Small Field Detectors and Measurement Uncertainty

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AAPM SPRING CLINICAL MEETING | 2024

Outline

- 1. Small Field Dosimetry
- 2. Detectors for Small Field Dosimetry
- 3. Considerations for Detector Selection
- 4. Uncertainties in Detector Implementations
- 5. Summary

1. Small Field Dosimetry

1. Small Field Dosimetry

Use of small field has increased in recent years with the new radiation treatment techniques.

What is considered a small field?

Std fields: >3cm x 3cm

Small fields: ≤3cm x 3cm

1- Photon beam source occlusion

2- Lateral electron disequilibrium

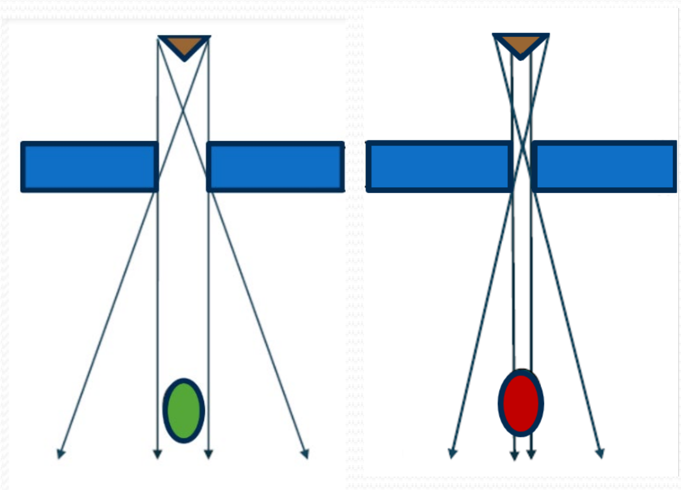
3- Volume average effect

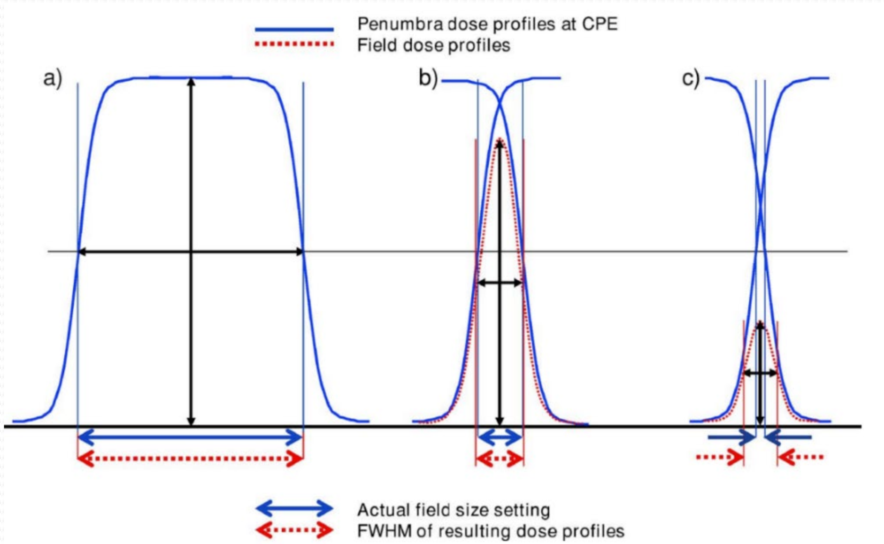
Choose right detector to minimize small field effects

1. Small Field Dosimetry

Photon beam source occlusion

- Partial part of the beam source is visible from the point of measurement
- Photon penumbra overlapping, profile widening, reduced output.
- Affects energy and angular fluence distribution (detector response)
- Measure field (S_{clin}) to define small field size





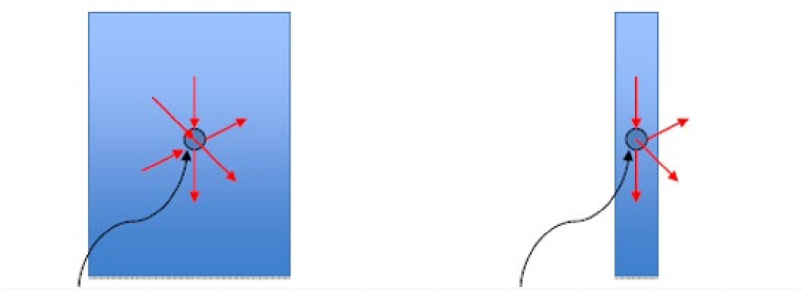
Das et. al. 2008 Med. Phys. 35 (1), 206-215

1. Small Field Dosimetry

Lateral electron disequilibrium

- Edge of radiation field too close to measurement volume results in dose being deposited outside the volume
- Loss of Lateral Charged Particle Equilibrium (LCPE)
- Depends on range of secondary electrons and energy
- Detector sensitive volume and material can influence LCPE

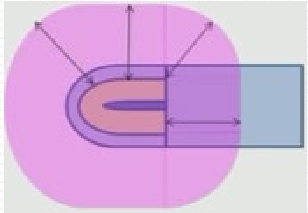
Small field



Detector

Detector

$$r_{\mathrm{LCPE}} = 8.369 \times \mathrm{TPR}_{20,10}(10) - 4.382$$

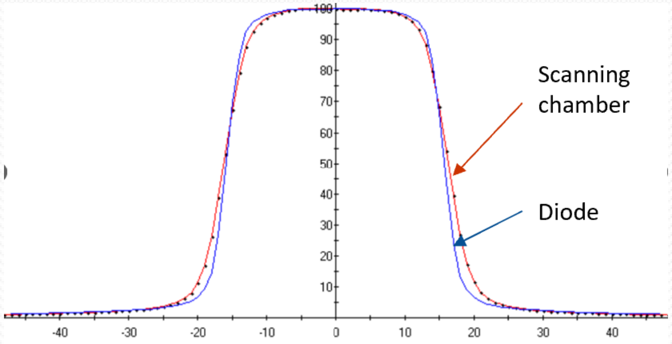


1. Small Field Dosimetry

Volume effect

- Depends on the detector used to characterize the field
- Field sizes ≤3cm (diameter or side of field) -> small field
- Detector size -> defines what is a “small” field

- Volume average effect
  - Dose changes with the detector
  - Field size can be overestimated
  - Width of penumbra overestimated



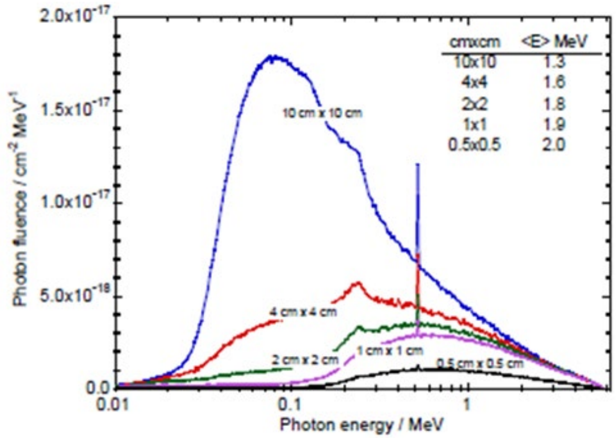
1. Small Field Dosimetry

Energy spectrum changes and small field detectors

- Beam hardening effect and increase in average photon energy:
    - Reduced scattered low energy photons from linac head
    - Amount of phantom scatter decreases with small fields

Results:

- Change in ratio of mass energy absorption coefficients between water and detector material
- Potential change of water to air stopping power ratio



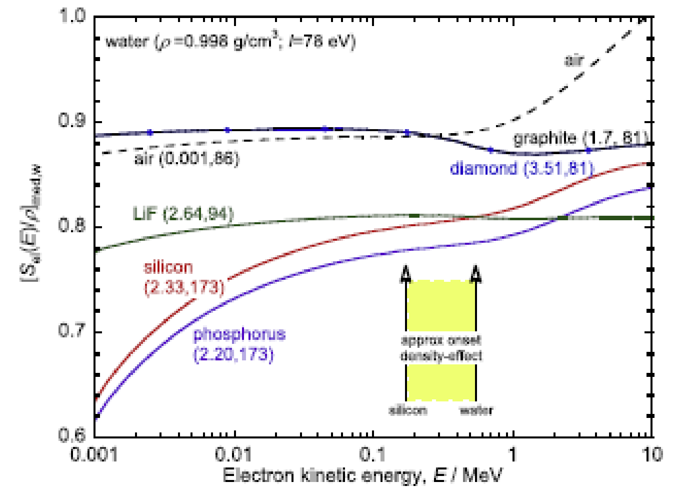
P. Andreo, The Physics of small field megavoltage photon beam dosimetry, Radiotherapy and Oncology 126(2018) 205-213

1. Small Field Dosimetry

Energy spectrum changes and small field detectors

- Changes in spectrum will 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

2. Detectors for Small Field Dosimetry

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2. Detectors for Small Field Dosimetry

- Ideal detector for small field dosimetry:
  - High spatial resolution
  - Energy independent
  - Water equivalent
  - No directional dependence
  - High stability
  - Good sensitivity
  - Dose rate independent
  - Stable
  - Easy to use

No ideal detector exists

1. Detectors for Small Field Dosimetry

- Spectra and beam quality changes as field size decreases
- The response from different detectors varies

- Detectors perturb particle 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)

2. Detectors for Small Field Dosimetry

Active detectors:

- Ion chamber (small volume)
- Diodes
- Diamond
- Plastic scintillators

Passive detectors:

- Gaphchromic film
- TLDs
- Alanine

2. Detectors for Small Field Dosimetry

Small volume ion chambers

ADVANTAGES	DISADVANTAGES
Reproducitility	Low sensitivity
Stability	Stem effect
Linearity	Cable effect
Dose rate independent	Volume effect
Can be used in different beam orientations	Electrode materials (perturbation if high Z)
MV energy dependence can be corrected (K_Q)	Ion recombination effect
Absolute dosimetry measurements	

2. Detectors for Small Field Dosimetry

Diode detectors

ADVANTAGES	DISADVANTAGES
Very small sensitive volume	Energy dependence (kV photons)
Good sensitivity	Field size dependent response (use shielded large fields)
Spatial resolution	Perturbation (unshielded preferred for small fields)
Energy independence (small fields, unshielded)	Non-water equivalent (Z=14)
	Radiation degradation
	Directional dependence
	Pre-irradiation

2. Detectors for small field dosimetry

Diamond detectors

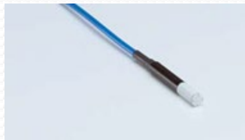
ADVANTAGES	DISADVANTAGES
Small sensitive volume	May exhibit dose rate dependence
Good sensitivity	Detector radius
Spatial resolution	Pre-irradiation
Response time	Some angular dependence
Near tissue equivalence (Z=6)	Dose rate dependence (older models)
Very small energy dependence	

2. Detectors for Small Field Dosimetry

Plastic scintillator

ADVANTAGES	DISADVANTAGES
Water equivalent	Detector implementation
Angular independence	Corrections for Cerenkov radiation
Stable photon energy resonse	Irradiation geometry
Spatial resolution	Some detectors still in development
Energy independent	

3. Considerations for Detector Selection



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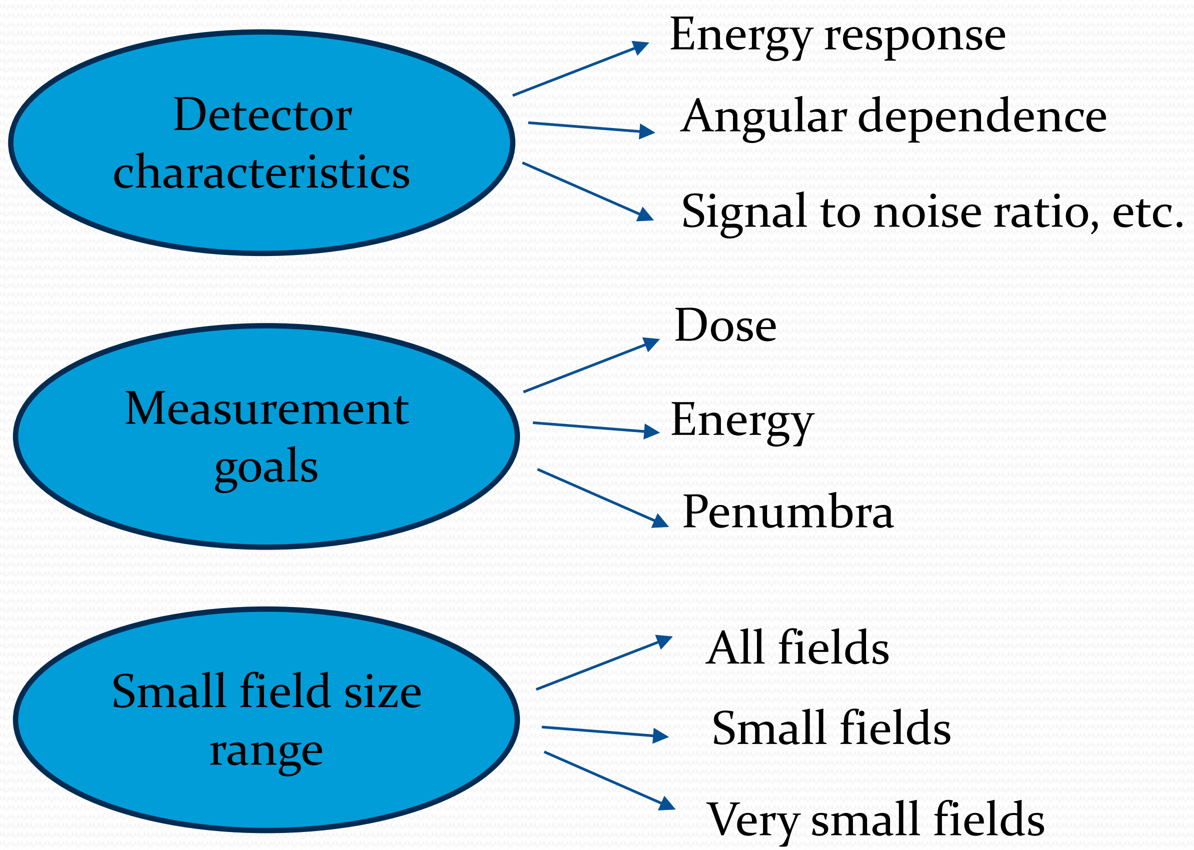
3. Considerations for Detector Selection

Large number of detectors in the market can make selecting the “right” detector overwhelming

- Data measurements can vary depending upon the detector selected
- An improper choice may lower the quality of the data measurement
- Understand the performance of the detector
- Know the limits of the detector
- Understand the measurement goals

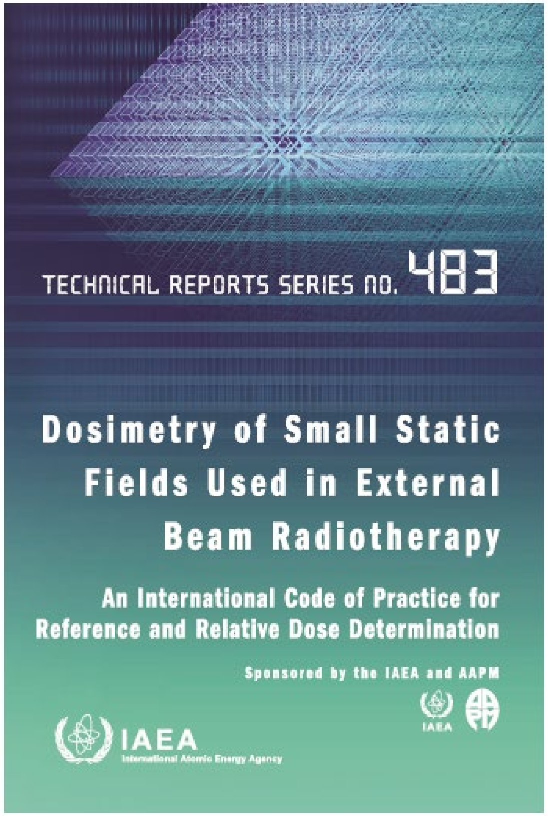
3. Considerations for Detector Selection



1. Considerations for Detector Selection

- Small field dose measurements are complex and can be challenging
- Increase use of small photon fields raised the need to standardize the dosimetry of small fields
- Protocol developed to standardize dose measurements for small fields:

  IAEA/AAPM TRS 483
- Tables of small field correction factors



1. Considerations for Detector Selection

TRS-483

Protocol formalizes the use of correction factors for small field dosimetry

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

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

$\Omega_{Q_{clin}Q_{ms}}^{f_{clin}f_{msr}}$ → 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 => $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$

1. Considerations for Detector Selection

Small field correction factors (TRS-483)

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

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

K_d: differences between detector materials and water (density perturbation)
K_{vol}: differences between point and volume-averaged doses (volume effect)

Correction factor:

- Directly measured value
- Experimental generic value
- Monte Carlo calculated value

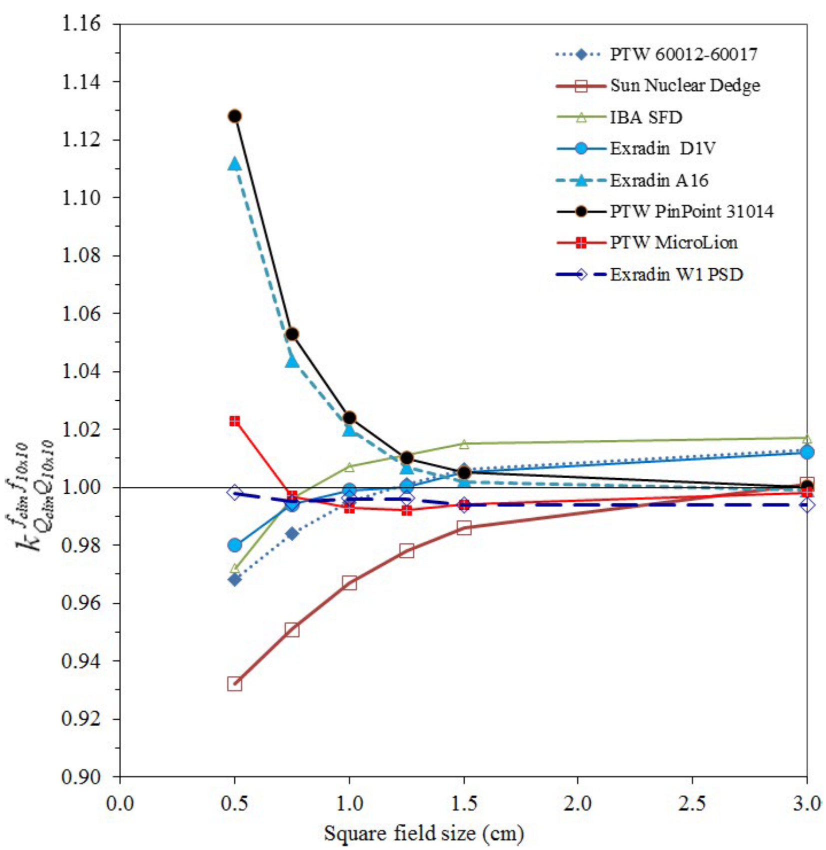
1. Considerations for Detector Selection

Output correction factors

- Variations between detectors
- For small fields:
  - Ion-chambers under-respond
  - Diodes over-respond

Tabulated data in TRS-483

and recent publications



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

3. Considerations for Detector Selection

- Use of correction factor tables:
  - Standardize small field measurements
  - Determine appropriateness of detector for field size
  - Use correction factors in selecting a detector

  (correction factors should remain <5% (from TRS 483)

3. Considerations for Detector Selection

TABLE 26. FIELD OUTPUT CORRECTION FACTORS $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ 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
Ionization chambers													
Exradin A14SL micro Shonka slimline	1.000	1.000	1.000	1.000	1.000	1.002	1.010	1.027	—	—	—	—	—
Exradin A16 micro	1.000	1.000	1.000	1.000	1.001	1.003	1.008	1.017	1.027	1.043	—	—	—
IBA/Wellhöfer CC01	1.002	1.004	1.007	1.008	1.008	1.009	1.011	1.013	1.018	1.027	1.047	—	—
IBA/Wellhöfer CC04	1.000	1.000	1.000	1.000	1.000	1.002	1.009	1.022	1.041	—	—	—	—
IBA/Wellhöfer CC13/IC10/IC15	1.000	1.000	1.000	1.001	1.002	1.009	1.030	—	—	—	—	—	—
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	—	—	—	—

3. Considerations for Detector Selection

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
Real time solid state dosimeters													
IBA PFD3G shielded diode	1.000	1.000	0.998	0.995	0.992	0.986	0.976	0.968	0.961	0.952	—	—	—
IBA EFD3G unshielded diode	1.005	1.009	1.014	1.016	1.016	1.015	1.012	1.008	1.004	0.998	0.988	0.983	0.976
IBA SFD unshielded diode (stereotactic)	1.008	1.017	1.025	1.029	1.031	1.032	1.030	1.025	1.018	1.007	0.990	0.978	0.963
PTW 60008 shielded diode	1.000	1.000	1.000	0.998	0.995	0.990	0.977	0.962	—	—	—	—	—
PTW 60012 unshielded diode	1.005	1.010	1.015	1.017	1.017	1.016	1.010	1.003	0.996	0.985	0.970	0.960	—
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 60003 natural diamond	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.003	1.009	1.026	1.045	—
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
Sun Nuclear EDGE Detector	1.000	1.000	1.000	0.999	0.998	0.994	0.986	0.976	0.966	0.951	—	—	—
Standard Imaging W1 plastic scintillator	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

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3. Considerations for Detector Selection

AAPM TG-155

- Detector choice considerations:
  - Detector with known correction factor preferably close to one

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AAPM SCIENTIFIC REPORT
MEDICAL PHYSICS

Report of AAPM Task Group 155: Megavoltage photon beam dosimetry in small fields and non-equilibrium conditions

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Abstract
Small-field dosimetry used in advance treatment technologies poses challenges due to loss of lateral charged particle equilibrium (LCPE), occlusion of the primary photon source, and the limited choice of suitable radiation detectors. These

- Field sizes ≤1cmx1cm
  - Electron diode
  - Unshielded SRS diode
  - Plastic scintillator
  - Microdiamond

- Field sizes >1cmx1cm
  - Very small ion chambers

3. Considerations for Detector Selection

New developments to improve detectors for small fields

- Pinpoint chambers:
  - Smaller volumes
  - Reduced perturbation (better materials used in electrodes – low Z)

- Solid state detectors:
  - High spatial resolution with smaller active area
  - Small detector to detector variation
  - Higher signal
  - Lower angular dependence
  - Low dose per pulse dependence
  - Low sensitivity variations with temperature variations
  - Materials to improve water equivalence
  - Longer lifespan

3. Considerations for Detector Selection

Detector changes for small field detector are geared toward minimizing the effects of the detector. These include smaller size, minimize perturbation, improve signal to noise ratio, accuracy of penumbra measurements, etc.

- Manufacturers have updated websites to help guide customers through the process of product selection
- Highlights related to improvements in detector construction and improvements in detector signal are noted in the descriptions
- Uniqueness of the detector is typically noted by the manufacturer
- Data sheet is generally available

3. Considerations for Detector Selection

New detectors and correction factors $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$

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

4. Uncertainties in Detector Implementation

4. Uncertainties in Detector Implementation

Errors in small field detector implementation can be prevented by understanding the principles of small field dosimetry. Considerations need to be taken when performing these types of measurements due to the potential of a large magnitude effect in the misuse of the detector or from selecting an inappropriate detector.

- Understand measurement needs
- Evaluate the detector characteristics
- Understand the detector limitations (field size, energy, reponse, etc)

4. Uncertainties in Detector Implementation

Increase accuracy in small field dosimetry:

1. Select the appropriate detector
2. Correct positioning of the detector
3. Correct alignment of the detector
4. Understand the detector limitations
5. Implement protocols for small field dosimetry
6. Correct use of correction factors
7. Use of multiple detectors to measure data

4. Uncertainties in Detector Implementation

Largest errors and uncertainties are typically encountered with dose and output factor measurements for small fields

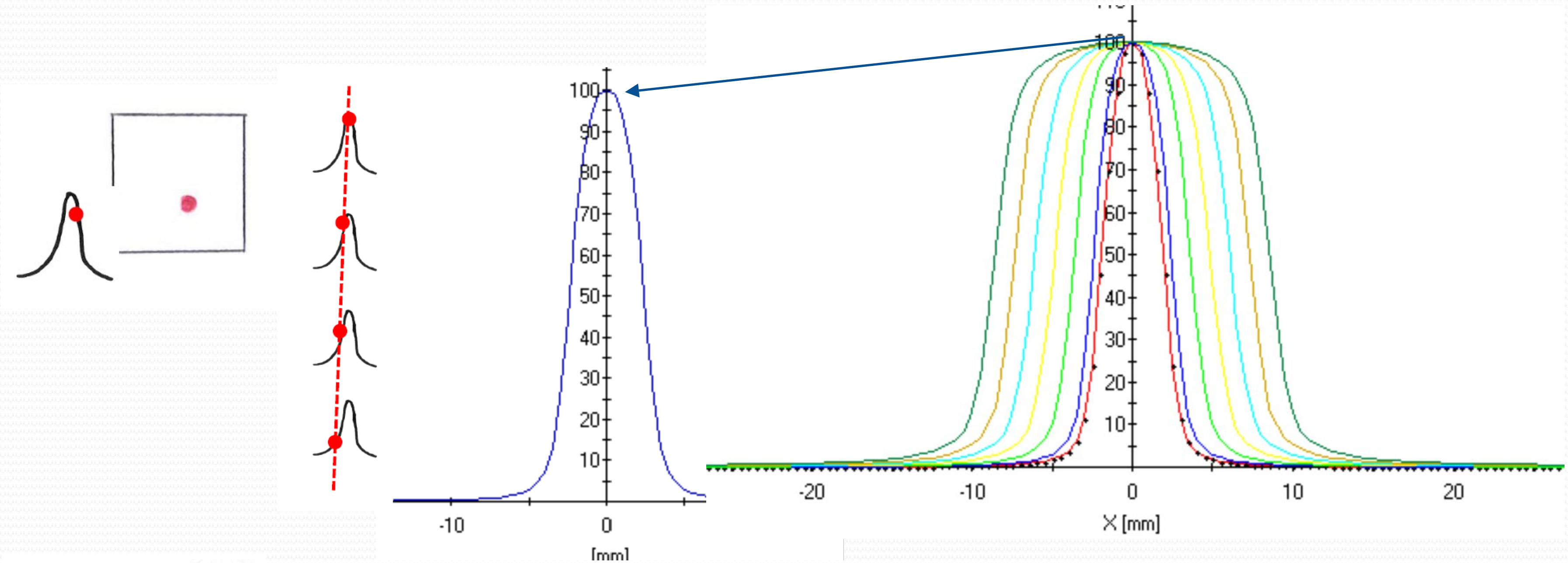
- Output factor measurements can have a direct influence on treatment planning system modeling
- Small field dose measurements have an influence in validation of beam modeling and dosimetry plans

4. Uncertainties in Detector Implementation

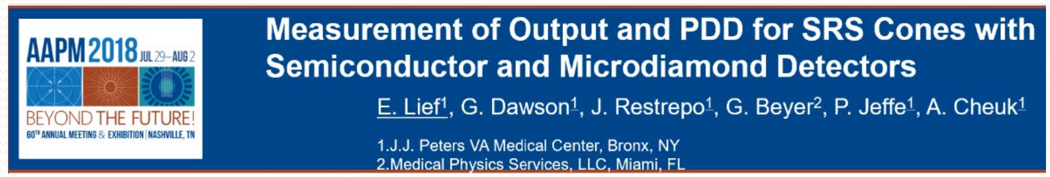
Positional accuracy for small fields:

- 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

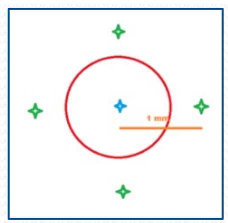


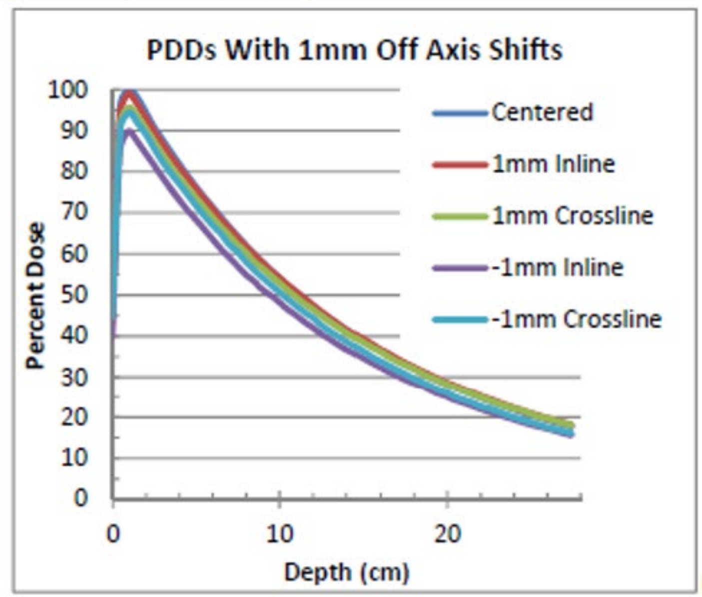
4. Uncertainties in Detector Implementation



Positional accuracy:

PDDs measured at central axis and off axis





4. Uncertainties in Detector Implementation

Correction factors increase accuracy of measurements

Considerations for application of correction factors:

- Energy
- Machine model
- Measurement setup
- Detector orientation
- Reference field normalization
- Field size definition TRS-483:

Rectangular

- $S_{clin} = \sqrt{AB}$

Circular

- $S_{clin} = 1.77\ r$

TRS 483

Read table caption carefully

Measure S_{clin}

Published data

Evaluate reference field size and measurement conditions

4. Uncertainties in Detector Implementation

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

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]

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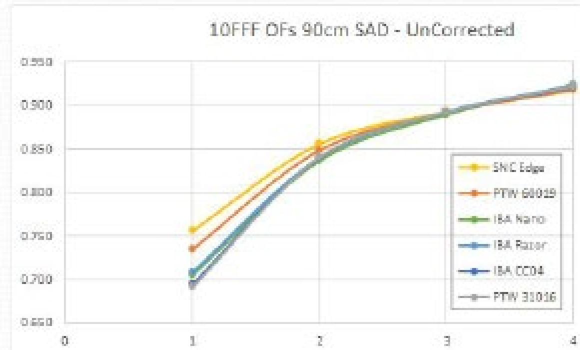
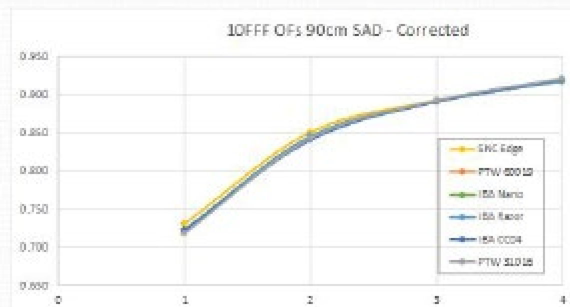
[2]Radiotherapy Department, Queen's Hospital, Romford, UK

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





4. Uncertainties in Detector Implementation

The need for small field correction factors to minimize measurement variability has been recognized by several studies

Physica Medica 81 (2021) 191–196

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

ELSEVIER

Original paper

Field output factors for small fields: A large multicentre study

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Radiation Physics and Chemistry 178 (2021) 108950

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

ELSEVIER

Small-field radiotherapy photon beam output evaluation: Detectors reviewed

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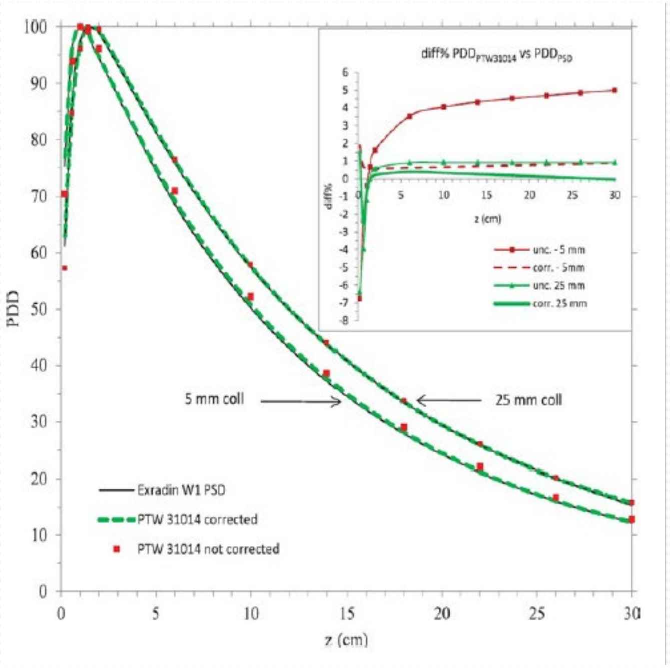
[b] *Department of Physics, University of Surrey, Guildford, Surrey, GU2 7XH, United Kingdom*

4. Uncertainties in Detector Implementation

PDD measurements:

- Ratio of readings not valid in small field if perturbation corrections vary with depth and field size
- Largest effect->buildup region:
  - ion chambers can under-respond up to 10%
  - diodes can over-respond up to 3%.
- After build-up region, small diodes and microdiamond detectors can measure PDD in water within 2%
- Choice of appropriate detector minimizes the effect
- Small ion chambers should only be used for field sizes >10mm



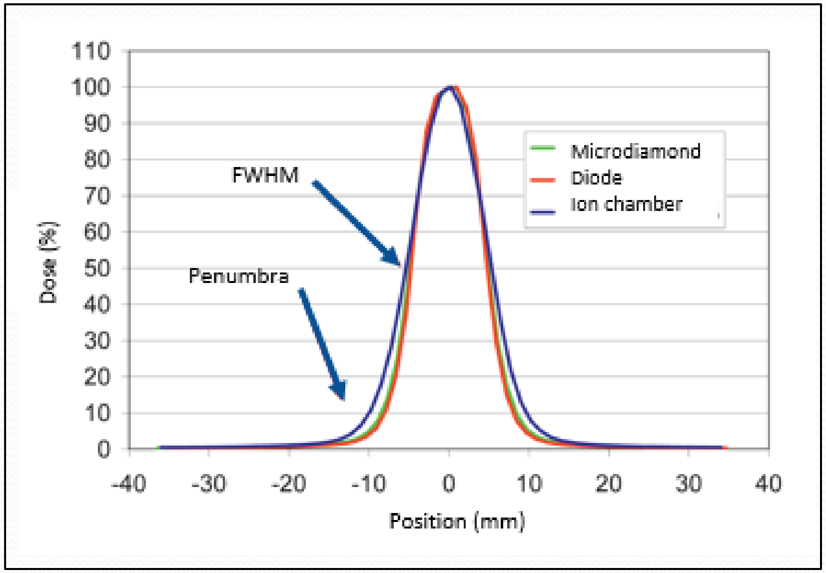
PDD of CyberKnife for 5 and 25 mm cones. Difference in dose compared with detector that does not require correction.

Francescon et. al. Medical Physics 2014 Vol. 41 (10)

4. Uncertainties in Detector Implementation

Profile measurements:

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



4. Uncertainties in Detector Implementation

Type of uncertainties for detector measurements:

- **Type A**: uncertainties evaluated by statistical methods. Derived from the analysis of a series of observations under the same condition. Account for random variations observed during multiple measurements of the same quantity. Precision of the measurement process.

- **Type B**: uncertainties not evaluated by means of statistical analysis. Include: calibration of instrument, reference standard uncertainties, environmental conditions, theoretical models used in measurements. Quantified based on manufacturer's specifications, previous measured data, or published references. Addresses accuracy of measurement process and potential systematic errors influencing the results.

4. Uncertainties in Detector Implementation

- Some uncertainty is inherent in small field measurements due to the complexity of small field dosimetry.
- The choice of detector and its implementation can affect the level of uncertainty.

Uncertainties of small field measurements include also:

- Response of detector
- Accuracy of correction factors

4. Uncertainties in Detector Implementation

Example of combined statistical uncertainty calculation parameters for output factor measurements with a small volume ion chamber:

$$u_c\left(\Omega^{f_{clin},f_{ref}}_{Q_{clin},Q_{ref}}\right) = \sqrt{\left(c_{M^{f_{clin}}_{Q_{clin}}} \times u_c\left(M^{f_{clin}}_{Q_{clin}}\right)\right)^2 + \left(c_{M^{f_{ref}}_{Q_{ref}}} \times u_c\left(M^{f_{ref}}_{Q_{ref}}\right)\right)^2 + \left(c_{k_{pol_{clin}}} \times u_c\left(k_{pol_{clin}}\right)\right)^2 + \left(c_{k_{pol_{ref}}} \times u_c\left(k_{pol_{ref}}\right)\right)^2 + \left(c_{k_{s_{clin}}} \times u_c\left(k_{s_{clin}}\right)\right)^2 + \left(c_{k_{s_{ref}}} \times u_c\left(k_{s_{ref}}\right)\right)^2}$$

$\Omega^{f_{clin},f_{ref}}_{Q_{clin},Q_{ref}\,IBA\,CC003}$: output factor for detector

$M^{f_{clin}}_{Q_{clin}}$: reading of clinical field

$M^{f_{ref}}_{Q_{ref}}$: reading of reference field

$k_{pol_{clin}}$: polarity correction factor for clinical field

$k_{pol_{ref}}$: polarity correction factor for reference field

$u_c\left(M^{f_{clin}}_{Q_{clin}}\right)$: combined uncertainty of the reading of clinical field

$u_c\left(M^{f_{ref}}_{Q_{ref}}\right)$: combined uncertainty of the reading of reference field

$u_c\left(k_{pol_{clin}}\right)$: combined uncertainty of the polarity correction factor of clinical field

$u_c\left(k_{pol_{ref}}\right)$: combined uncertainty of the polarity correction factor of reference field

$c_{M^{f_{clin}}_{Q_{clin}}}$: sensitivity coefficient of the reading of clinical field

$c_{M^{f_{ref}}_{Q_{ref}}}$: sensitivity coefficient of the reading of reference field

$c_{k_{pol_{clin}}}$: sensitivity coefficient of the polarity correction factor of clinical field

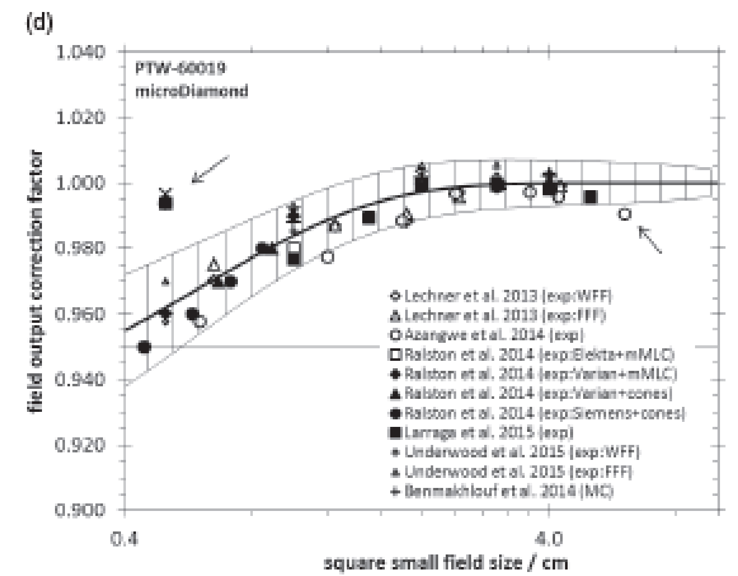
$c_{k_{pol_{ref}}}$: sensitivity coefficient of the polarity correction factor of reference field

Mateus et. al. 2024. Biomed.Phys. Eng. Express 10 (2024)

4. Uncertainties in Detector Implementation

TRS 483 correction factors

- Large amount of data available but:
  - Scattered for smallest field sizes
  - Majority for 6MV
  - Lack of homogeneity for SSD or SDD
  - Depth of measurement or calculation
  - Definition of field size differences
  - Lack of proper estimation of uncertainty in steps involved



4. Uncertainties in Detector Implementation

TRS-483 Uncertainties

- Uncertainties for the correction factors data tables detailed in the protocol

II.2. MEAN VALUES AND UNCERTAINTY ESTIMATES

Mean values of the field output correction factors and uncertainty estimates have been derived following as closely as possible Ref. [10], according to a procedure adapted from Ref. [11]:

(i) Based on the detailed uncertainty estimates made by some authors [50, 136, 196], uncertainties for the datasets used in the present analysis have been taken as 1% for all the field sizes in Monte Carlo calculations, 1% for the experimental values with fields larger than 1 cm × 1 cm, and 2% for the experimental values with fields equal to or smaller than 1 cm × 1 cm. These uncertainties are considered overall uncertainties of type B, henceforth referred to as u_{B_1}. This common choice precludes any bias due to the uncertainties quoted by the authors of the different datasets, here assumed to be identical for all the sets within each modality, experimental or Monte Carlo.
It is emphasized that measurements for the smallest field sizes are always troublesome, mainly due to the alignment of each detector, which justifies the criteria above. Monte Carlo calculations for these fields are in principle not affected by this constraint, although there are other important contributions to their uncertainty (see step (iii)).

(ii) For each detector, the entire set of data for all field sizes (experimental and Monte Carlo) has been fitted with respect to the field size S by a function having the form:

164

4. Uncertainties in Detector Implementation

Example of clinical method to determine correction factors

- Study used the corrected output factors for six detectors from the protocol for determining the correction factor for two new detectors and included an analysis for the uncertainty of measurements
- Largest source of uncertainty was the correction factors from TRS-483
- Study concluded that the approach to calculate correction factors from average of a number of corrected detector measurements resulted in an acceptable level of uncertainty for small field dosimetry

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

4. Uncertainties in Detector Implementation

Quality assurance procedures for output factor measurements

- Study evaluated measurements of different detectors for output factors
- Provide linac specific output factor curves
- Example uncertainty calculations were established for a solid state detector and a small ionization chamber
- Recommend measurement follow-up depending on the spread of the output factors measured with different detectors using linac-type curves

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RESEARCH ARTICLE
MEDICAL PHYSICS

A multi-institutional evaluation of small field output factor determination following the recommendations of IAEA/ AAPM TRS-483

Lechner et. al. Medical Physics 2022, 49 (8) pp5537-5550

4. Uncertainties in Detector Implementation

EVALUATION OF TRS-483 — MEDICAL PHYSICS — 5541

TABLE 3 An example uncertainty budget for the determination of SFOFs using a PTW 60019 microDiamond

Physical quantities or procedure	Type	Relative standard uncertainty		
		0.5 cm x 0.5 cm	1 cm x 1 cm	≥2 cm x 2 cm
Reference field				
Dosimeter reading in ref. field	A	0.1%	0.1%	0.1%
Clinical field				
Dosimeter reading in clinical field	A	0.2%	0.2%	0.2%
Influence quantities in clinical field				
k_{FS}	B	2.3%	0.5%	0.1%
k_{pos}	B	0.4%	0.2%	0.1%
k_{drift}	B	0.3%	0.3%	0.3%
$k_{Q_{clin},Q}^{f_{clin},f_{ref}}$	B	0.8%	0.5%	0.4%
k_{other}	B	0.1%	0.1%	0.1%
Combined standard uncertainty (coverage factor = 1)	**combined**	**2.5%**	**0.9%**	**0.6%**

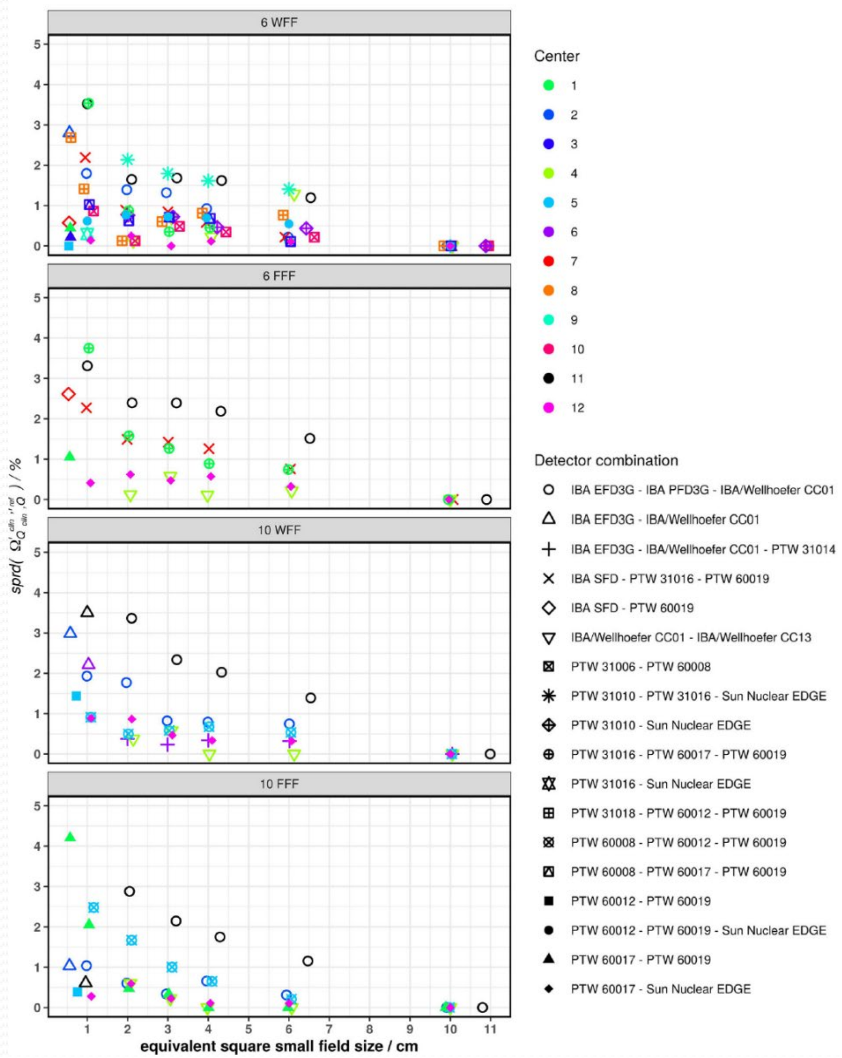
TABLE 4 An example uncertainty budget for the determination of SFOFs using an IBA/Wellhöfer CC01

Physical quantities or procedure	Type	Relative standard uncertainty		
		0.6 cm x 0.6 cm	1 cm x 1 cm	≥2 cm x 2 cm
Reference field				
Dosimeter reading in ref. field	A	0.1%	0.1%	0.1%
Clinical field				
Dosimeter reading in clinical field	A	0.2%	0.2%	0.2%
Influence quantities in clinical field				
k_{FS}	B	2.1%	0.5%	0.1%
k_{pos}	B	0.7%	0.4%	0.1%
k_{drift}	B	0.3%	0.3%	0.3%
$k_{Q_{clin},Q}^{f_{clin},f_{ref}}$	B	2.5%	1.1%	0.4%
k_{other}	B	0.1%	0.1%	0.1%
Combined standard uncertainty (coverage factor = 1)	**combined**	**3.4%**	**1.4%**	**0.6%**

4. Uncertainties in Detector Implementation

Quality assurance procedures for output factor measurements:

- Study spread of OFs measured
- Provide benchmark for uncertainties
- Determine follow-up measurement range
- Uncertainty in S_{clin} measurements



5. Summary

5. Summary

- Considerations for small field detector selection include knowing the detector characteristics, knowing the specific measurement goals, and knowing the small field size range to be measured.
- Correction factors are used to understand the detector magnitude of the detector effect in measuring small field sizes
- New small field detectors continue to evolve to provide smaller measurement volumes and minimize perturbation in the field
- Errors in small field detector implementation can be prevented with understanding the principles of small field dosimetry
- Some uncertainty is inherent in small field measurements due to the complexity of small field dosimetry
- The choice of detector and its implementation can affect the level of uncertainty