Primary air-kerma strength 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]:
  - Early stage non-small-cell lung cancer
  - 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

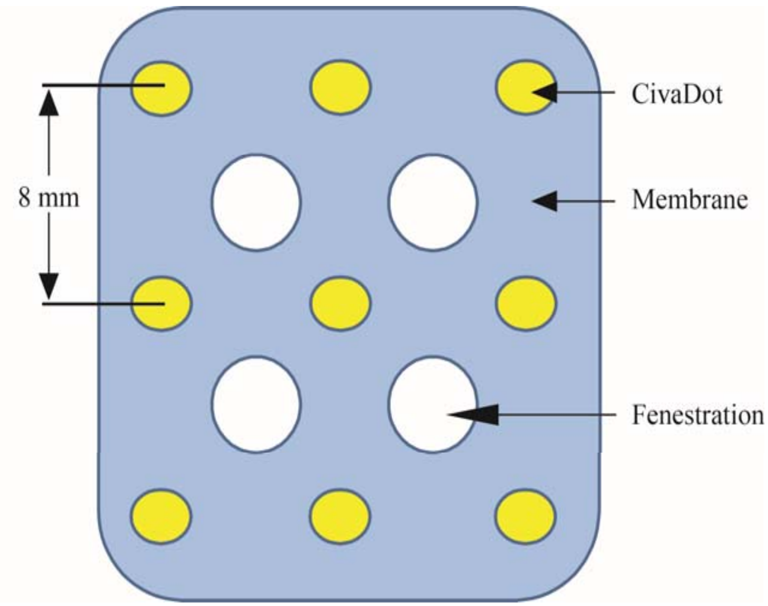
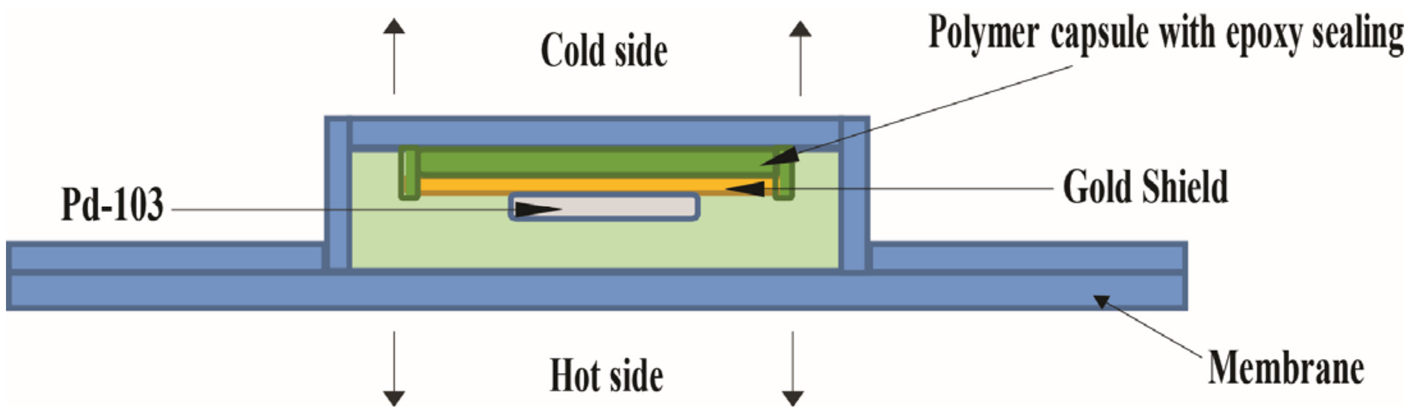


Fig: An example of a CivaSheet having 9 dots[1].

[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]

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Motivation and Goals

- **<u>MOTIVATION</u>:**
  - Source geometry and design for the CivaDot different than conventional LDR cylindrically-symmetric sources:
    - Planar and directional
    - Fluorescence from the gold shield
  - AAPM Task Group-43 Update[1] protocol's traditional definition of air-kerma strength (S_K) precludes the use of this source:
    - S_K needs to be adapted to accommodate the CivaDot

- **<u>GOALS</u>:**
  - Develop a clinically-viable source strength framework for a CivaDot
  - Help in establishment of a NIST-traceable source strength standard for the CivaDot:
    - CivaDot spectrum – measure and predict
    - New source-specific correction factors for S_K measurements
    - Primary S_K measurements

[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, 633–674 (2004).

CivaDot Spectrum

Methods

CivaDot Spectrum

- Measured CivaDot Spectrum:
  - Measurement performed at NIST
  - High-purity germanium spectrometer

- Predicted CivaDot Spectrum:
  - Source was modeled using MCNP6 v1.0
  - Monte Carlo simulations performed
  - All simulations assumed a palladium loading[1] of 50%.

- Comparison – Measured and Predicted Spectrum:
  - Detector energy-resolution limitation:
    - Sum different energy bins of the simulated spectrum together according to the corresponding measured spectral energy

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

Results

CivaDot Spectrum

Spectral Peak	Energy (keV)	NIST - Measured Spectrum (Relative Intensity)	UW - Monte Carlo Predicted Spectrum (Relative Intensity)	Difference (%)
Au L_α	9.7	0.0205	0.0167	0.38%
Au L_β	11.4	0.0191	0.0144	0.47%
Au L_β	11.7	0.0059	0.0050	0.09%
Rh K_α	20.1	0.7892	0.8073	-1.81%
Rh K_β	22.7	0.1393	0.1322	0.71%
Rh K_β	23.1	0.0250	0.0209	0.41%
γ	39.7	0.0009	0.0009	0.00%

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CivaDot –
Primary S_K measurements

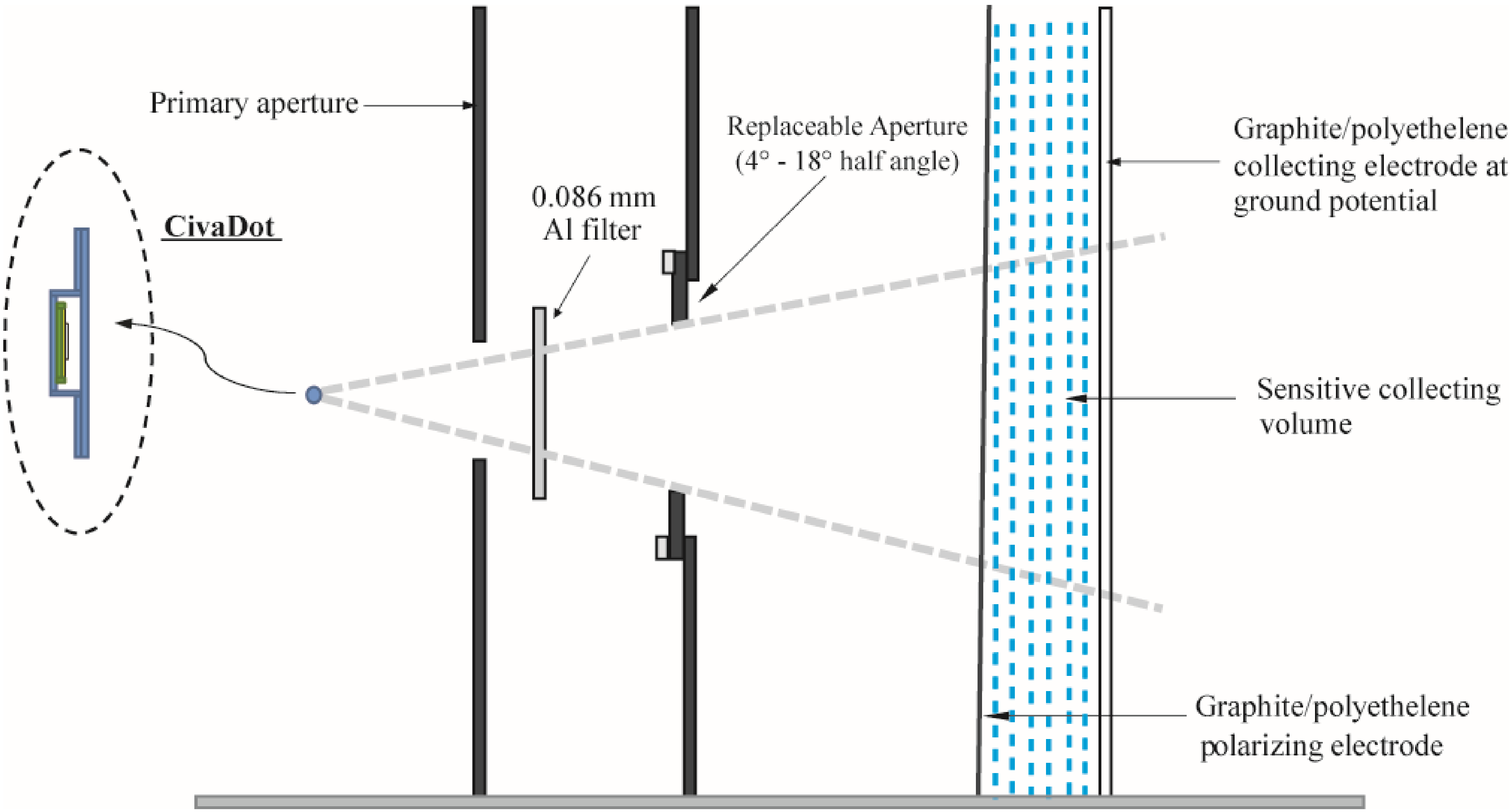
Methods

CivaDot – Primary S_K measurements

- Primary S_K measurements performed using two different free-air chambers:
  - NIST Wide-Angle Free-Air Chamber (NIST WAFAC)[1], the U.S. primary standard for S_K determination for low-energy photon emitting LDR sources
  - University of Wisconsin Variable-Aperture Free-Air Chamber (UW VAFAC)[2], a research instrument
- The traditional definition[3] of S_K adapted:
  - Static on-axis measurement instead of an averaged transverse-axis measurement
- Primary S_K measurements of a total of eight CivaDots performed:
  - Three CivaDots – September 2015
  - Five CivaDots – December 2015

[1]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).
[2]Culberson *et al.*, "Large-volume ionization chamber with variable apertures for air-kerma measurements of low-energy radiation sources", Rev. Sci. Instrum. 77, (2006).
[3]M. J. Rivard *et al.*, "Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations," Med. Phys. 31, 633–674 (2004).

Methods
S_K measurement – UW VAFAC



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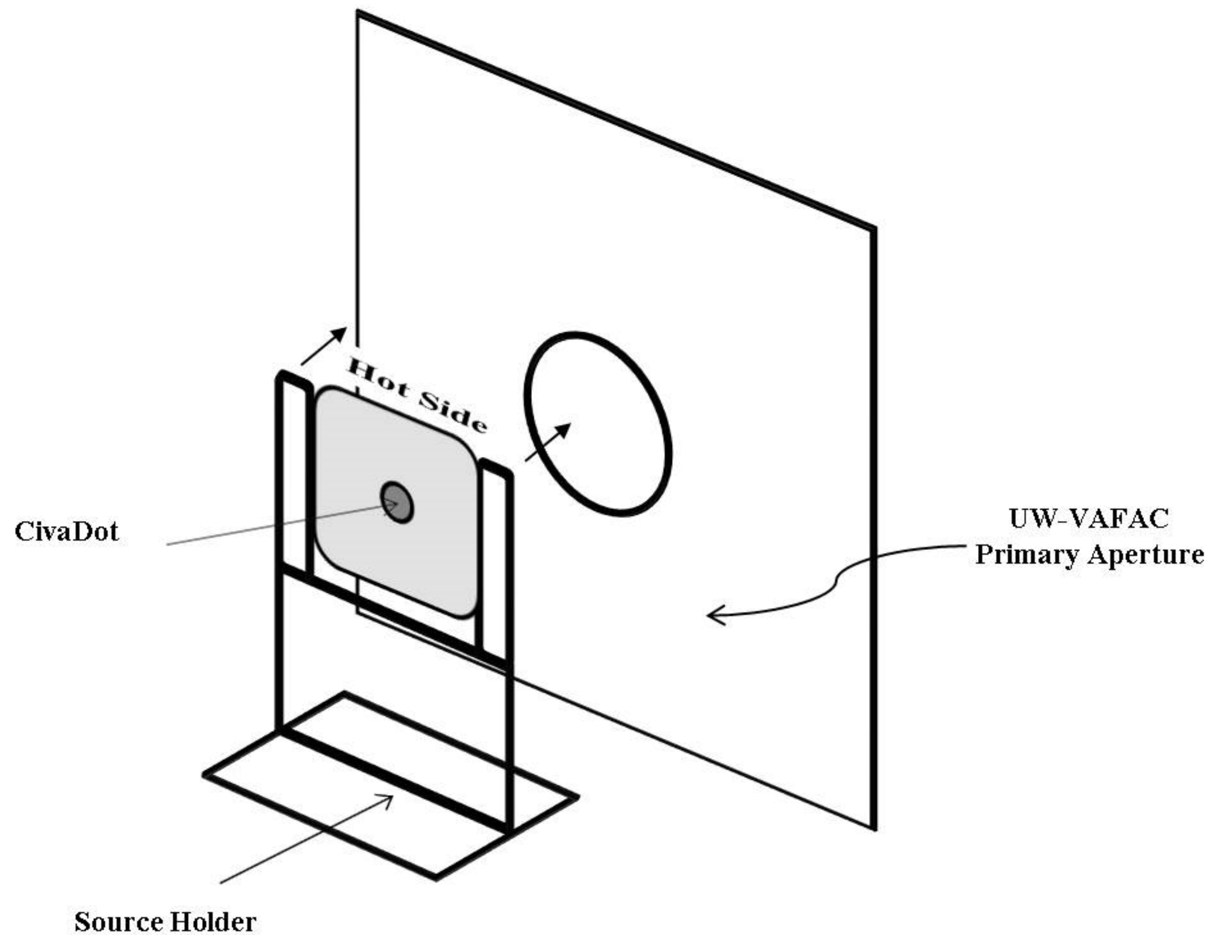

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Results

CivaDot S_K measurements

NIST Source ID (#)	UW VAFAC S_K (U)	u (%)	NIST WAFAC S_K (U)	u (%)	Difference (%)
005 A	5.265	1.82	5.27	1.74	-0.1%
005 B	5.304	1.80	5.28	1.78	0.4%
005 C	5.169	1.82	5.16	1.79	0.2%
CSH-010-1	4.218	1.80	4.20	1.69	0.4%
CSH-010-5	4.205	1.82	4.16	1.76	1.1%
CSH-010-7	4.214	1.79	4.20	1.80	0.3%
CSH-010-13	4.130	1.80	4.13	1.75	0.0%
CSH-010-14	4.159	1.80	4.15	1.86	0.2%

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CSH-010-14	4.159	1.80	4.15	1.86	0.2%

CivaDot: Source-specific S_K correction factors

Methods

Source-specific correction factors

- NIST WAFAC:
  - Methods outlined by Seltzer et al.[1]
  - Use the measured spectrum and analytical calculations
- UW VAFAC:
  - Methods outlined by Culberson et al.[2]
  - Source and UW VAFAC geometry modeled using MCNP6
  - Monte Carlo simulations
  - All simulations assumed palladium loading of 50%

[1] 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).

[2] Culberson *et al.*, "Large-volume ionization chamber with variable apertures for air-kerma measurements of low-energy radiation sources", Rev. Sci. Instrum. 77, (2006).

Results

Source-specific correction factors

Source-Specific Correction Factors - Description	NIST WAFAC		UW VAFAC – Aperture #2	
	Correction factor	CivaDot	Correction factor	CivaDot
Attenuation in aluminum filter	k_{foil}	1.1493	k_{fil}	1.1400
Attenuation in air from the aperture to the FAC	$k_{att\text{-}WAFAC}$	1.0133	$k_{att\text{-}VAFAC}$	1.0233
Attenuation in air from the source to the aperture	$k_{att\text{-}SA}$	1.0413	$k_{att\text{-}SA}$	1.0383
Inverse-square correction for aperture	k_{invsq}	1.0089	k_{invsq}	1.0086
Humidity correction	$k_{humidity}$	0.9971	$k_{humidity}$	0.9979
Internal photon scatter correction	$k_{int\text{-}scatt}$	0.9964	$k_{int\text{-}scatt}$	0.9917
Aperture-penetration correction	k_{pen}	0.9997	k_{pen}	0.9985
External photon scatter correction	$k_{ext\text{-}scatt}$	0.9945	$k_{ext\text{-}scatt}$	0.9909
Attenuation through the entrance electrode	$k_{att\text{-}el}$	1.0000	$k_{att\text{-}el}$	1.0032
	Π k	1.2085	Π k	1.2000

Results

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Source-Specific Correction Factors - Description	NIST WAFAC		UW VAFAC – Aperture #2	
	Correction factor	CivaDot	Correction factor	CivaDot
Attenuation in aluminum filter	k_{foil}	1.1493	k_{fil}	1.1400
Attenuation in air from the aperture to the FAC	$k_{att\text{-}WAFAC}$	1.0133	$k_{att\text{-}VAFAC}$	1.0233
Attenuation in air from the source to the aperture	$k_{att\text{-}SA}$	1.0413	$k_{att\text{-}SA}$	1.0383
Inverse-square correction for aperture	k_{invsq}	1.0089	k_{invsq}	1.0086
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Introduction

Aluminum filter - Impact

Source-Specific Correction Factors - Description	NIST WAFAC		UW VAFAC	
	Correction factor[2]	CivaDot	Correction factor[3]	CivaDot
Attenuation in aluminum filter	k_{foil}	1.1493	k_{fil}	1.1400
	Π k	1.2085	Π k	1.2000

Aluminum filter (TG-43)

S_K measurements – no Al filter

- Primary S_K measurements without Al filter:
  - Three CivaDots – September 2015
  - Using UW VAFAC
  - Aluminum filter removed
  - Results compared to NIST WAFAC S_K values with the filter present

NIST Source ID (#)
005 A
005 B
005 C
CSH-010-1
CSH-010-5
CSH-010-7
CSH-010-13
CSH-010-14

Results

S_K measurements – no Al filter

NIST SOURCE ID (#)	UW VAFAC S_K without Al Filter (U)	u (%)	NIST WAFAC S_K with Al Filter (U)	u (%)	Difference (%)
005 A	5.246	1.05	5.271	1.74	-0.5%
005 B	5.256	1.08	5.284	1.78	-0.5%
005 C	5.136	1.05	5.160	1.79	-0.5%

Results

S_K measurements – no Al filter

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005 C	5.136	1.05	5.160	1.79	-0.5%

Conclusions

- Primary S_K measurements of the CivaDot with the NIST WAFAC and UW VAFAC show promise:
  - S_K appropriate as a source strength metric
  - Good reproducibility and repeatability
- Source-specific correction factors for the CivaDot:
  - Significantly different from conventional ^{103}Pd seeds – due to gold fluorescence
  - Using measured and simulated spectra
  - Determined analytically, and using Monte Carlo methods – good agreement
- Primary S_K measurements of the CivaDot without the aluminum filter:
  - Reduced the UW VAFAC measurement uncertainty
  - Warrant a discussion about the use of a filter in the S_K

Acknowledgments

- The work at UWMRRC was partially supported by NCI contract (HHSN261201200052C) through CivaTech Oncology, Inc.
  - Dr. Kristy Perez
- Staff and students of UWMRRC
  - Dr. Joshua Reed, Jeff Radtke, Wendy Kennan
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- NIST for sponsoring the CIRMS Student Travel Grant

Thank you for your attention!!

QUESTIONS ???