Small Field Detectors and Implementation Considerations

Gloria P. Beyer, Ph.D., DABR

Medical Physics Services, LLC

Miami, FL

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Outline

- 1. Detectors for Small Field Dosimetry
- 2. Small Field Correction Factors
- 3. New Detectors Implementation
- 4. Small Field Measurements and QA
- 5. Summary

1. Detectors for Small Field Dosimetry

1. Detectors for Small Field Dosimetry

Increased use of small field treatments has resulted in the need for implementation of small field detectors

What is considered a small field?

1- Photon beam source occlusion

2- Lateral electron disequilibrium

3- Volume average effect

Std fields: >3cm x 3cm

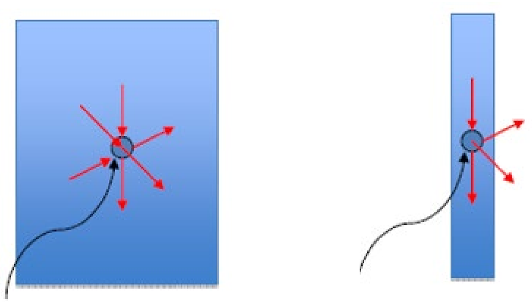
Small fields: ≤3cm x 3cm

Choose right detector to minimize small field effects

1. Detectors for Small Field Dosimetry

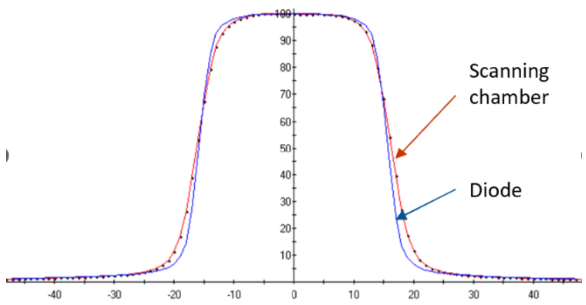
Lateral electron disequilibrium

- Edge of radiation field too close to measurement volume
- Loss of charged particle equilibrium (CPE) (depends on range of sec. e-)
  - Detector material
  - Volume



Volume effect

- Detector size -> defines what is a “small” field
- Dose changes within the detector
  - Field size can be overestimated
  - Penumbra can be overestimated



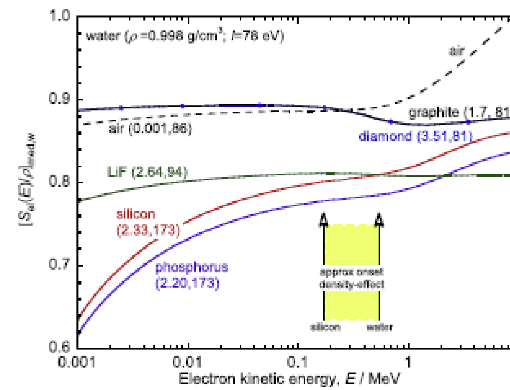
1. Detectors for Small Field Dosimetry

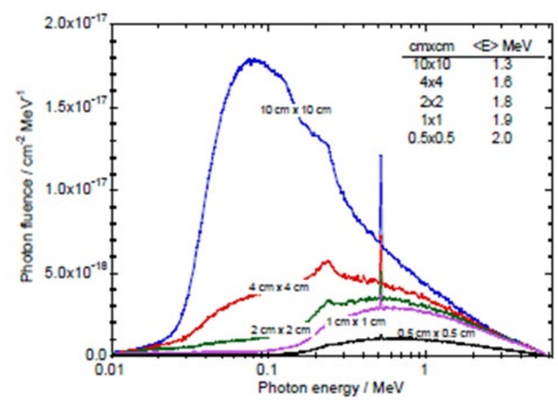
Energy spectrum changes

- Beam hardening effect
  (phantom scatter decreases with small fields)
- Increase in average photon energy

- Changes in energy spectrum can affect response of certain detectors

- Variation in stopping power and perturbation factors can be incorporated into a field dependent correction factor





P. Andreo, The Physics of small field megavoltage photon beam dosimetry, Radiotherapy and Oncology 126(2018) 205-213

1. Detectors for Small Field Dosimetry

- Detectors perturb fluence in photon beams
  - Finite size of detector will perturb photon fluence
  - Detector volume - loss of charged particle equilibrium
  - Material different than medium (composition and density)
  - Perturbation of charged particle fluence (detector geometry, beam energy, field size, etc)

1. Detectors for Small Field Dosimetry

- Data measurements can vary depending upon the detector selected
- An improper choice may lower the quality of the data measurement

Understand performance of the detector

Know the limits of the detector

Understand the measurement goals and range

Small field detector changes are geared to minimize the effects of the detector.

1. Detectors for Small Field Dosimetry

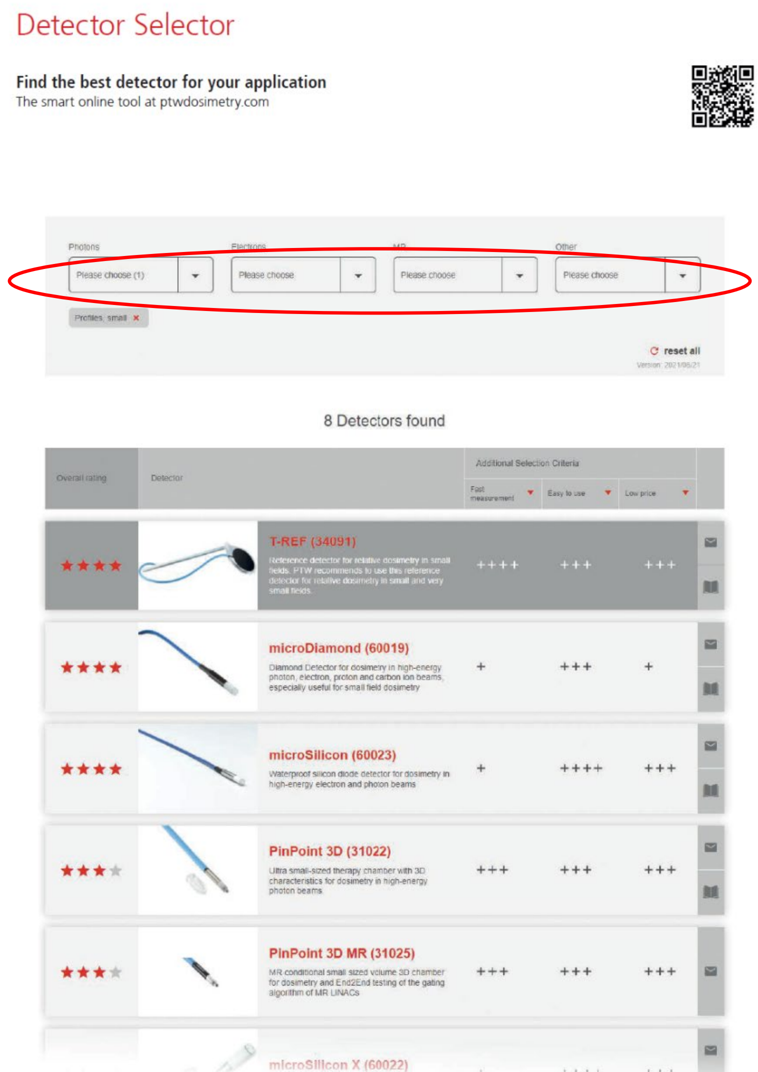
New developments to improve detectors for small fields

- Pinpoint chambers:
  - Smaller volumes
  - Reduced perturbation
  - Improved chamber design

- Solid state detectors:
  - Materials and construction to improve water equivalence
  - High spatial resolution with smaller active area
  - Minimal detector to detector variation
  - Higher signal
  - Lower angular dependence
  - Low dose per pulse dependence

1. Detectors for Small Field Dosimetry

- Use detector selection option i PTW website



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1. Detectors for Small Field Dosimetry

- PTW
  - Solid-state detectors and pinpoint chamber options
  - Several options for small field dosimetry

microDiamond

Synthetic Diamond Detector for High-Precision Dosimetry

microSilicon

Silicon detector for small photon and all electron fields

microSilicon X

Shielded Silicon Detector for all Photon Fields

PinPoint 3D Ion Chamber

Ultra small-sized therapy chamber with 3D characteristics for dosimetry inhigh-energy photon beams

1. Detectors for Small Field Dosimetry

Microdiamond

- Nearly water equivalent for all beam energies
- Very small sensitive volume (0.004 mm³) - perfect choice for small field dosimetry
- Suitable for all field sizes up to 40 cm x 40 cm
- Precise, accurate measurements in photon, electron and proton fields
- Excellent radiation hardness, minimal energy, temperature and directional dependence
- No high voltage required. Suitable for all connecting systems (BNT, TNC, M)

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1. Detectors for Small Field Dosimetry

- New detectors for small field dosimetry

microSilicon

Silicon Detector for Small Photon and all Electron Fields

OVERVIEW

Key Features

- THE silicon detector for small photon fields
- Unshielded diode, perfectly suited for electrons
- Excellent dose stability (@6MV only 0.1%/ kGy)
- Very small detector to detector variation
- Very low dose per pulse dependence
- Very small sensitivity variation with temperature
- Improved water equivalence

1. Detectors for Small Field Dosimetry

- New detectors for small field dosimetry

PinPoint 3D Ion Chamber

Ultra small-sized therapy chamber with 3D characteristics for dosimetry inhigh-energy photon beams

- Small-sized cylindrical ion chamber with vented sensitive volume of only 0.016 cm^3
- Small polarity effect
- Minimal cable irradiation effect
- Minimized directional response
- Short ion collection time, low pre irradiation dose
- Suitable for field sizes from 2 cm x 2 cm to 40 cm x 40 cm

2. New Detectors Implementation

2. New Detectors Implementation

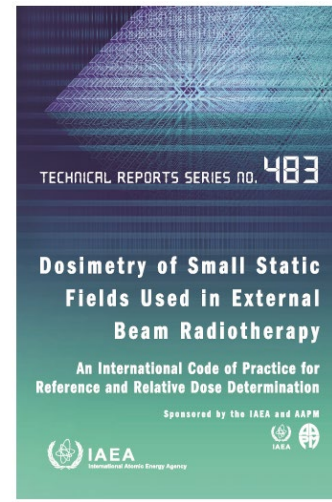
TRS-483

Protocol formalizes the use of correction factors for small field dosimetry

$$D_{w,Q_{clin}}^{f_{clin}} = D_{w,Q_{msr}}^{f_{msr}} \Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}},$$

$$\Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$$

$\Omega_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}}$ → Ratio of dose delivered to water in clinical field to dose delivered in reference field



Output factor requires a **correction factor** applied to the detector reading ratio

- Field size definition, energy, linac type, detector type => $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$

2. New Detectors Implementation

Small field correction factors

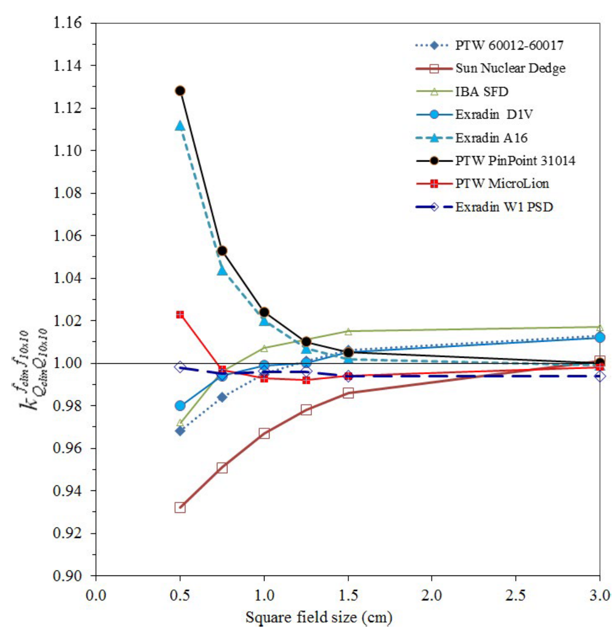
- Volume averaging effect
- Density difference between detector material and water

$$k^{f_{\mathrm{clin}}, f_{\mathrm{msr}}}_{Q_{\mathrm{clin}}, Q_{\mathrm{msr}}} = [k_{\mathrm{vol}}]^{f_{\mathrm{clin}}, f_{\mathrm{msr}}}_{Q_{\mathrm{clin}}, Q_{\mathrm{msr}}} \cdot [k_{\mathrm{d}}]^{f_{\mathrm{clin}}, f_{\mathrm{msr}}}_{Q_{\mathrm{clin}}, Q_{\mathrm{msr}}}$$

K_d: density perturbation
K_{vol}: volume effect

- For small fields:
  - Ion-chambers under-respond
  - Diodes over-respond

Correction factors:
-Tabulated data in TRS-483
- Recent publications
- Manufacturers data



Das et. al, Medical Physics, 2021; 48 (10): e886-e921

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2. New Detectors Implementation

TRS-483 FIELD OUTPUT CORRECTION FACTORS $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ FOR FIELDS COLLIMATED BY AN MLC OR SRS CONE AT 6 MV WFF AND FFF MACHINES, AS A FUNCTION OF THE EQUIVALENT SQUARE FIELD SIZE

Detector	Equivalent square field size, S_{clin} (cm)												
	8.0	6.0	4.0	3.0	2.5	2.0	1.5	1.2	1.0	0.8	0.6	0.5	0.4
PTW 31002 Flexible	1.000	1.000	1.001	1.004	1.009	1.023	—	—	—	—	—	—	—
PTW 31010 Semiflex	1.000	1.000	1.000	1.001	1.002	1.008	1.025	—	—	—	—	—	—
PTW 31014 PinPoint	1.000	1.000	1.000	1.002	1.004	1.009	1.023	1.041	—	—	—	—	—
PTW 31016 PinPoint 3D	1.000	1.000	1.000	1.001	1.001	1.004	1.013	1.025	1.039	—	—	—	—
PTW 60016 shielded diode	1.000	1.000	0.999	0.995	0.991	0.984	0.970	0.956	—	—	—	—	—
PTW 60017 unshielded diode	1.004	1.007	1.010	1.011	1.011	1.008	1.002	0.994	0.986	0.976	0.961	0.952	—
PTW 60018 unshielded diode (stereotactic)	1.004	1.007	1.010	1.011	1.009	1.006	0.998	0.990	0.983	0.973	0.960	0.952	—
PTW 60019 CVD diamond	1.000	1.000	1.000	1.000	0.999	0.997	0.993	0.989	0.984	0.977	0.968	0.962	0.955

2. New Detectors Implementation

$$k_{Q_{\text{clin}},Q_{\text{msr}}}^{f_{\text{clin}},f_{\text{msr}}}$$

New detectors and correction factors

- New detectors are not included in TRS-483 protocol correction factors tables
- Revised publications of correction factors
- Manufacturer may provide information regarding correction factors including reference publications or studies
- Other methods for clinical implementation have suggested experimental methods by comparing measurements with detectors from the protocol.

2. New Detectors Implementation

PTW documentation

PinPoint 3D (31022)

- Beam quality: 6 MV
- Field size defined by FWHM
- Measured in water
- SSD: 90 cm
- Depth: 10 cm
- **Detector orientation: radial (stem perpendicular to beam)**

Eq. sq. square field size [cm]	10	8	6	4	3	2.5	2	1.5	1.2	1	0.8	0.6	0.5	0.4
PinPoint 3D, type 31022	1.000	1.000	1.000	1.000	1.000	1.001	1.002	1.005	1.010	1.018	1.033	–	–	–

Data has been compiled from [Looe2018], [Poppinga2018] and [Casar2020]. Correction factor for 0.7 cm field size is 1.049

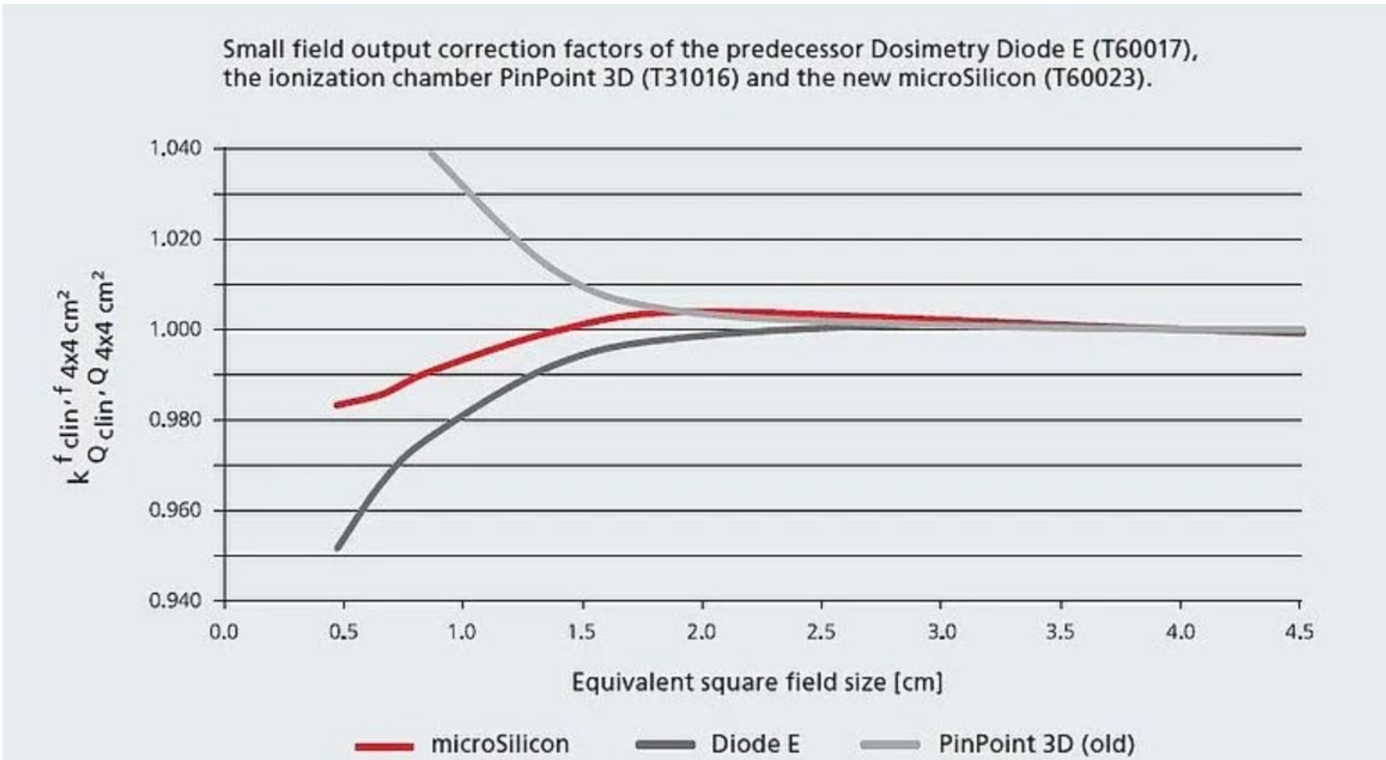
microSilicon (60023) – classical linac 6 MV

- Detector orientation: axial (stem parallel to beam)

Eq. sq. square field size [cm]	10	8	6	4	3	2.5	2	1.5	1.2	1	0.8	0.6	0.5	0.4
microSilicon, type 60023	1.000	1.004	1.007	1.011	1.013	1.014	1.014	1.012	1.009	1.004	0.997	0.984	0.975	0.963

Data is fit through the following three data sets: [Weber2020] experimetnal, [Weber2020] Monte Carlo and [Schoenfeld2019] experimental. For [Weber2020], we have used the experimental data from 4 cm x 4 cm to 10 cm x 10 cm also for the Monte Carlo data. For [Schoenfeld2019] we have used SIEMENS Artiste data to compare 4×4 cm² with 10×10 cm². Data for field sizes below 0.55 cm has been extrapolated using the [TRS483] fitting curve.

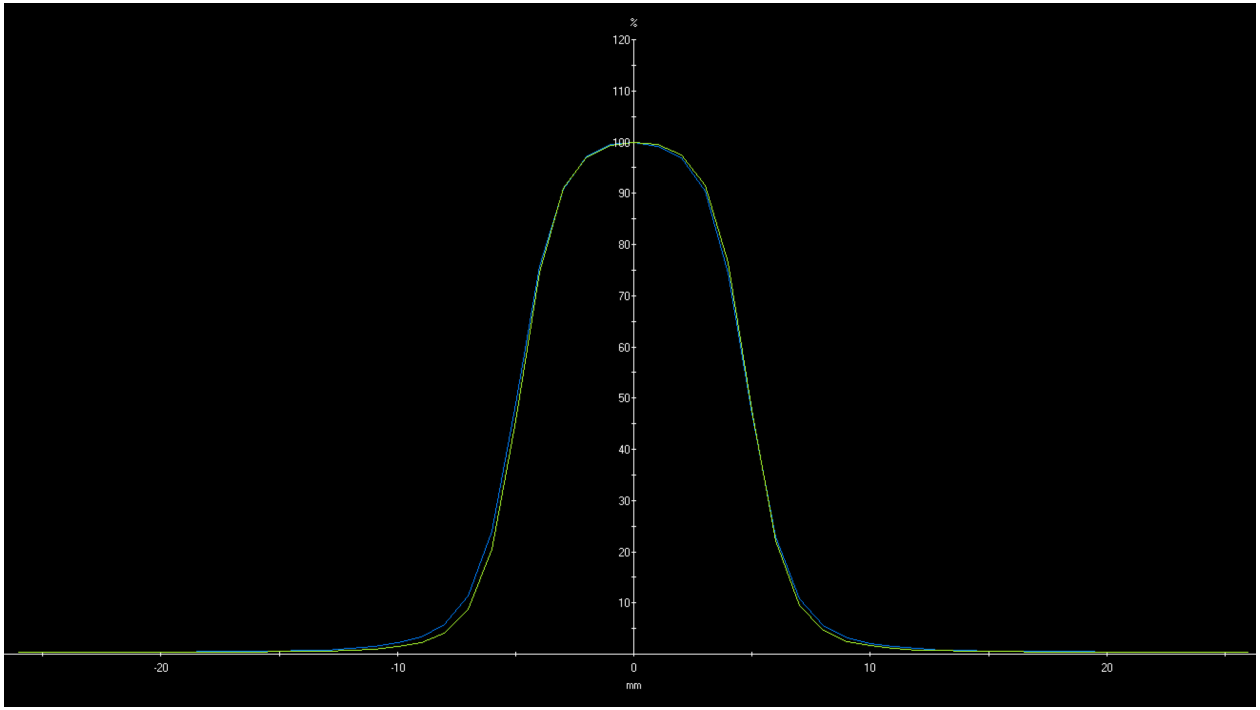
2. New Detectors Implementation



Graph PTW website

2. New Detectors Implementation

Comparisons with other detectors



SNC Edge in blue
PTW Microsilicon in green

Data and graphs provided by TrueNorth

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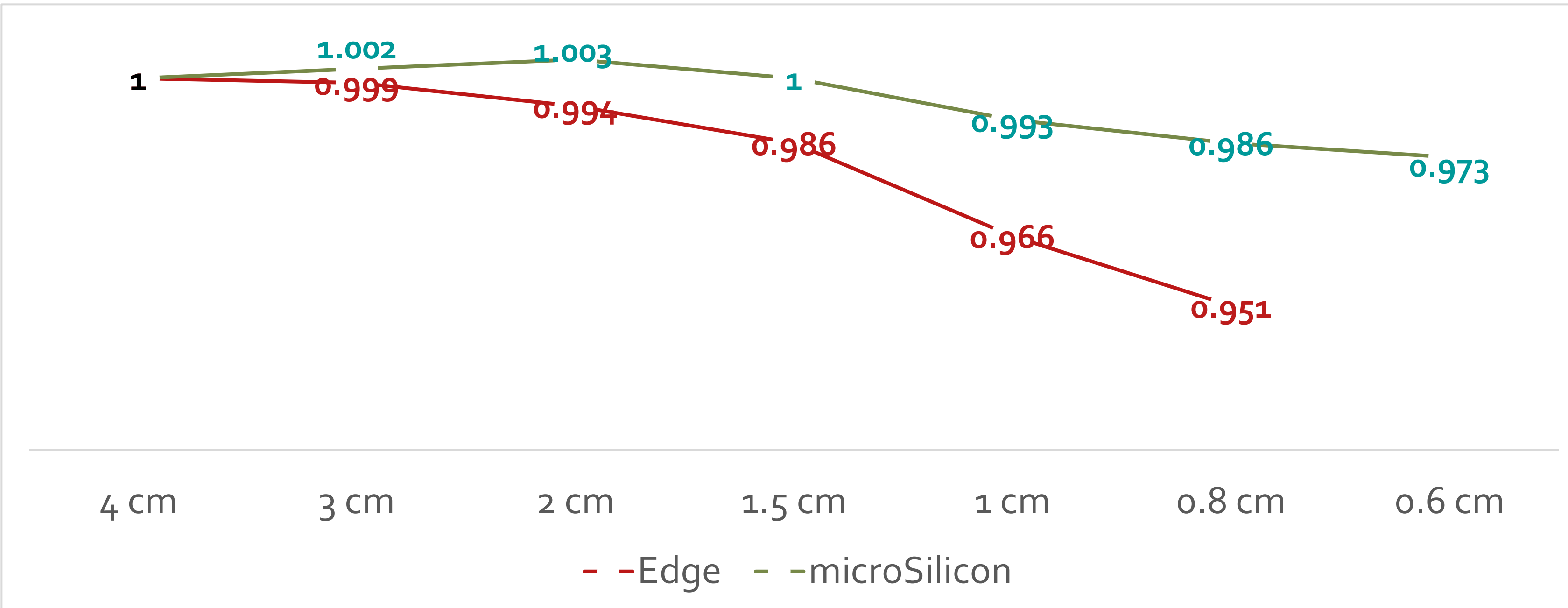
2. New Detectors Implementation

Comparisons



MicroSilicon factors from PTW documentation

Edge factors from TRS-483

Data and graphs provided by TrueNorth

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2. New Detectors Implementation

Difference in response from small field detectors show the need for applying correction factors.

PTW Microdiamond used to determine experimental correction factor values for two new detectors

ESTRO 2020, Vienna, Austria

Evaluation of IAEA small field correction factors using different detectors for FF and FFF energies

Gloria P. Beyer[1], Ghirmay Kidane[2], Raquel Paiva[1], Vasu Ganesan[2] , Liz Crees[2]

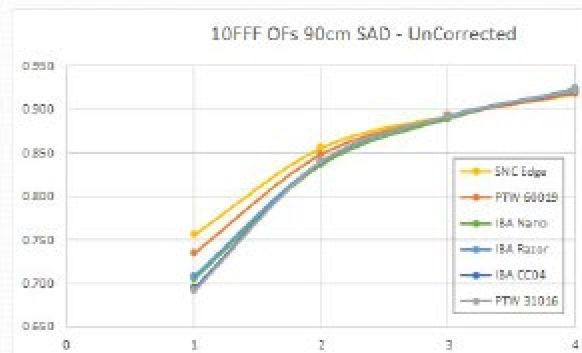
[1]MPSi Medical Physics Services International Ltd., Cork, Ireland

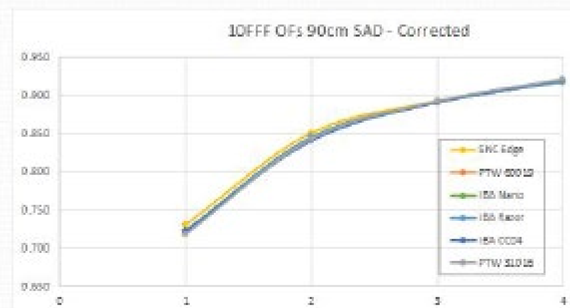
[2]Radiotherapy Department, Queen's Hospital, Romford, UK

Uncorrected OFs - 10FFF		
CC04, Mdiam, PinPt, Edge		
Field Size	AVE	ST DEV
4x4	0.919	0.2%
3x3	0.892	0.1%
2x2	0.846	0.8%
1x1	0.719	3.2%

Corrected OFs - 10FFF		
CC04, Mdiam, PinPt, Edge		
Field Size	AVE	ST DEV
4x4	0.919	0.2%
3x3	0.892	0.1%
2x2	0.845	0.4%
1x1	0.724	0.5%

DERIVED CORR. FACTORS		
10FFF	IBA Razor	IBA Nano
4x4	0.997	0.996
3x3	1.000	1.003
2x2	1.007	1.011
1x1	1.021	1.026





2. New Detectors Implementation

- Study used the corrected output factors for five detectors included in IAEA protocol for determining the correction factor for two new detectors

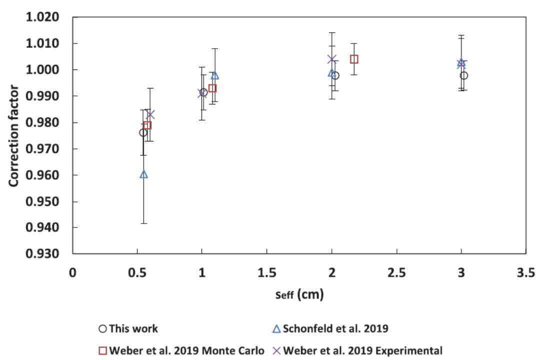


FIGURE 9 Correction factors for the microSilicon detector in this work compared to the literature for 6-MV

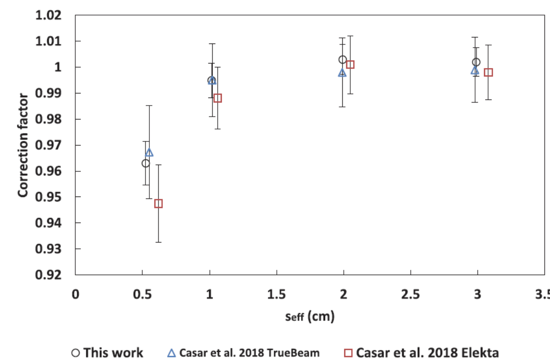


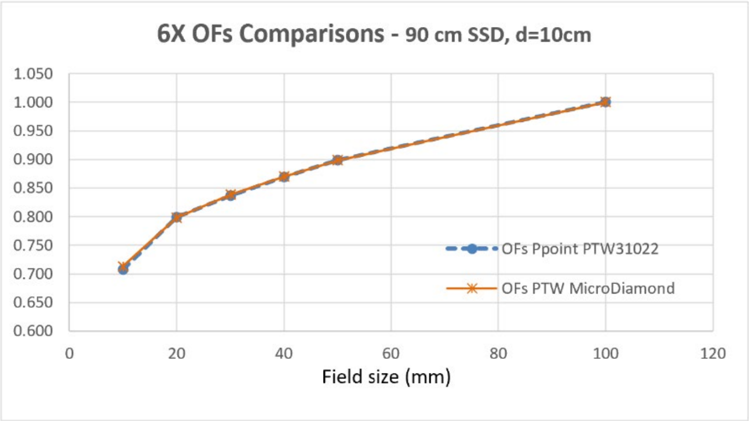
FIGURE 8 Correction factors for the Razor detector in this work compared to the literature for 10-FFF

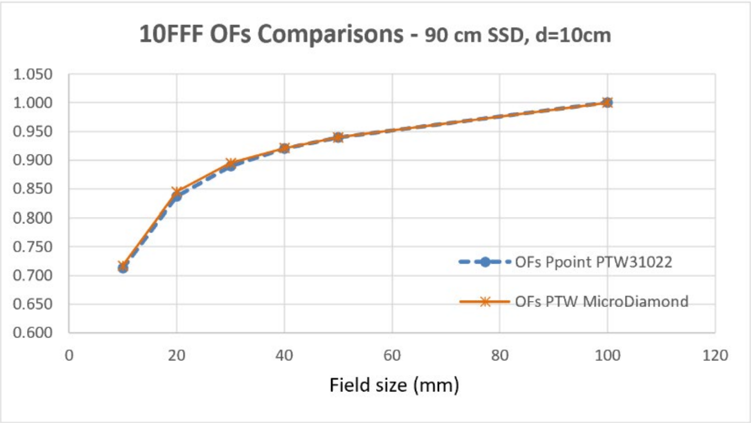
The microSilicon correction factors for 6-MV show a maximum difference of 1.6% for a 0.5 × 0.5 cm^2 field size to Schönfeld et al.[3] and less than 0.7% to all field sizes of Weber et al.[5]

McGrath et. al. J App Clin Med Phys. 2022

2. New Detectors Implementation

- Applying IAEA (PTW microdiamond) and vendor compiled (PTW31022) correction factors





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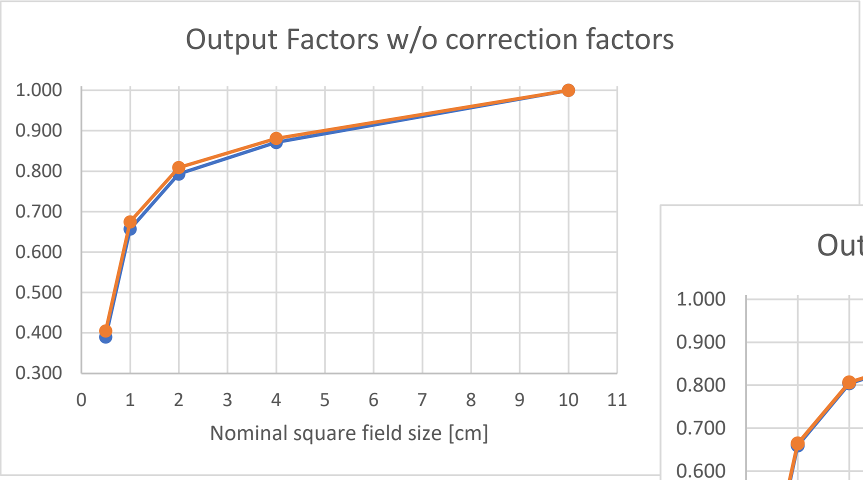
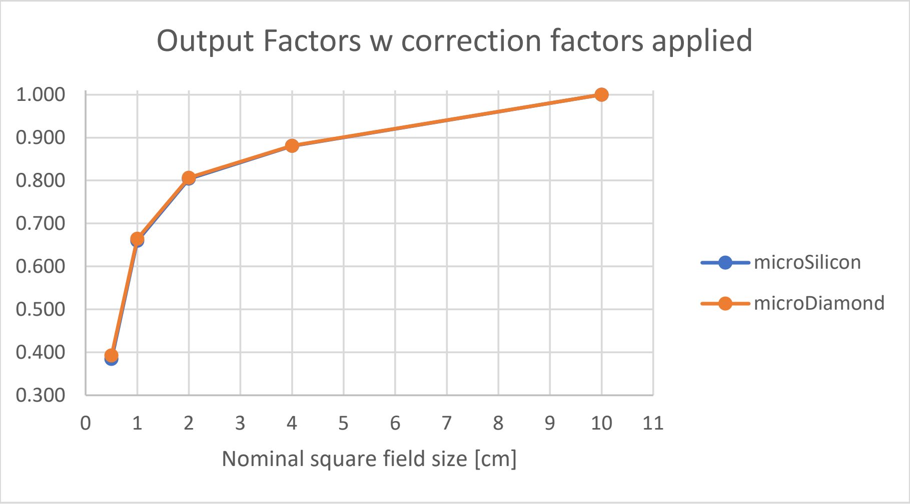
2. New Detectors Implementation

- Applying IAEA (PTW microdiamond) and vendor compiled (PTW Microsilicon) correction factors





Data and graphs provided by PTW

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3. Small Field Measurements and QA

3. Small Field Measurements and QA

Increase accuracy in small field dosimetry:

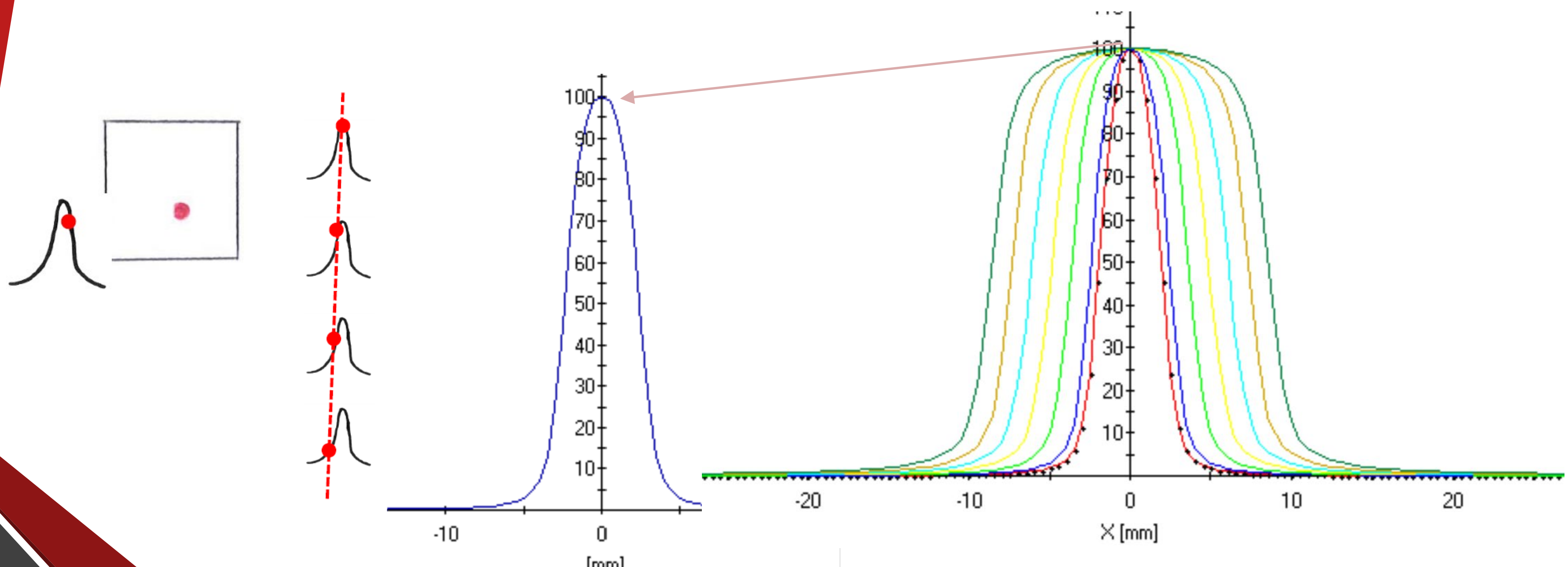
1. Select the appropriate detector
2. Use of correction factors for small field dosimetry
3. Understand the detector limitations (field size, energy, reponse, etc)
4. Use of multiple detectors to measure data
5. Correct positioning of the detector
6. Correct alignment of the detector

3. Small Field Measurements and QA

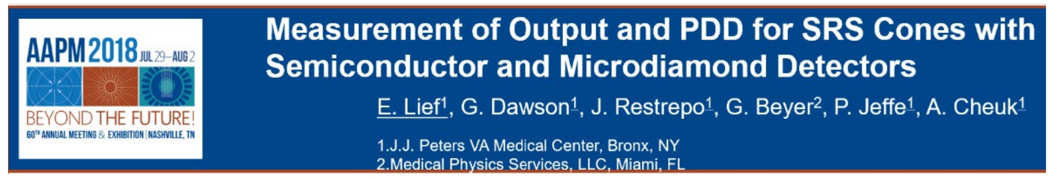
Positional accuracy for small fields:

- Position of detector off central axis can lead to errors due to the beam shape

Ex: Errors in positioning can result in smaller OFs and incorrect PDDS and profiles

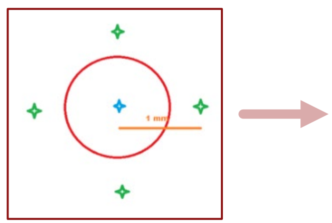


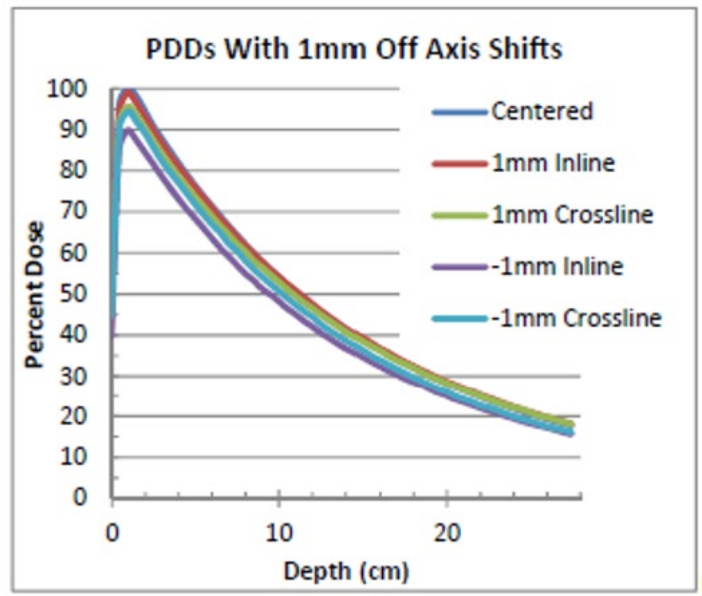
3. Small Field Measurements and QA



Positional accuracy:

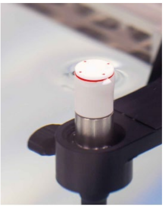
PDDs measured
at central axis
and off axis

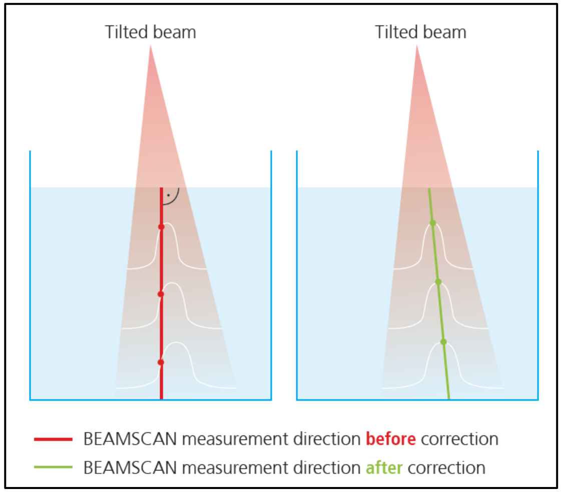




3. Small Field Measurements and QA

- Small field setup with PTW BeamScan
  - Center detector positioning (Auto Alignment)
  - Aligned with beam axis (Beam Inclination correction)





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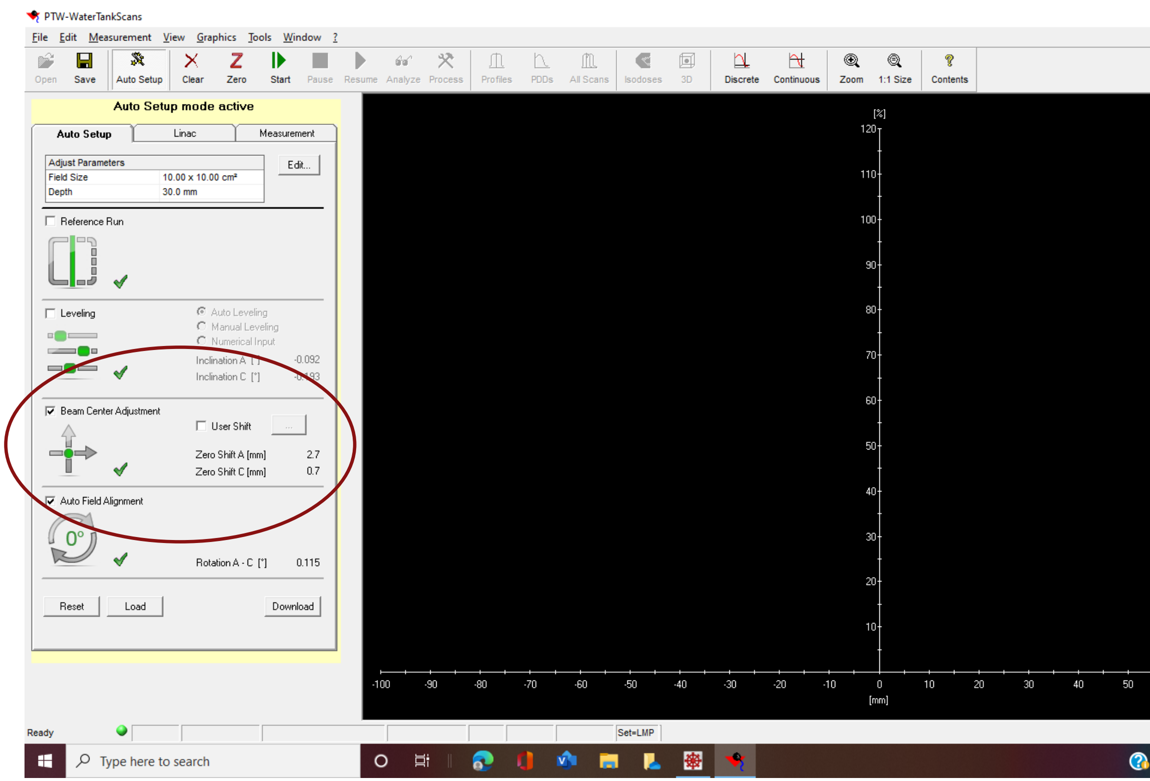
3. Small Field Measurements and QA



Centering can be rerun for different fields or setups

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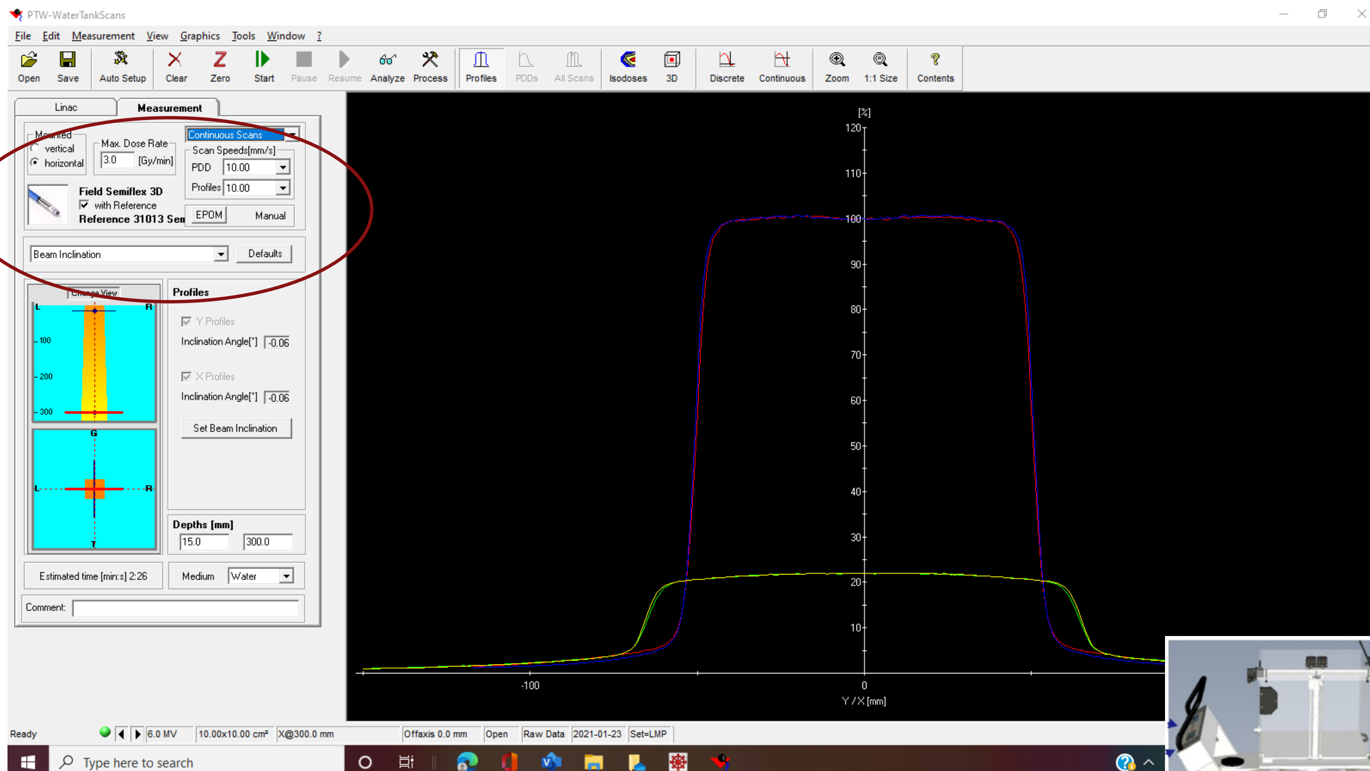
3. Small Field Measurements and QA



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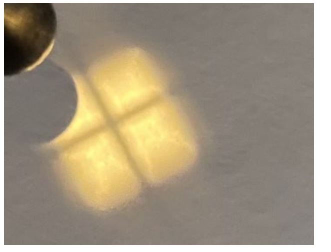
3. Small Field Measurements and QA

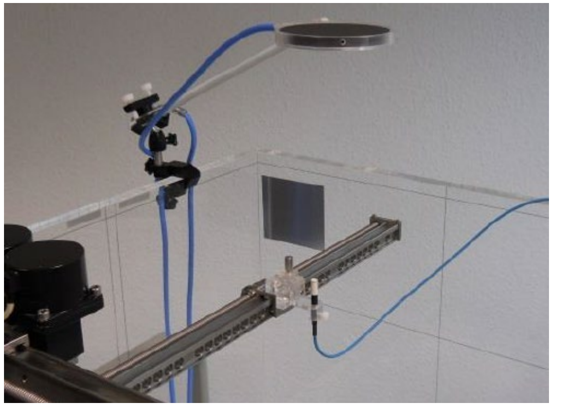
Reference chamber:

- reduces noise artifacts and dose rate variation in the scans
- Difficult to place in small fields



In-Field Reference chamber:

- Small field measurements
- Reduction in measuring time
- Less noise in signal



PTW T-Ref (<10x10 cm^2)

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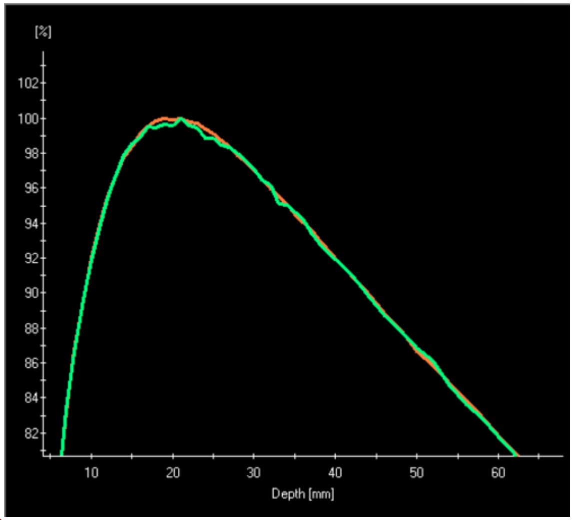
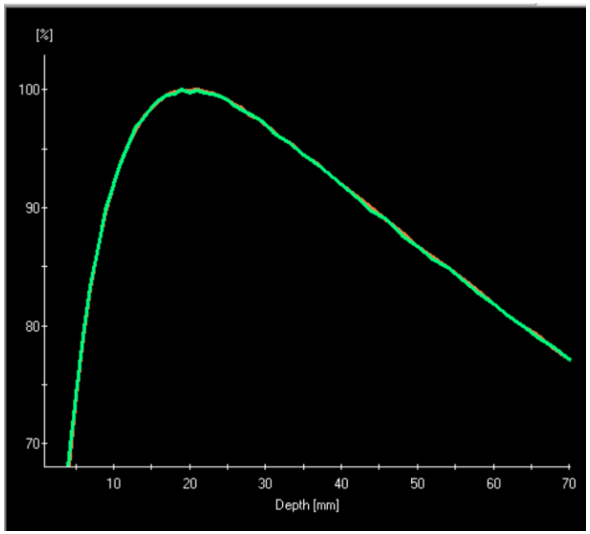
3. Small Field Measurements and QA

In-Field reference chamber comparisons

10FFF PDD for 2x2 with pinpoint:
- PTW TRef as reference (brown)
- No reference (green)
- Same scanning time (t=0.5 sec)

10FFF PDD for 2x2 with pinpoint:
- PTW TRef as reference (brown **t=0.5 sec**)
- No reference (green, **t=1.0 sec**)

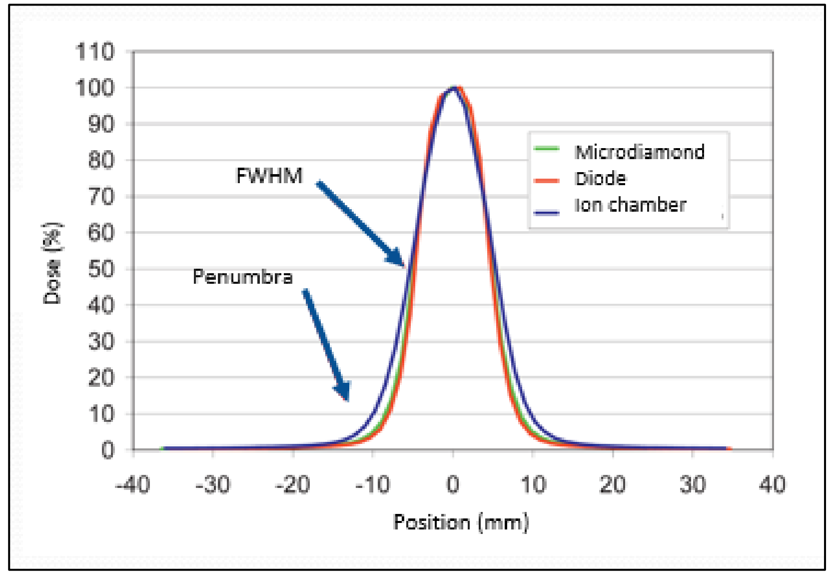




3. Small Field Measurements and QA

Profile measurements:

- Accuracy in determination of FWHM important for accuracy in field size definition and for applying the correction factors
- Considerations:
  - Detector positioning
  - Detector choice
- Volume average effect from detector a consideration
  - Penumbra measurement
  - Field size measurement



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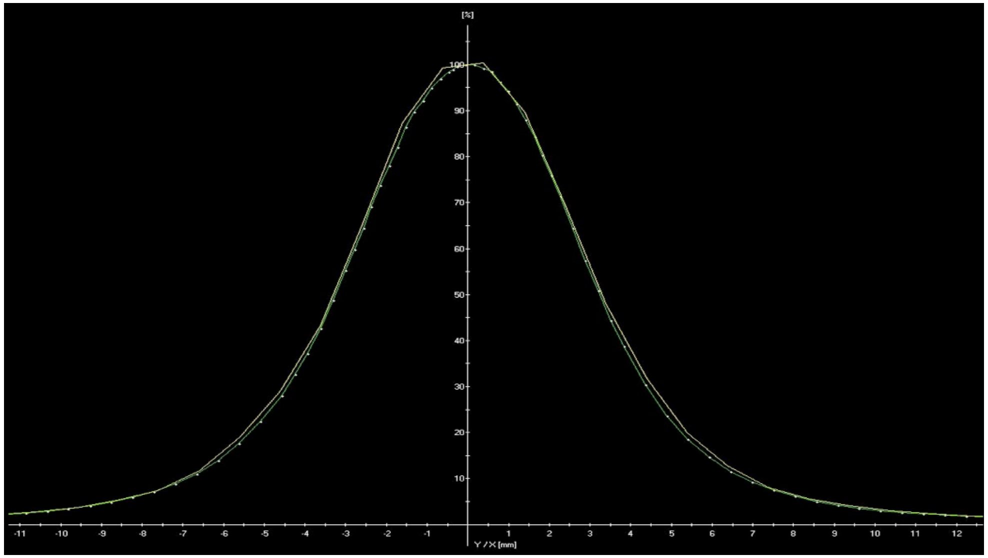
3. Small Field Measurements and QA



Scan mode can affect penumbra and scan noise:

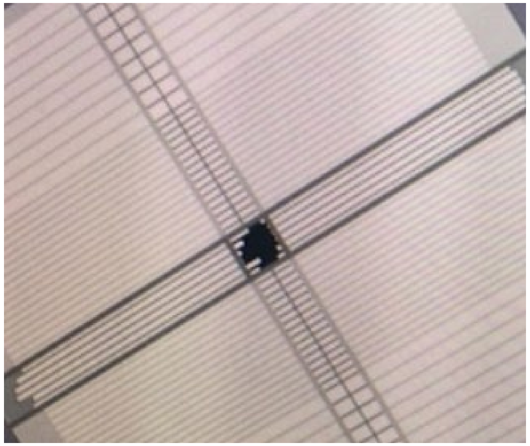
- Step-by-step vs continuous
- Smaller steps can improve scan quality
- Lengthen sample time

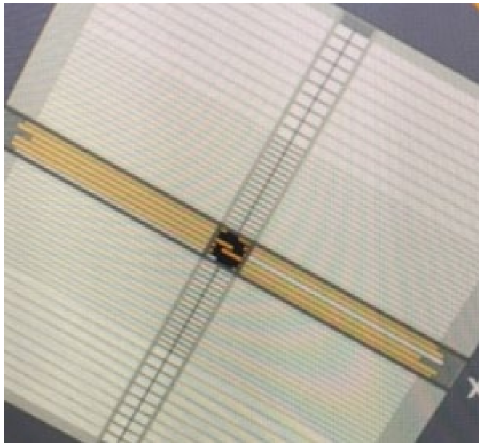
Data provided by TrueNorth

3. Small Field Measurements and QA

:

- Definition of field size in complex dynamic treatment deliveries
- No clear consensus -> detectors with small correction factors preferred





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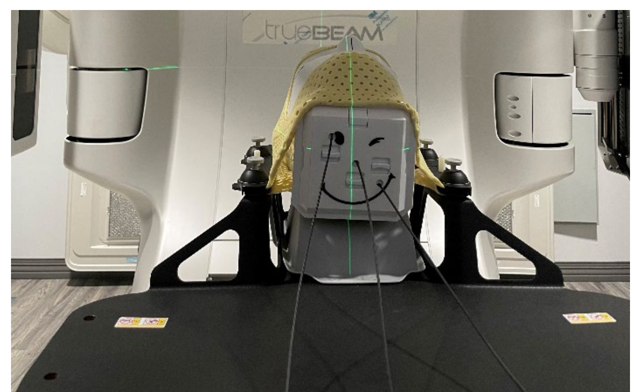
3. Small Field Measurements and QA

:

- Small field detectors used for QA measurements in phantom

Ruby Head Phantom - 3 Target HyperArc Results

Location	Target Size (cm)	Eclipse (cGy)	MicroDiamond (cGy)	% Diff.
Target1	1.0	1029.09	1002.96	-2.5%
Target2	1.0	931.2	917.89	-1.4%
Target3	1.0	825.45	831.02	0.7%
Target1	2.0	993.74	975.80	-1.8%
Target2	2.0	894.52	888.55	-0.7%
Target3	2.0	794.06	797.17	0.4%



Data provided by TrueNorth

4. Summary

4. Summary

- New small field detectors have improved to provide smaller measurement volumes and improved materials to minimize volume effect and perturbation in the field
- To implement small field detectors, it is important to know the detector characteristics, the specific measurement goals, and the small field size range to be measured.
- Correction factors can be used to help select the appropriate detector and to understand the magnitude of the detector effect for the field sizes to be measured
- The choice of detector and its measurement implementation can affect the accuracy in small field data measurements

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Thank you!