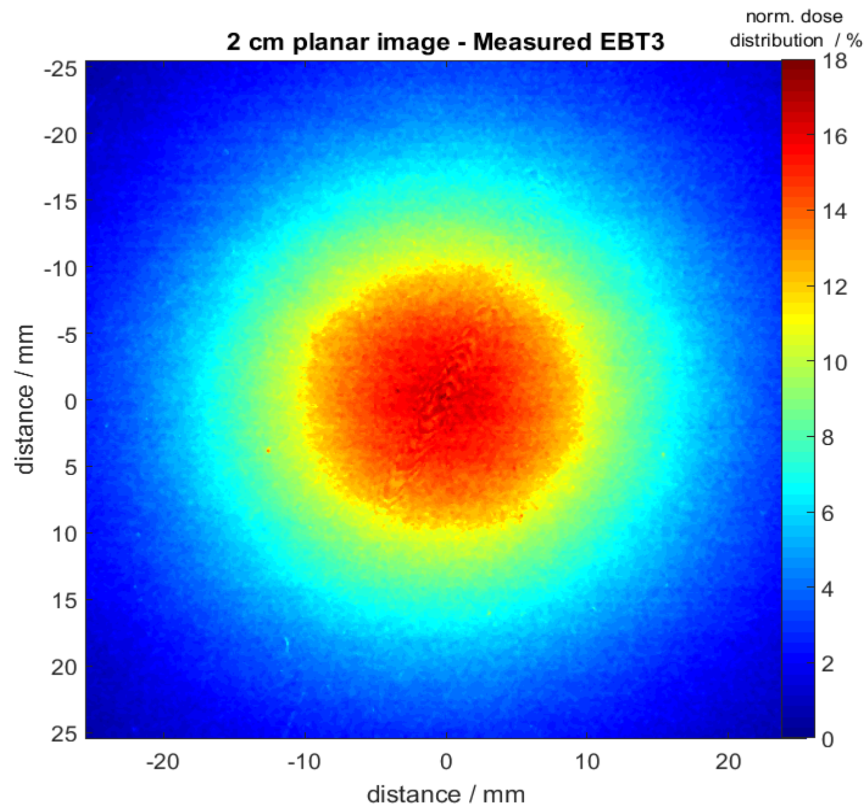
EBT3 calibration curve

- Calibration curve determined using the UW NIST-matched M40 x-ray beam (effective energy: 19.2 keV, 40 kVp)
- Sixty-two dose-to-water levels used, with four films irradiated for each dose

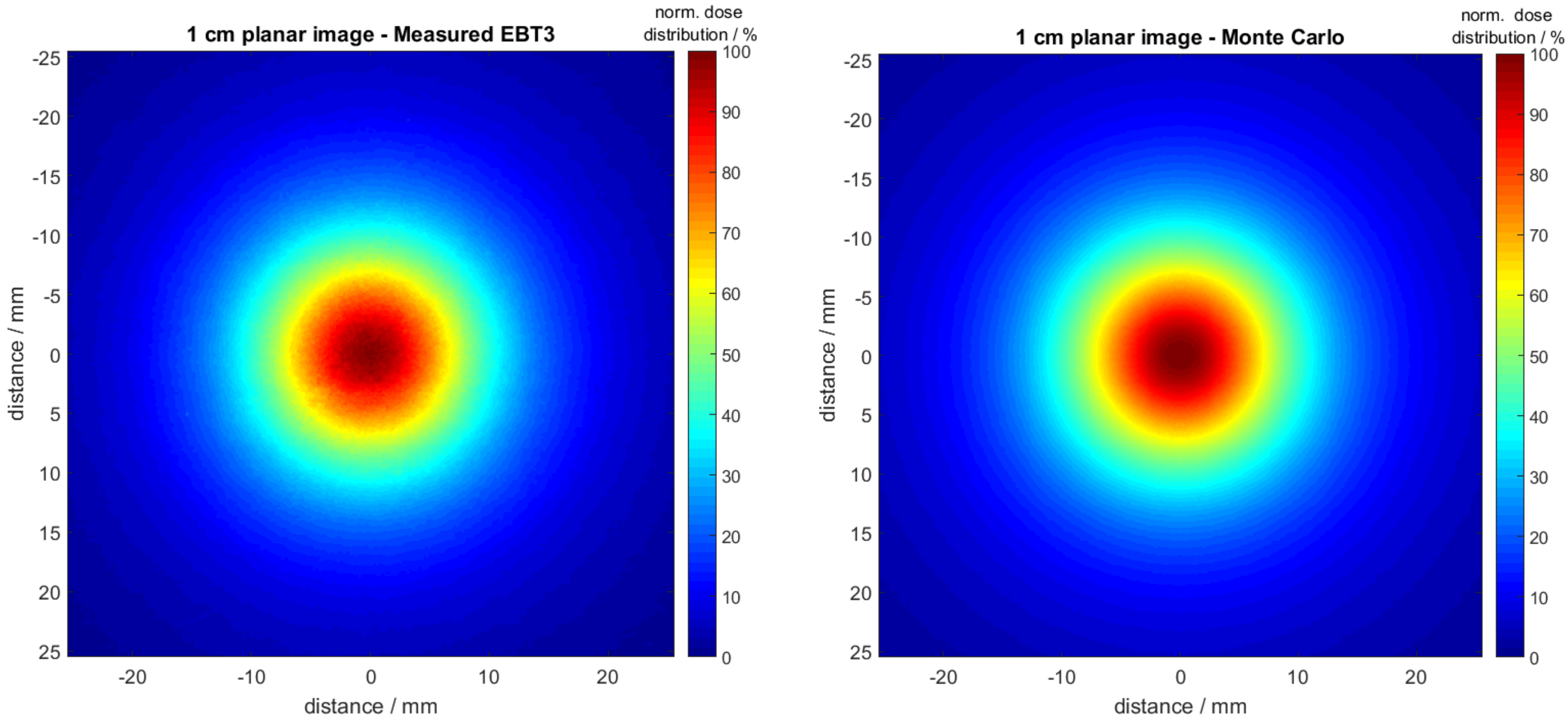


Dose distribution measurements



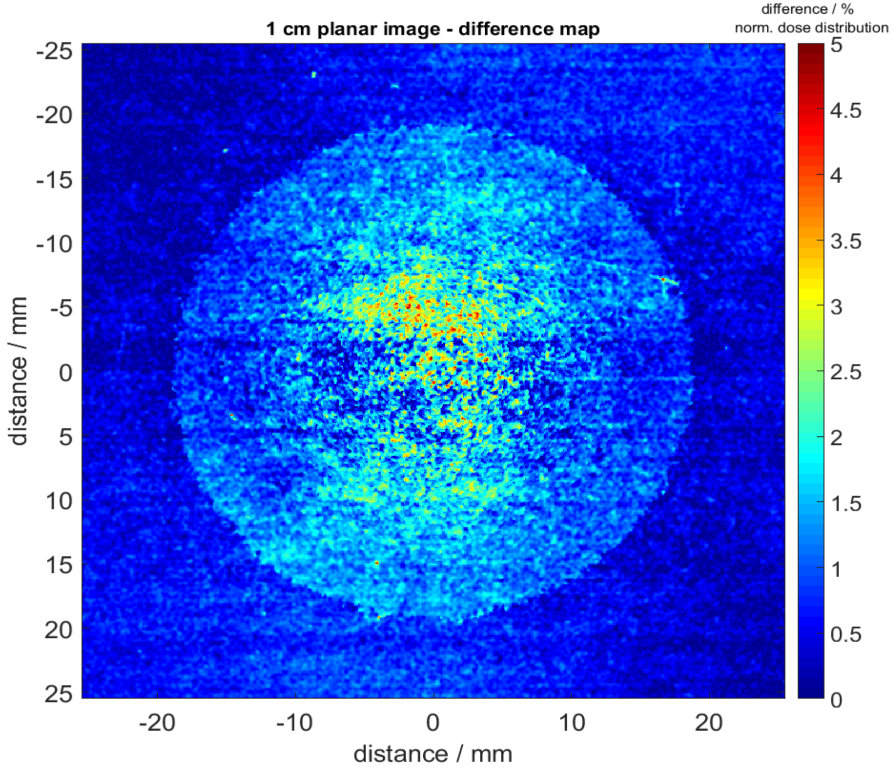


Dose distribution comparison

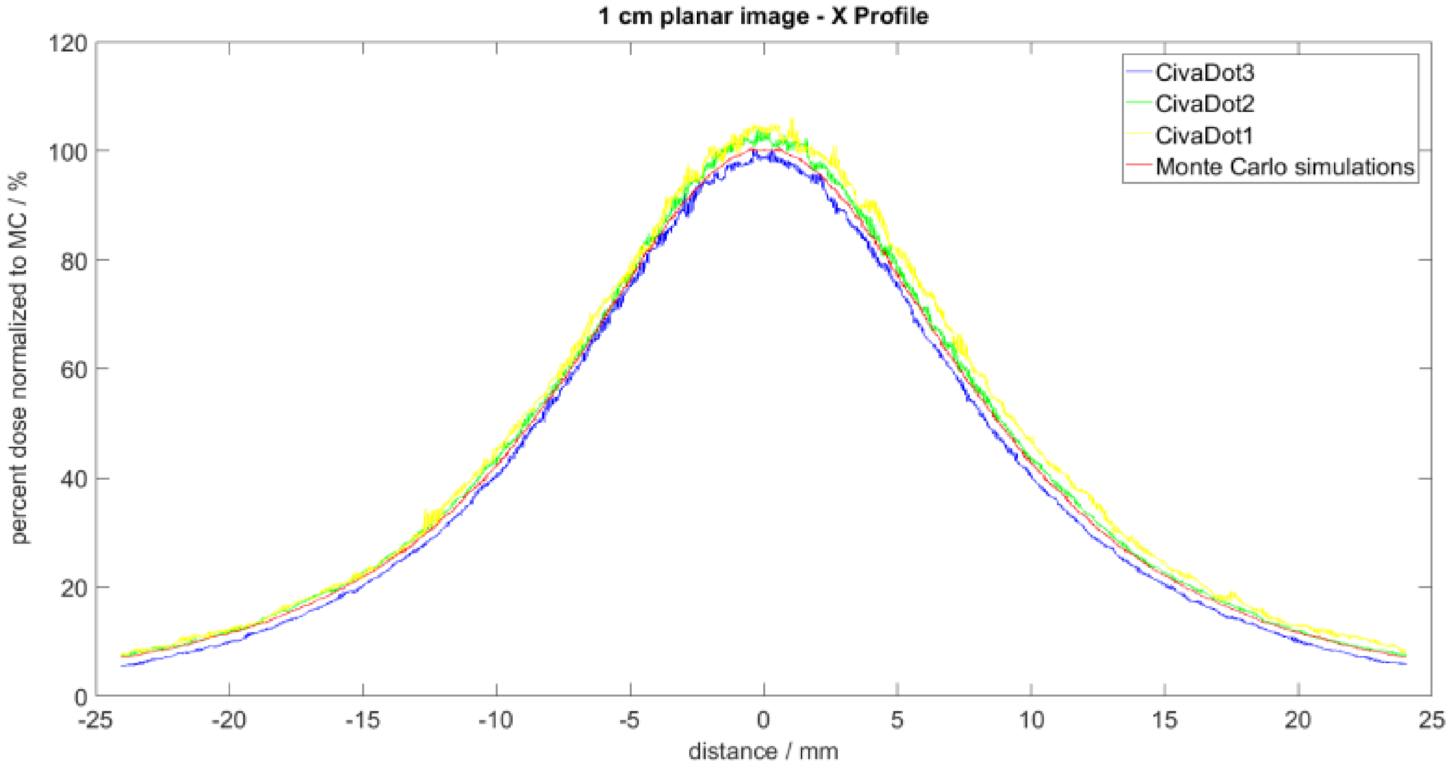


Results

1 cm – pixel-by-pixel difference map

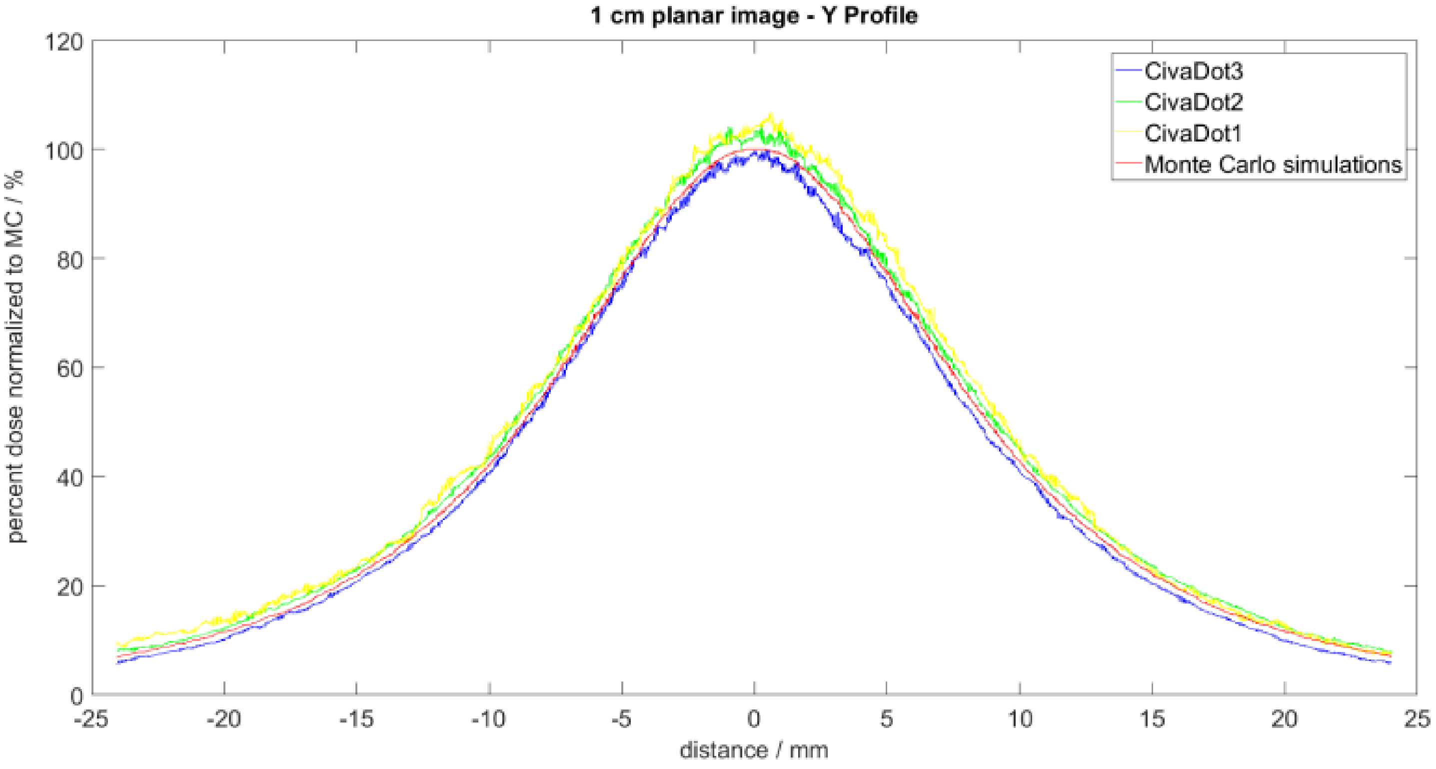


X Profile – 1 cm



Results

Y Profile – 1 cm



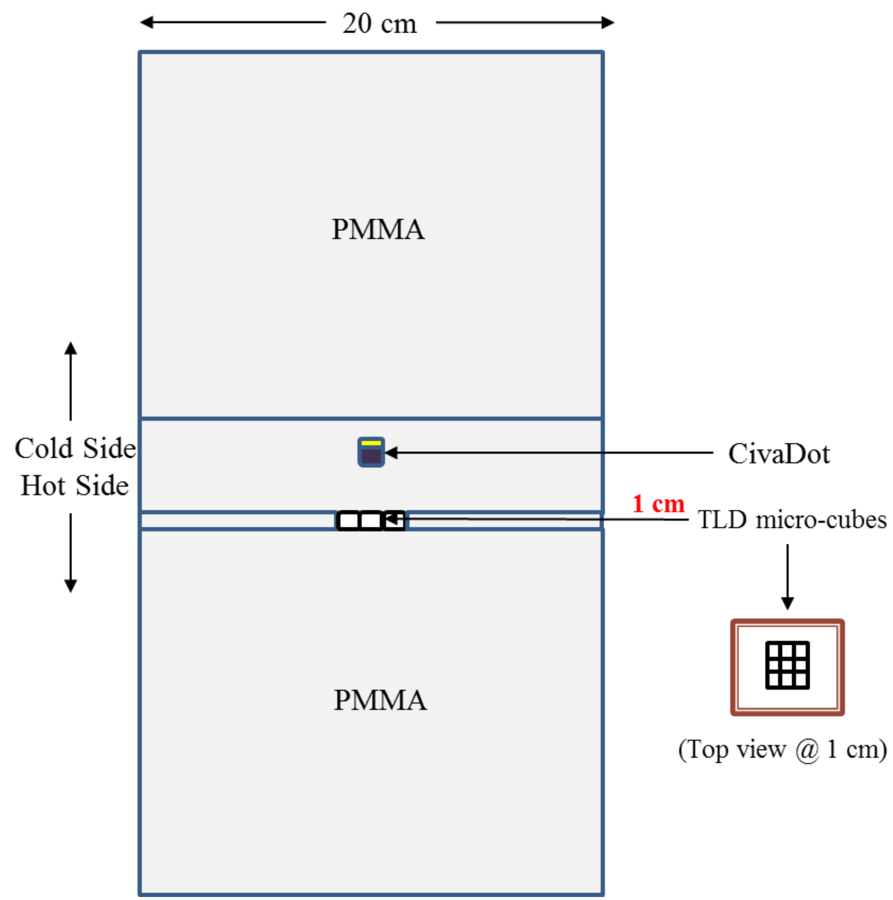
Dose rate constant analog

$$\dot{D}(r,\theta) = \boxed{\Lambda}$$

Methods

TLD100 micro-cube measurements

- PMMA phantom (20x20x12) cm^3
- Nine TLD100 micro-cubes ($3x3x1\ mm^3$ slot) irradiated along the source central axis at a distance of 1 cm
- Calibration (cGy/nC) using ^{60}Co beam
- Phantom/detector correction factors using MCNP6 simulations
- Intrinsic energy correction factor – average of the values reported by Reed *et al.*[1] and Nunn *et al.*[2]

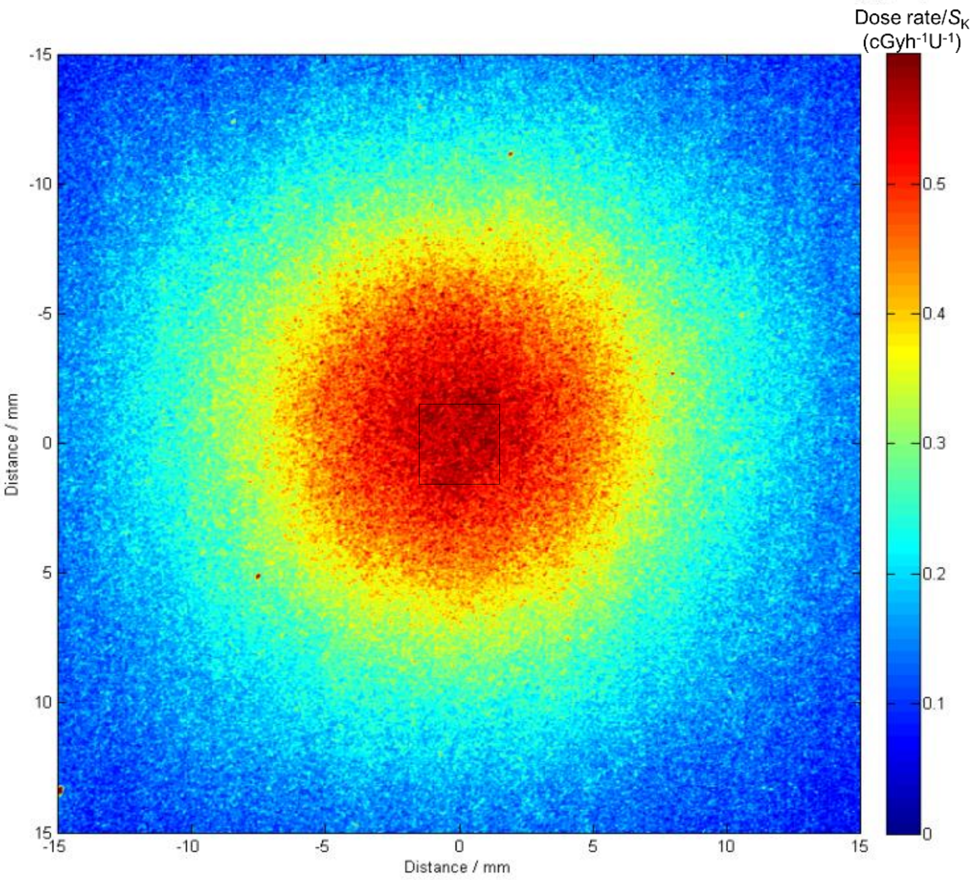


[1]J. Reed et al., "Determination of the intrinsic energy response of LiF:Mg,Ti thermoluminescent dosimeters for ^{125}I and ^{103}Pd brachytherapy source relative to ^{60}Co," Med. Phys. 41 (2014).
[2]A.A. Nunn et al., "LiF:Mg,Ti TLD response as a function of photon energy for moderately filtered x-ray spectra in the range of 20-250 kVp relative to ^{60}Co," Med Phys 35 (2008).

DRC analog measurements - TLDs

Source ID (#)	Av. Measured DRC and DRC - MCNP6 Diff (%)
Sep2015-CivaDot1	-1.1%
Sep2015-CivaDot2	-2.6%
CSH-010-13	-2.5%
CSH-010-14	+0.2%
Dec2015-CivaDot2	-4.6%
Dec2015-CivaDot3	-4.9%
Dec2015-CivaDot4	-2.8%
Dec2015-CivaDot5	-2.2%
Average	**-2.6%**
Std Dev (%)	**1.7%**

Results
DRC analog measurements – EBT3 film



DRC analog measurements – EBT3 film

Source ID (#)	**Av. Measured DRC - EBT3 and DRC - MCNP6 Diff (%)**
Sep2015-CivaDot1	-0.5%
Sep2015-CivaDot2	-1.0%
Sep2015-CivaDot3	1.0%
CSH-010-13	2.9%
CSH-010-14	-2.8%
May2016-CivaDot1	3.9%
Aug2016-CivaDot1	2.4%
Nov2016-CivaDot1	-1.2%
Average	**-0.6%**
Std Dev	**2.3%**

Conclusions

- Preliminary dose distribution measurements of the CivaDot:
  - EBT3 film stack successfully used as a quantitative dosimeter for brachytherapy dose distribution measurements
  - Comparison to Monte Carlo predicted dose distributions encouraging
  - Existing recommended dosimetric formalisms can be adapted to accommodate planar and directional sources
- Future work:
  - Integrate analog dosimetric parameters into a TPS
  - Test the feasibility of an adapted TG-43 dosimetric formalism
  - Realization of a clinically viable dosimetric framework for the CivaSheet

Acknowledgments

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Thank you for your attention!!

QUESTIONS ???