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Small field dosimetry on linear accelerators: TRS-483 Code of Practice

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1. Background

2. Basic physics of small fields

3. TRS-483 CoP: concepts and formalism

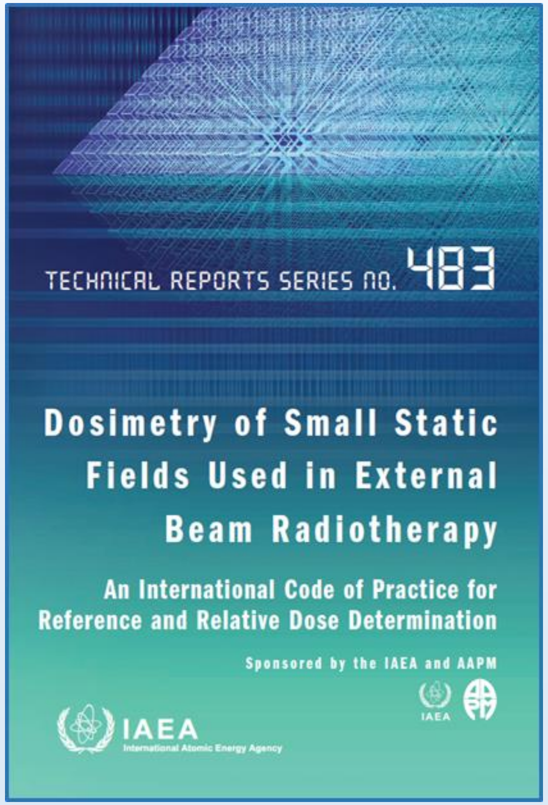
4. Detector specific output correction factors

5. On the orientation of the ionization chambers

6. Acknowledgments

Background

- Rapid development of **modern technologies** has facilitated the use of advanced radiotherapy techniques such as IMRT, SRS, SBRT, VMAT.
- Modern RT techniques use **single or multiple/composite small (narrow) fields** (< 4 cm)
- Dosimetry protocols designed for broad beams (TRS-398, TG 51, …) are not suitable for small beam dosimetry and do **not provide guidance** for dosimetry in small fields
- Misunderstanding of this limitations and absence of suitable dosimetry protocol for small fields resulted in the occurrence of **dosimetric errors and several clinical accidents**



TECHNICAL REPORTS SERIES NO. 483

Dosimetry of Small Static Fields Used in External Beam Radiotherapy

An International Code of Practice for Reference and Relative Dose Determination

Sponsored by the IAEA and AAPM

IAEA
International Atomic Energy Agency

IAEA TRS – 483 Code of Practice for small field dosimetry (2017)

… however, issues pointed out in the TRS-483

- *"… there is a large amount of experimental and Monte Carlo calculated data available for specific output correction factors,* $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ *, particularly for certain solid state detectors and ionization chambers on the central axis of* ***6 MV beams****."*
- *"Unfortunately, the published data are* ***rather scattered for certain field sizes****, especially for the smallest fields, and* ***lack homogeneity*** *with regard to the SSD or SDD used, the depth of measurement or calculation, the* ***definition of field size*** *at the surface or at a reference depth, etc."*
- *"To further complicate the determination of average values for the different detectors and their subsequent statistical analysis, most of the published data* ***lack a proper estimation of the uncertainty*** *in the various steps involved in the determination of the correction factors given by different authors."*

H. Palmans, P. Andreo, M. S. Huq, J. Seuntjens and K. Christaki. Dosimetry of small static fields used in external beam radiotherapy: An IAEA-AAPM international Code of Practice for reference and relative dose determination. IAEA Technical Report Series No. 483. International Atomic Energy Agency, Vienna, 2017.

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Small field conditions

At least one of the **three** physical conditions will be fulfilled for an external photon beam to be designated a small as defined in new dosimetry protocol for small static beams IAEA/AAPM TRS-483 CoP

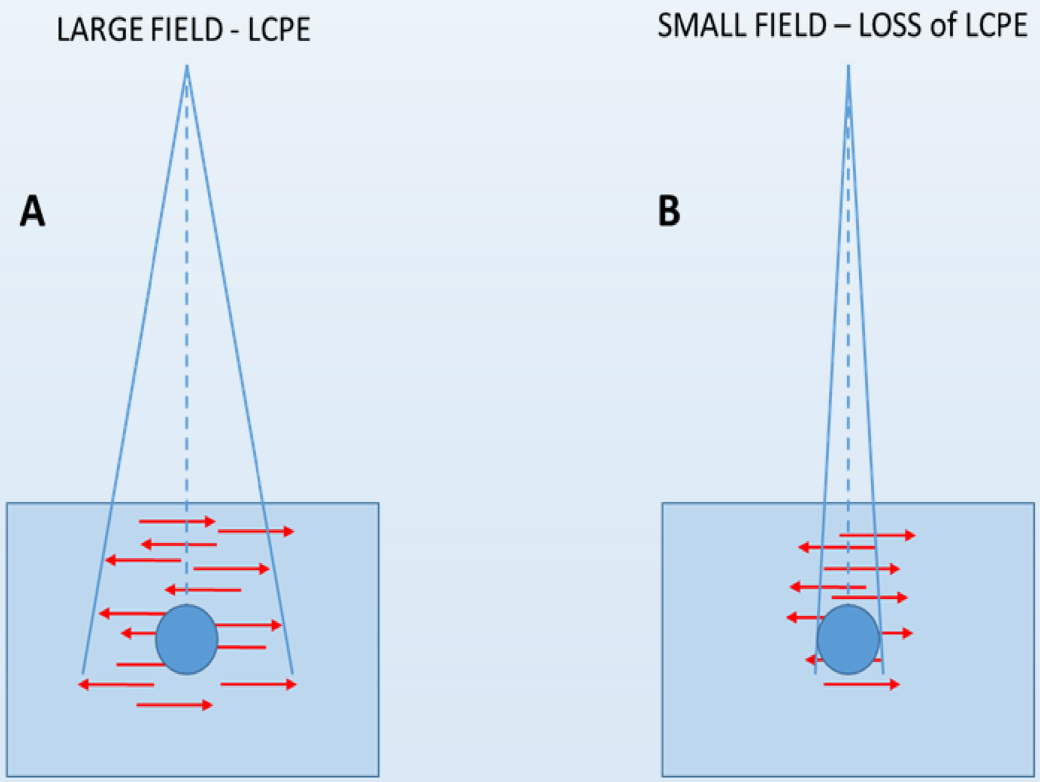
Beam related small field conditions

1. There is a **loss of lateral charged particle equilibrium (LCPE)** on the beam axis
2. There is **partial occlusion (geometrical shielding) of the primary photon source** by the collimating devices (MLC, jaws) as seen from the point of measurement - on the beam axis

Detector related small field condition

3. The **size of the detector** is similar or large compared to the beam dimensions

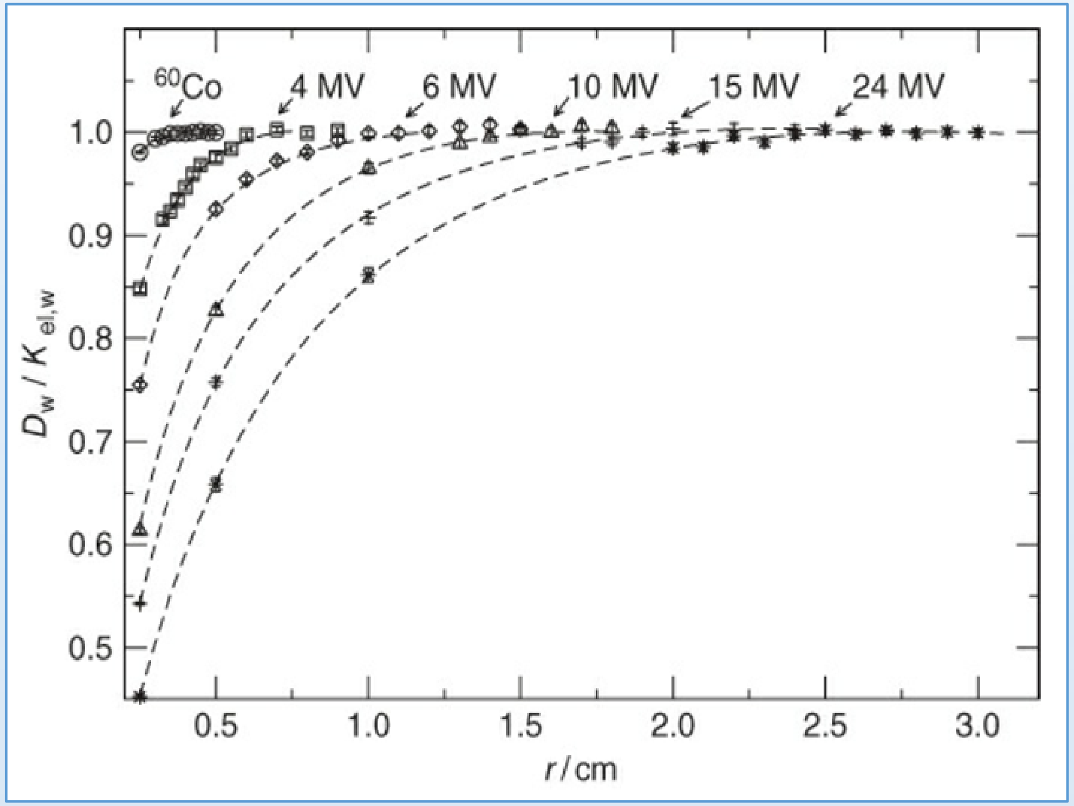
1.1. Loss of LCPE on the beam axis



- LCPE - the number of charged particles exiting the sensitive volume (cavity) of the detector - ***"out-scattering"*** - is equal to the number of charged particles entering the sensitive volume (cavity) of the detector – ***"in-scattering"***

- Loss of LCPE - out-scatter from the beam **is not compensated** by the in-scatter

1.2. LCPE and equivalency of D_w and $K_{col,w}$



- Water collision kerma $K_{col,w}$ is equal to the absorbed dose to water D_w as long as CPE exists

- The minimum half width (radius) of the beam at which $\boldsymbol{K_{col,w} = D_w}$ still holds is defined as the *lateral charged particle equilibrium range* $\boldsymbol{r_{LCPE}[cm]}$

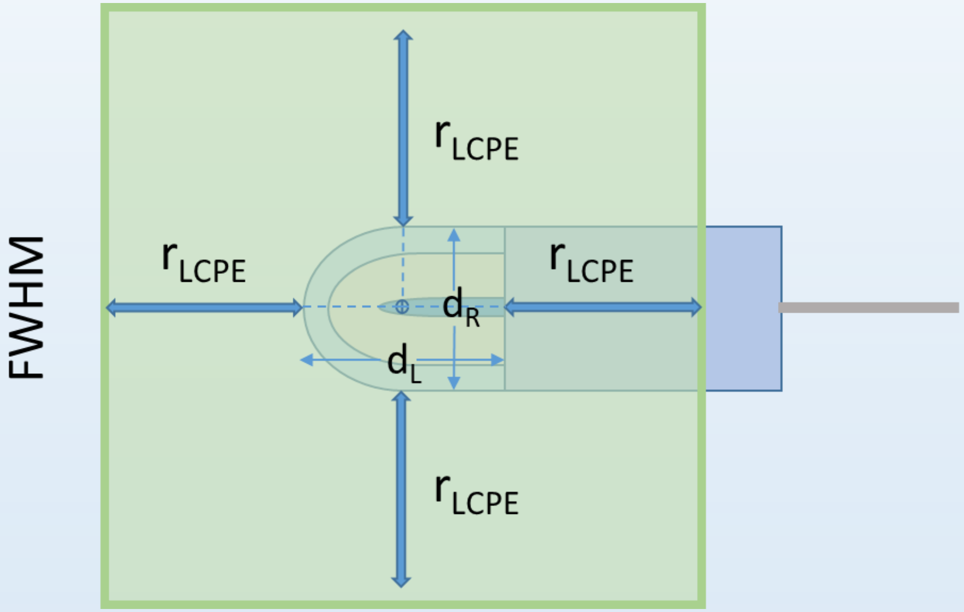
1.3. Lateral charged particle equilibrium range

The first condition defining small fields is a size parameter ***r_{LCPE}*,** which is a measure of the range of laterally scattered electrons

$$r_{LCPE}[cm] = 8.369 \cdot TPR_{20,10} - 4.382$$

LCPE exists when radiation field extends at least a distance r_{LCPE} beyond the outer boundaries of the ionization chamber

$$FWHM \geq 2r_{LCPE} + d$$

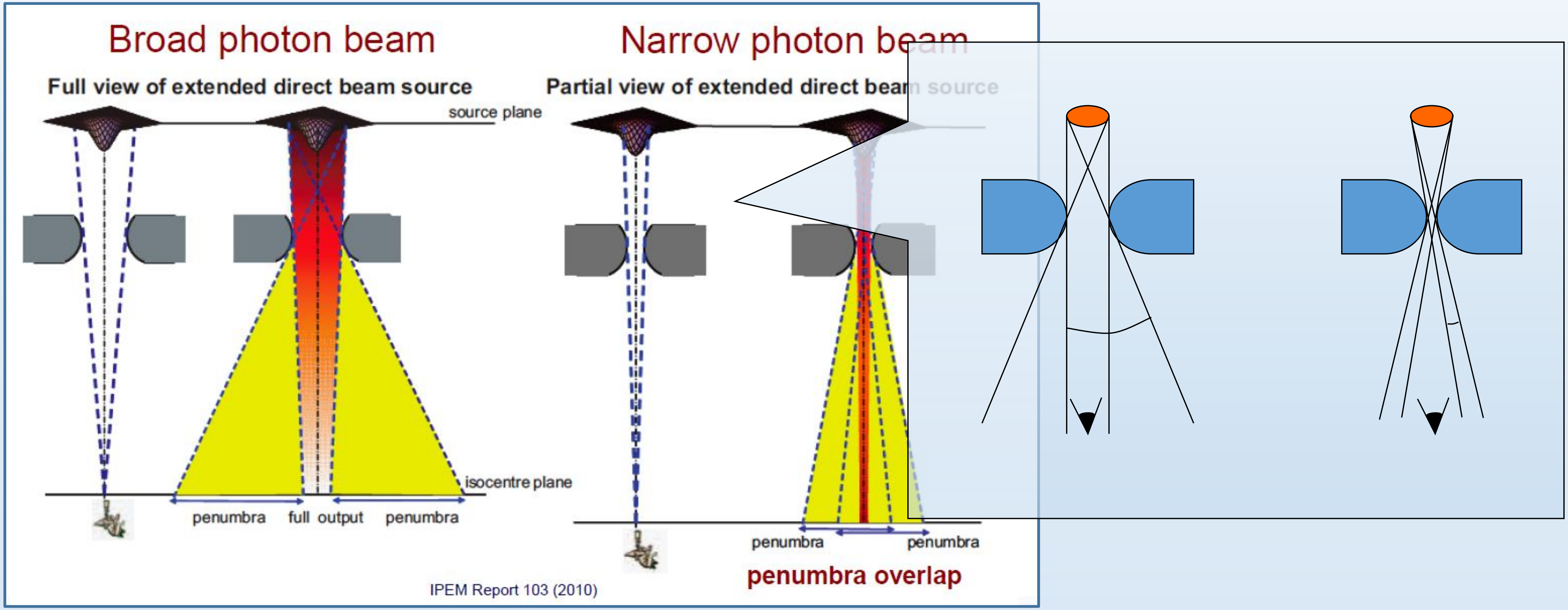


6 MV photons: $r_{LCPE} \approx 1.2$ cm

X.A. Li, M. Soubra, J. Szanto and L.H. Gerig. Lateral electron equilibrium and electron contamination in measurements of head-scatter factors using miniphantoms and brass caps. Medical Physics, 1995, 22, 1167-70.

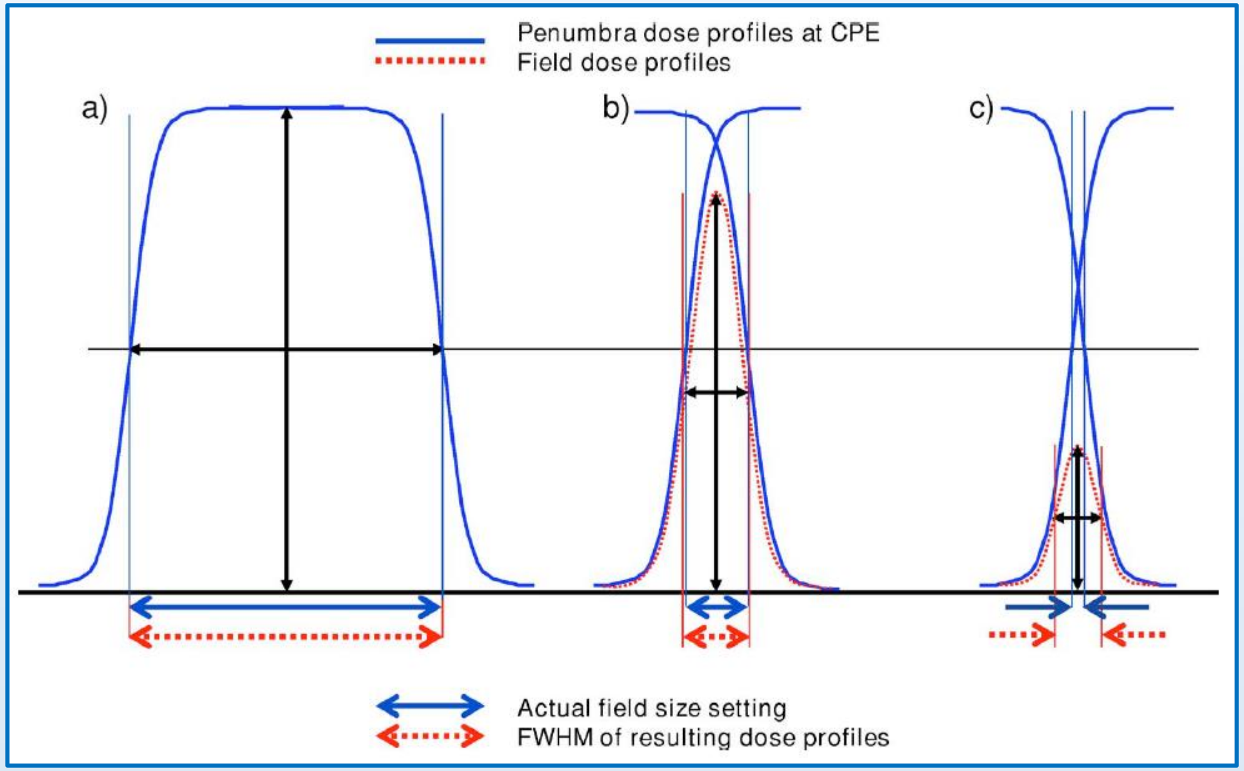
P. Papaconstadopoulos. On the detector response and the reconstruction pf the source intensity distribution in small photon fields. PhD Thesis, 2016, McGill University, Montreal, Canada.

2.1 Partial source occlusion



IPEM Report 103 (2010)

2.2. Partial source occlusion



a) Large field sizes: LCPE exists, source fully viewed;
FWHM = nominal field size

a) Field sizes of the same order as the charge particle diffusion distance;
FWHM ≥ nominal field size
output lowered

a) Small fields: LCPE does not exist, radiation source partially hidden by the collimators;
FWHM > nominal field size
output further lowered

Figure from I. J. Das, G. X. Ding, and A. Ahnesjö. Small fields: Non-equilibrium radiation dosimetry. *Med. Phys.*, 35:206-215, 2008.

3.1 Volume averaging

- Any detector will average the dose across its sensitive volume if not infinitesimally small.
- This averaging can yield to a different signal compared to the signal which would be measured by an infinitesimally small detector.

↓

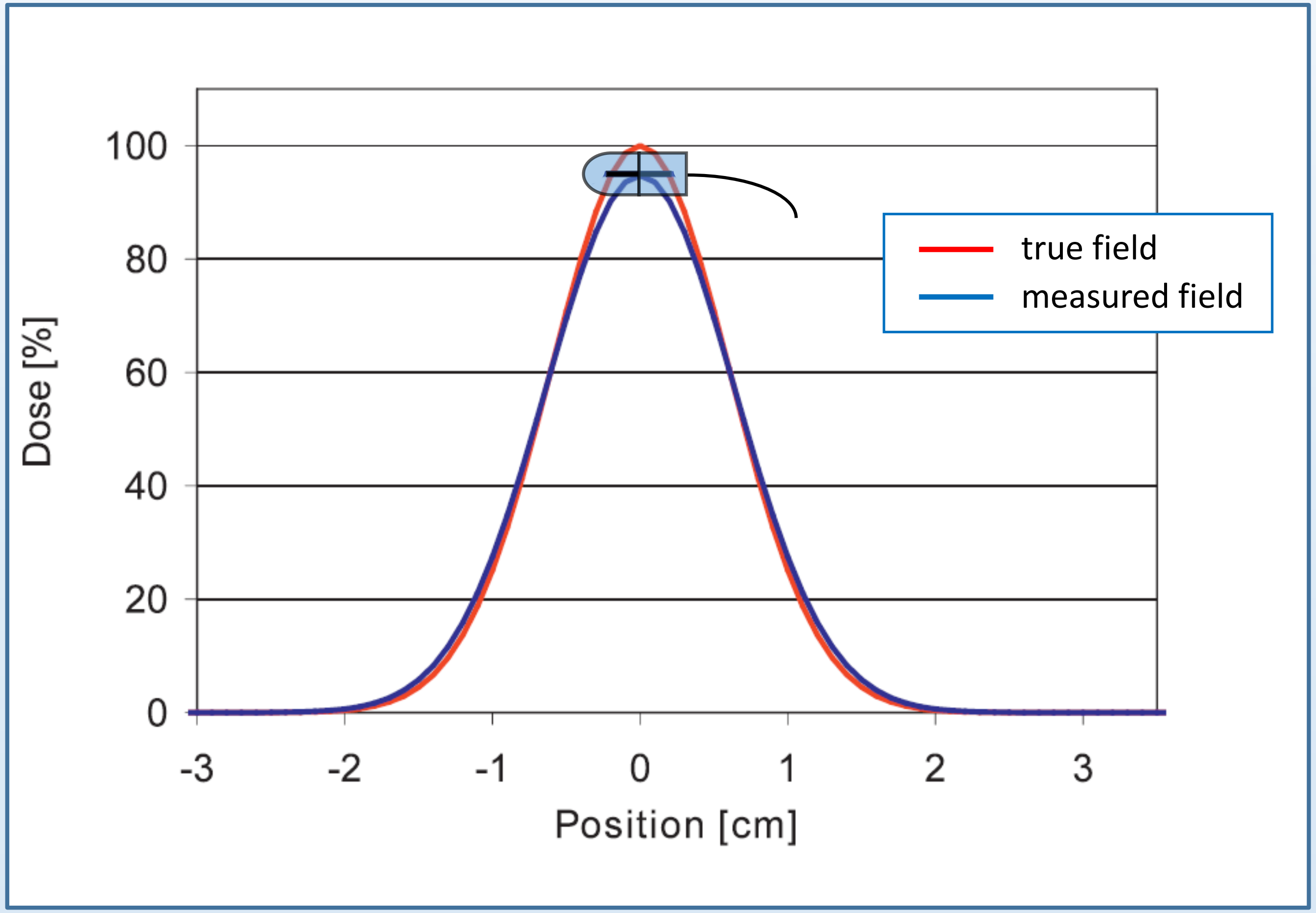
VOLUME AVERAGING EFFECT

↓

- Dose underestimation when measuring output factors in small fields
- Broadening of the penumbra in beam profile measurements

!

3.2. Volume averaging



- The size of ionization chamber in 1.5 x 1.5 cm^2 photon field of approximately Gaussian shape.
- IC is too big for accurate measurements in that field
- Signal (collected charge) will be averaged across its sensitive volume → **volume averaging** → **lower dose**
- Blue curve is the result after averaging: **the CAX dose is underestimated, and the penumbra is broadened**

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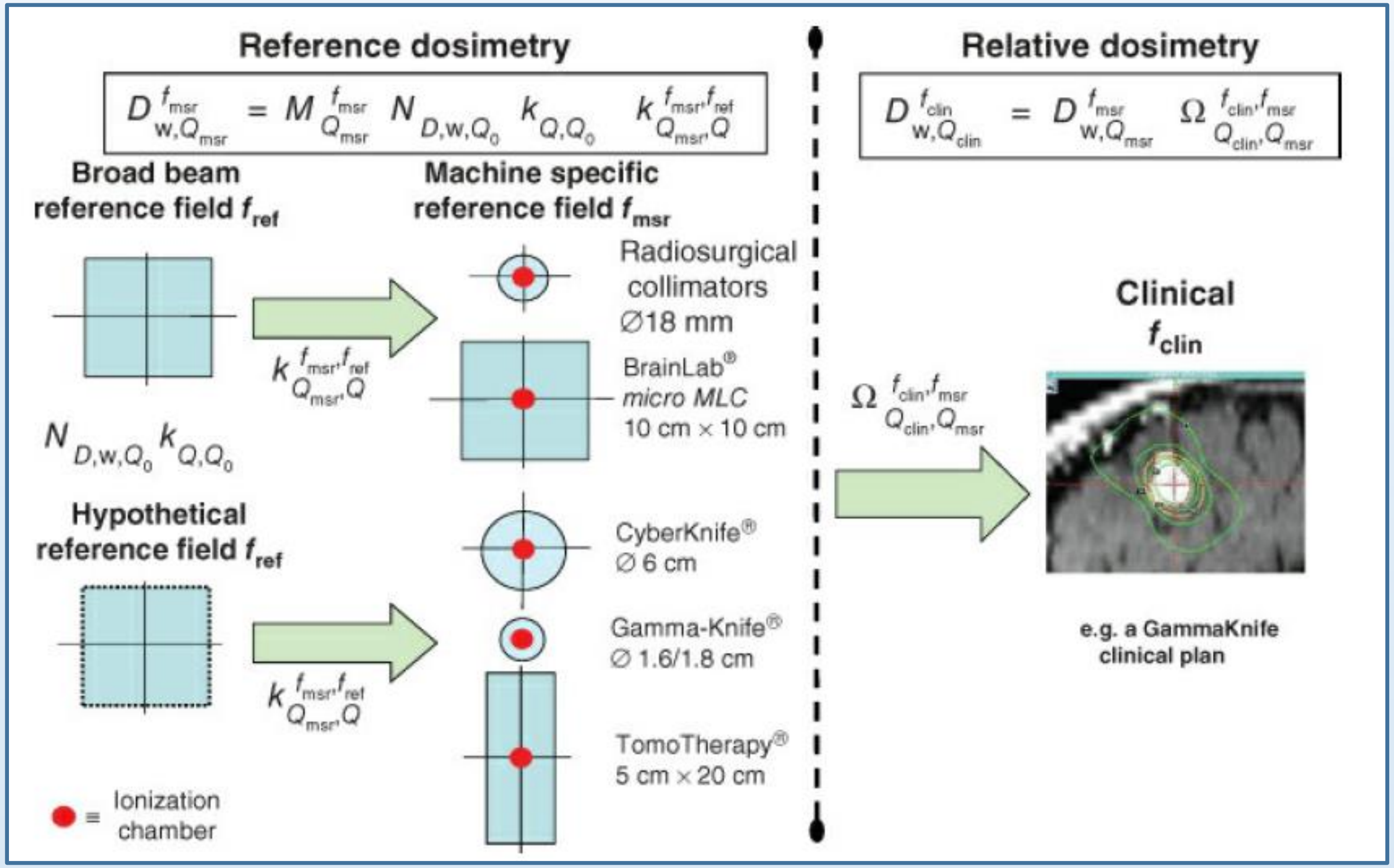
TRS-483 content

- The IAEA TRS-483 CoP (collaboration of IAEA and AAPM) provides **guidelines for reference and relative dosimetry in small static fields used in radiotherapy**.

- In addition to the recommendation on the characteristics of detectors suitable for reference and relative dosimetry, as well as on required measurement conditions, TRS-483 presents **a dosimetry formalism based on the work of Alfonso et al. (slightly modified).**

- In particular, TRS-483 provides the guidance for the determination of **field output factors** and **detector specific output correction factors** in small fields which were two key elements in our work.

TRS-483 formalism: Alfonso et al.



R. Alfonso, P. Andreo, R. Capote, M. S. Huq, W. Kilby, P. Kjall, T. R. Mackie, H. Palmans, K. Rosser, J. Seuntjens, W. Ullrich, and S. Vatnitsky. A new formalism for reference dosimetry of small and nonstandard fields. *Med. Phys.*,35:5179-5186, **2008.**

Concepts of small fields

- The field size is the **pair of dimensions** (in the case of rectangular fields) or the **diameter** (in the case of a circular field) that define(s) the area of the field at the measurement distance.

- Each dimension is defined by the **FWHM** of the lateral beam profile measured at a depth sufficient to eliminate the contribution of contamination electrons - depth of 10 cm in water with the detector's reference point at the isocentre is advised.

- It is advised to record the collimator settings as a **nominal** identification for practical purposes.

WHY?

- the treatment planning system (TPS) and the record and verify (R&V) system use the nominal field setting rather than the FWHM relative to which the profile data, patient treatment plan and radiation delivery are referenced. This guidance is analogous to that of stating the nominal accelerating potential (MV) to refer in practice to a beam with a certain quality index *Q*.

TRS-483 definitions for fields

The formalism for reference dosimetry in the TRS-483 is the same to that recommended by Alfonso et al.[8] with some minor modifications. Several important definitions for field sizes were introduced in the new formalism:

- f_{ref} – **conventional reference field 10 cm × 10 cm** used for calibrations at the standard laboratory and for clinical reference dosimetry for radiotherapy machines where such field can be established in reference conditions i.e., SAD = 100 cm and 10 cm depth
- f_{msr} – **machine specific reference field** for radiotherapy treatment units **where conventional reference field 10 cm × 10 cm cannot be established** e.g., GammaKnife, Tomotherapy, and CyberKnife. The ***msr*** field is usually the largest achievable field as close as possible to the size of the conventional reference field
- f_{clin} – **clinical small radiation field** at which we need to determine the absorbed dose to water

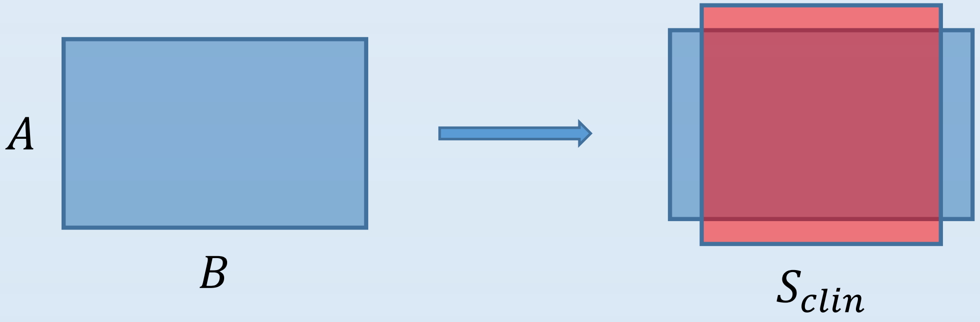
Equivalent square small field size - *rectangular*

For rectangular small fields with uneven in-plane and cross-plane dosimetric field widths defined as the FWHM, the **equivalent square small field size or clinical field size $\boldsymbol{S_{clin}}$** (or also $\boldsymbol{f_{clin}}$) s given as

$$\boxed{S_{clin} = \sqrt{A \cdot B}}$$

where A corresponds to the radiation field width (FWHM) in in-line direction y and B (FWHM) for cross-line direction x perpendicular to the former

Condition for the applicability of the equation for S_{clin} : $0.7 < A/B < 1.4$



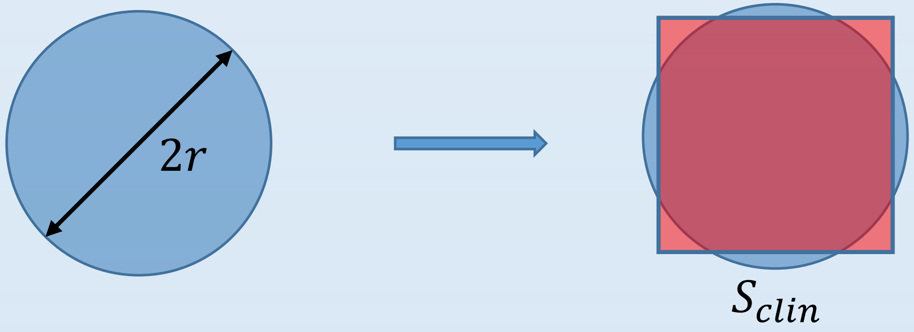
GEOMETRICAL EQUIVALENCY

Equivalent square small field size - *circular*

For **circular** small fields with dosimetric field widths defined as the FWHM, the **equivalent square small field size or clinical field size S_{clin}** is given as

$$\boxed{S_{clin} = r \cdot \sqrt{\pi} \approx 1.77 \cdot r}$$

where r to the radius of the circular field, defined by the points where, on average, the dose level amounts to 50% of the maximum dose at themeasurement depth



GEOMETRICAL EQUIVALENCY

Detectors for relative dosimetry

- Assumption: a detector used for dosimetry in large fields will not perform well in small fields.
- Although the air filled ionization chamber is the most commonly used detector in relative dosimetry, there will always be a field size below which volume averaging becomes unacceptably high.
- Below certain field size only ion liquid chambers and solid state detectors are suitable for small field dosimetry. However, even those can exhibit substantial perturbations for the smallest fields.

Detectors for relative dosimetry:

- Air filled ionization chambers
- Liquid ionization chambers
- Silicon diodes
- Diamond detectors
- Plastic and organic scintillators
- Radiographic films
- Radiochromic films
- Thermoluminiscent dosimeters (TLD)
- ALANINE detectors
- ….

No single detector stands out as having characteristics close to the ideal ones!

Characteristics of detectors for relative dosimetry

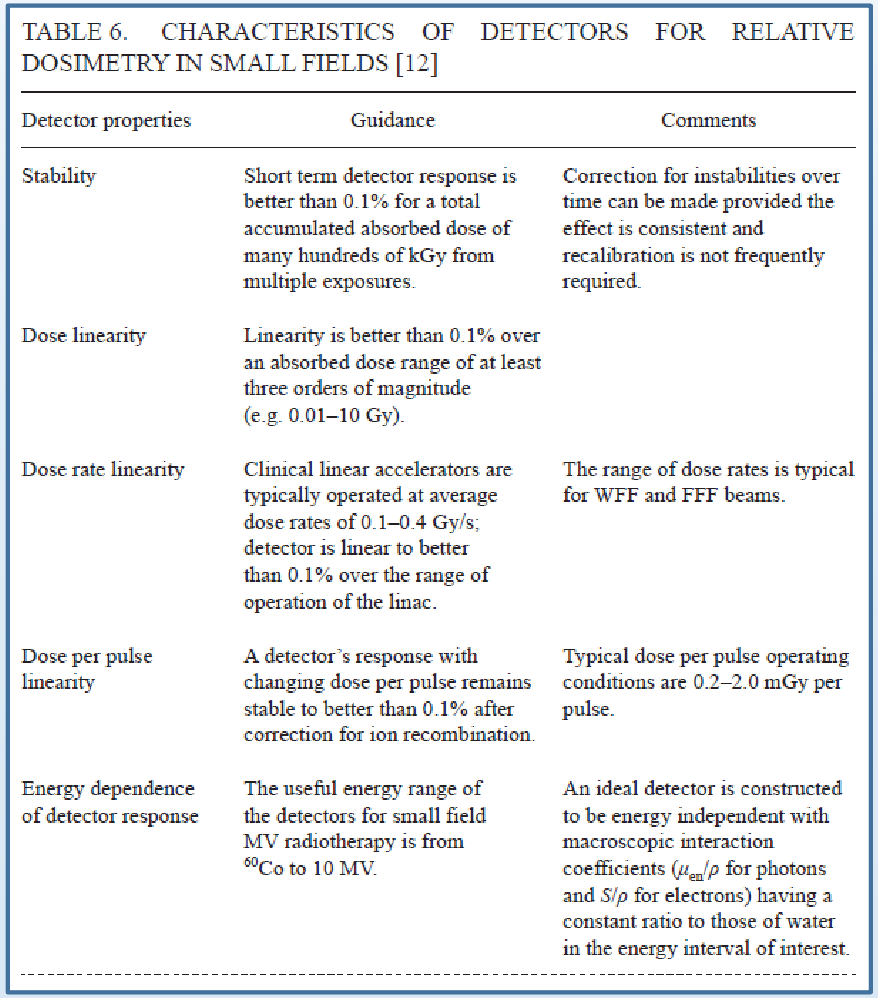


TABLE 6. CHARACTERISTICS OF DETECTORS FOR RELATIVE DOSIMETRY IN SMALL FIELDS [12]

Detector properties	Guidance	Comments
Stability	Short term detector response is better than 0.1% for a total accumulated absorbed dose of many hundreds of kGy from multiple exposures.	Correction for instabilities over time can be made provided the effect is consistent and recalibration is not frequently required.
Dose linearity	Linearity is better than 0.1% over an absorbed dose range of at least three orders of magnitude (e.g. 0.01–10 Gy).	
Dose rate linearity	Clinical linear accelerators are typically operated at average dose rates of 0.1–0.4 Gy/s; detector is linear to better than 0.1% over the range of operation of the linac.	The range of dose rates is typical for WFF and FFF beams.
Dose per pulse linearity	A detector's response with changing dose per pulse remains stable to better than 0.1% after correction for ion recombination.	Typical dose per pulse operating conditions are 0.2–2.0 mGy per pulse.
Energy dependence of detector response	The useful energy range of the detectors for small field MV radiotherapy is from ^{60}Co to 10 MV.	An ideal detector is constructed to be energy independent with macroscopic interaction coefficients (μ_{en}/ρ for photons and S/ρ for electrons) having a constant ratio to those of water in the energy interval of interest.

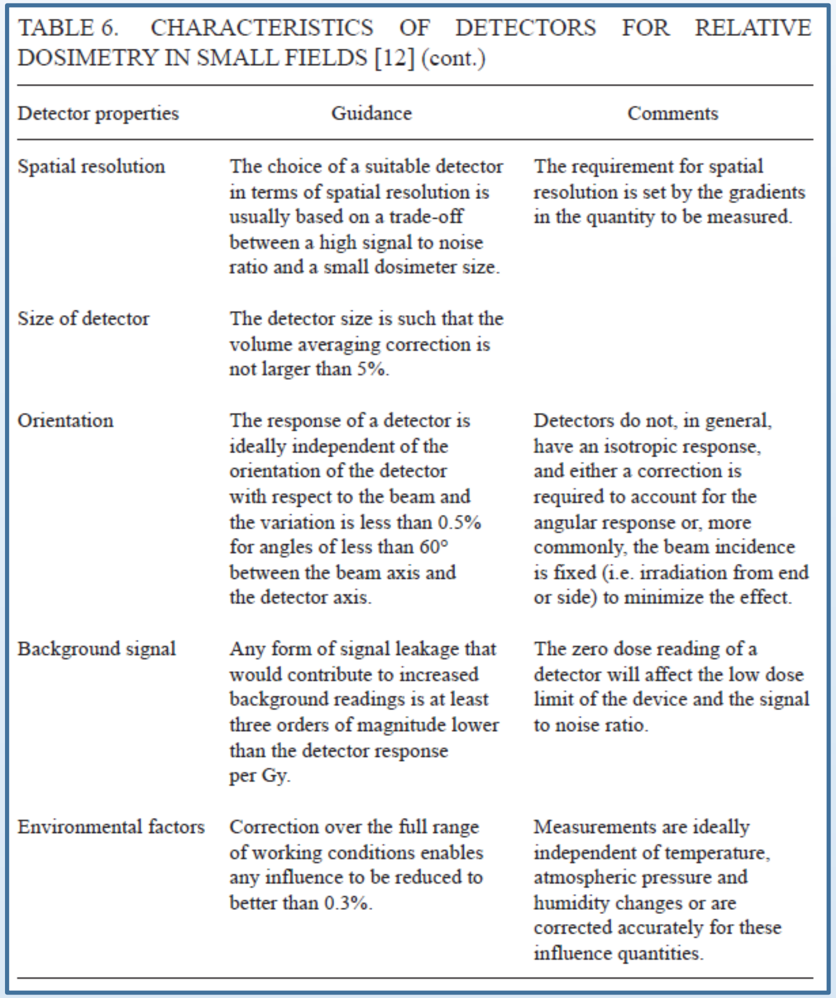


TABLE 6. CHARACTERISTICS OF DETECTORS FOR RELATIVE DOSIMETRY IN SMALL FIELDS [12] (cont.)

Detector properties	Guidance	Comments
Spatial resolution	The choice of a suitable detector in terms of spatial resolution is usually based on a trade-off between a high signal to noise ratio and a small dosimeter size.	The requirement for spatial resolution is set by the gradients in the quantity to be measured.
Size of detector	The detector size is such that the volume averaging correction is not larger than 5%.	
Orientation	The response of a detector is ideally independent of the orientation of the detector with respect to the beam and the variation is less than 0.5% for angles of less than 60° between the beam axis and the detector axis.	Detectors do not, in general, have an isotropic response, and either a correction is required to account for the angular response or, more commonly, the beam incidence is fixed (i.e. irradiation from end or side) to minimize the effect.
Background signal	Any form of signal leakage that would contribute to increased background readings is at least three orders of magnitude lower than the detector response per Gy.	The zero dose reading of a detector will affect the low dose limit of the device and the signal to noise ratio.
Environmental factors	Correction over the full range of working conditions enables any influence to be reduced to better than 0.3%.	Measurements are ideally independent of temperature, atmospheric pressure and humidity changes or are corrected accurately for these influence quantities.

From TRS-483

Requirements for detectors

Detector choice for small field dosimetry can be made considering three main rules:

- The detector has a **small active volume** to minimize volume averaging effect. In the ideal case, the detector should sample the fluence at a point.
- The detector is **water equivalent**, i.e., it is constructed of materials which minimize perturbation effects.
- The detector has a **linear response which is energy independent** or with clearly known energy dependence

Detectors for measuring FOF

- There is no ideal detector for measurements of field output factors in small fields.
- The use of two or preferably three different types of suitable detectors is advised.
- A combination of detectors with correction factors above and below unity is advise, so that the product of these factors is close to one.
- TRS-483 recommends:

  - small air filled ionization chamber, radiochromic film and an unshielded diode

  or

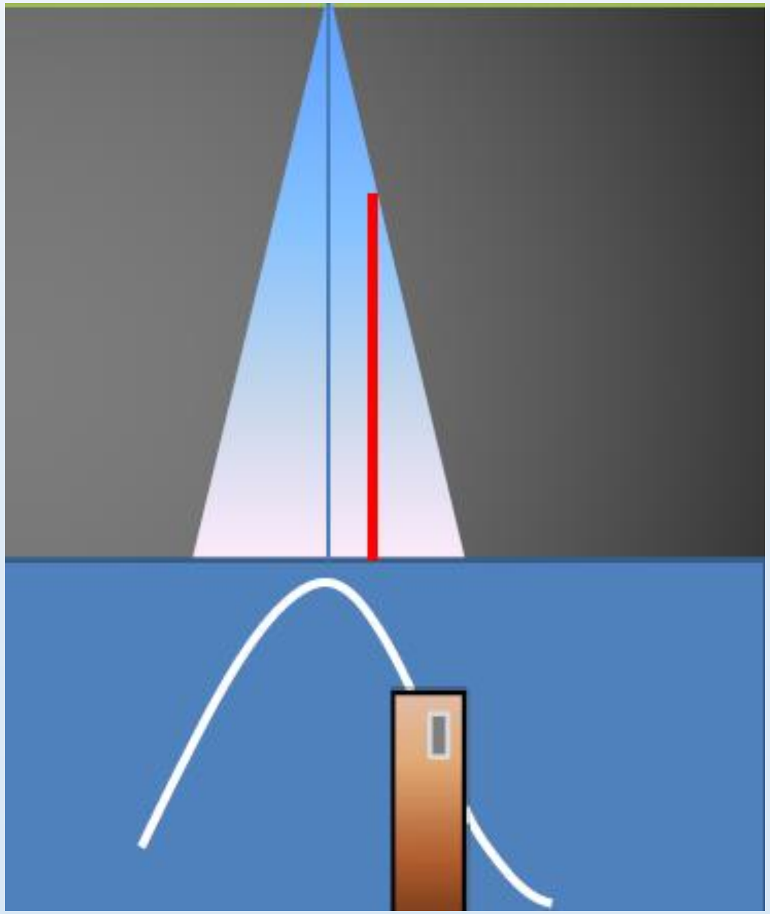
  - diamond detector, liquid ion chamber and an organic scintillator

Detector set-up

- QC on alignment of collimators.
- Accurate set-up of the detector in a 3D full scatter water phantom is required (for waterproof detectors).
- Detector orientation with respect to the beam axis (main axis perpendicular or parallel to the beam axis).
- Placement of the detector's reference point at the reference depth.
- Detector alignment with beam central axis.
- Set-up of SSD or SAD

  - the measurement of FOF and lateral beam profiles is performed at the same SSD or SAD as was used for reference dosimetry

Lateral alignment of detector with central axis of the beam



- For every setup crossline and inline scans (profiles) have to be acquired. ODI and lasers are not accurate enough.
- "True" centre of radiation field is determined on beam axis as a midpoint between two 50% signal values (FWHM).
- Even small misalignment of the detector can result in substantial changes of the absorbed dose to water at the centre of the field, leading to the underestimation of the profile maximum

$$M_{eff}(x,y) < M_c \text{ (center: } x=0, y=0)$$

Detector orientation – beam profiles and FOF

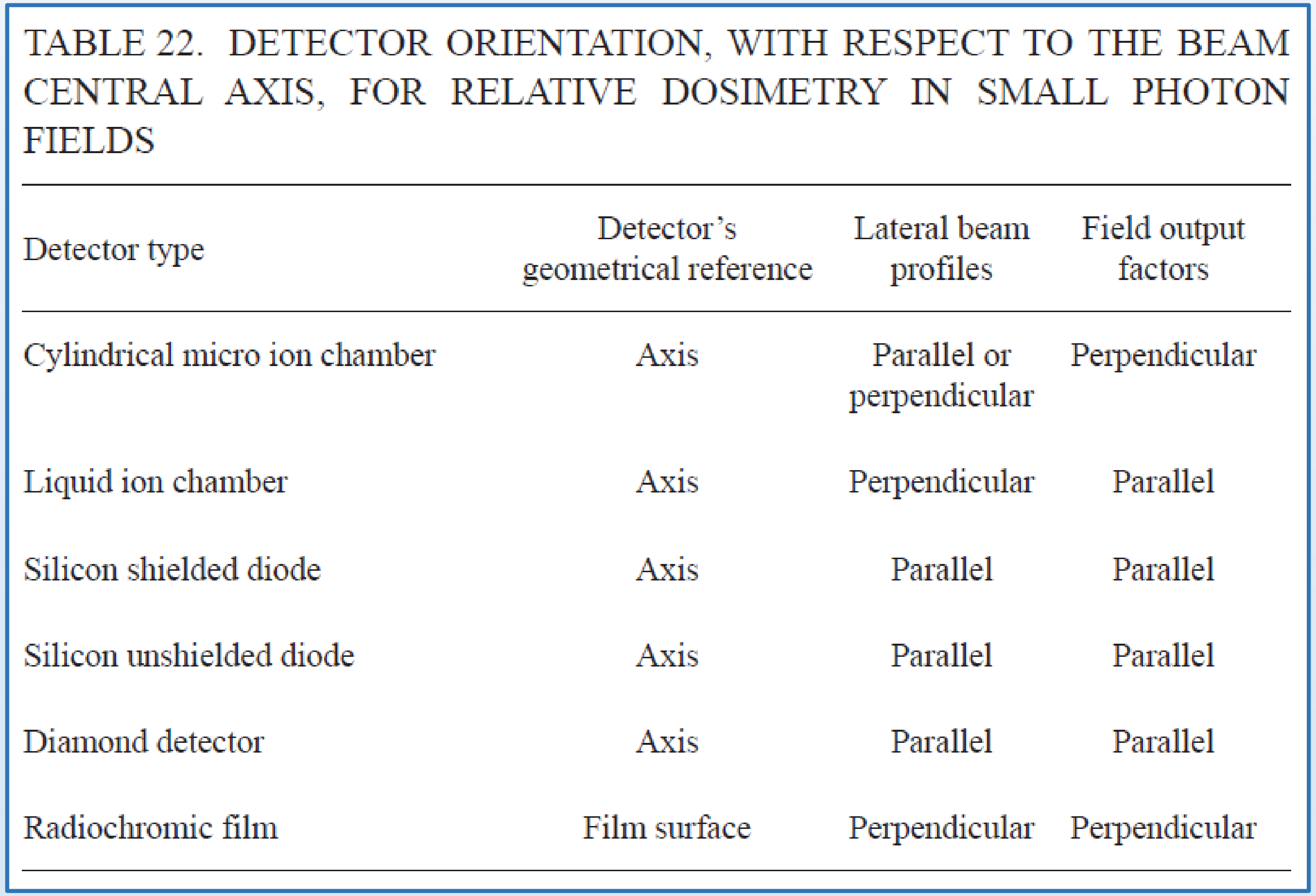
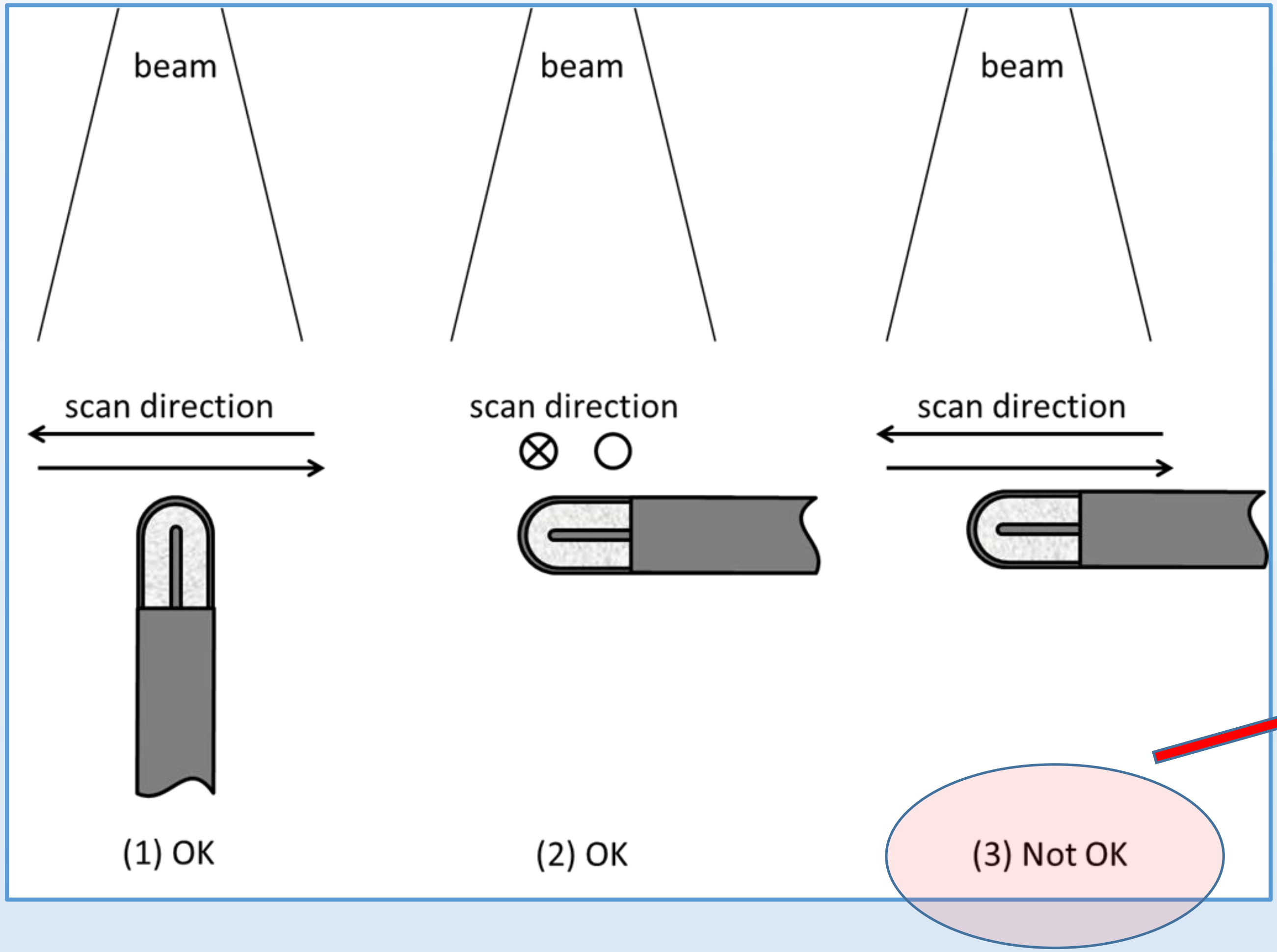


TABLE 22. DETECTOR ORIENTATION, WITH RESPECT TO THE BEAM CENTRAL AXIS, FOR RELATIVE DOSIMETRY IN SMALL PHOTON FIELDS

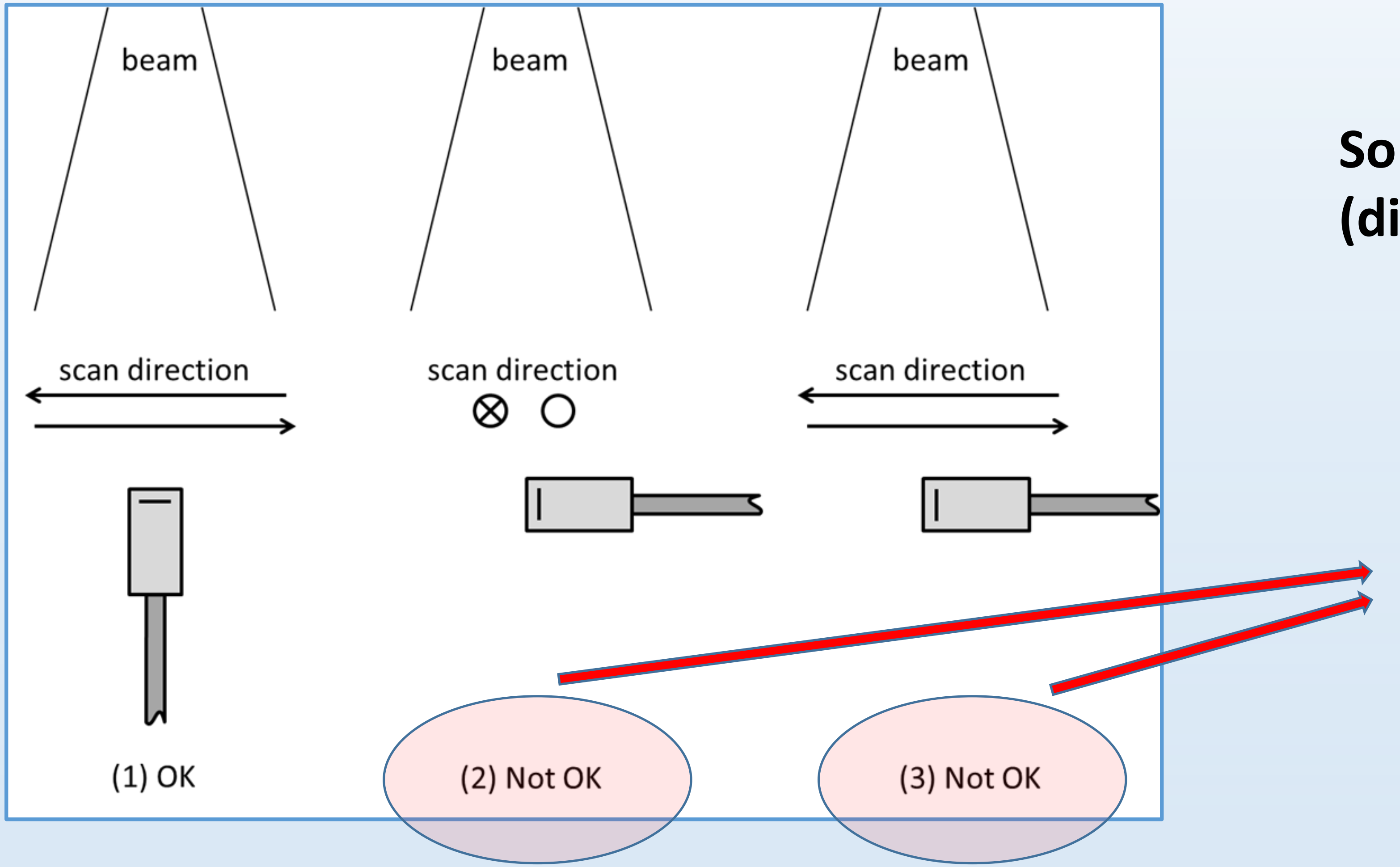
Detector type	Detector's geometrical reference	Lateral beam profiles	Field output factors
Cylindrical micro ion chamber	Axis	Parallel or perpendicular	Perpendicular
Liquid ion chamber	Axis	Perpendicular	Parallel
Silicon shielded diode	Axis	Parallel	Parallel
Silicon unshielded diode	Axis	Parallel	Parallel
Diamond detector	Axis	Parallel	Parallel
Radiochromic film	Film surface	Perpendicular	Perpendicular

Detector orientation for lateral beam profiles



Thimble (cylindrical) ionization chambers

Detector orientation for lateral beam profiles



Solid state detectors (diodes, diamonds)

TRS-483 formalism

Relative dosimetry of large fields (TRS-398 and TG 51): **output factors OF (RDF)**

$$\boxed{OF = \frac{D_{w,Q_{clin}}^{f_{clin}}}{D_{w,Q_{ref}}^{f_{ref}}} \approx \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{ref}}^{f_{ref}}}}$$

Relative dosimetry of small fields (TRS-483): **field output factors $\Omega_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$**

$$\boxed{\Omega_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}} = \frac{D_{w,Q_{clin}}^{f_{clin}}}{D_{w,Q_{ref}}^{f_{ref}}} \neq \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{ref}}^{f_{ref}}}} \xrightarrow{k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}} \boxed{\Omega_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}} = \frac{D_{w,Q_{clin}}^{f_{clin}}}{D_{w,Q_{ref}}^{f_{ref}}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{ref}}^{f_{ref}}} \cdot \boxed{k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}}}$$

Necessary introduction of ***detector specific field output correction factor*** $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$, which converts detector readings ratio into a true dose ratio.

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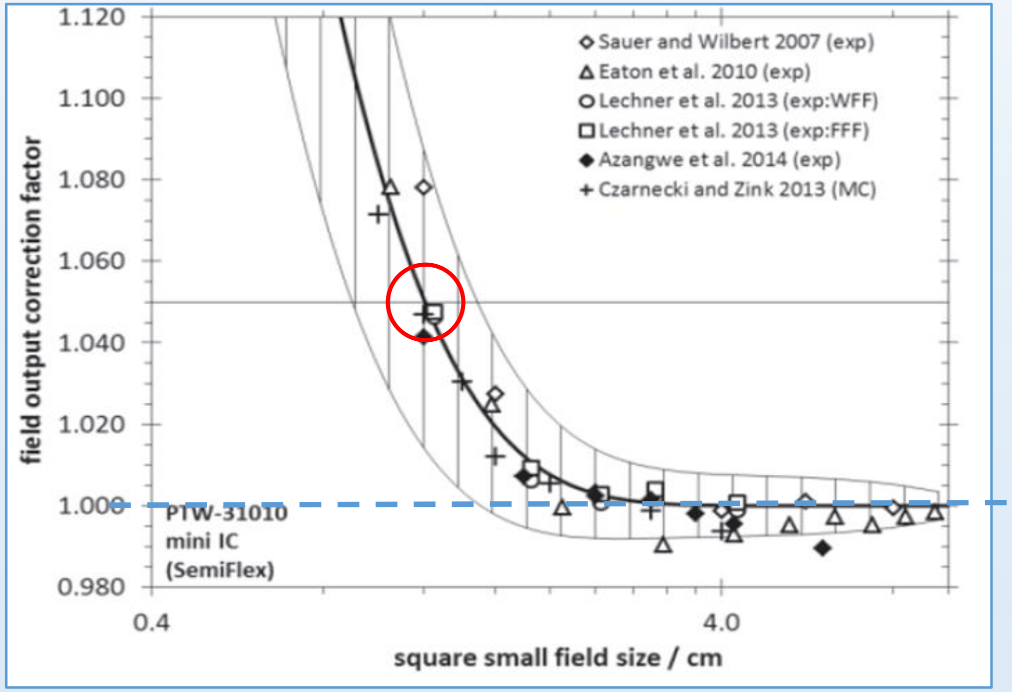
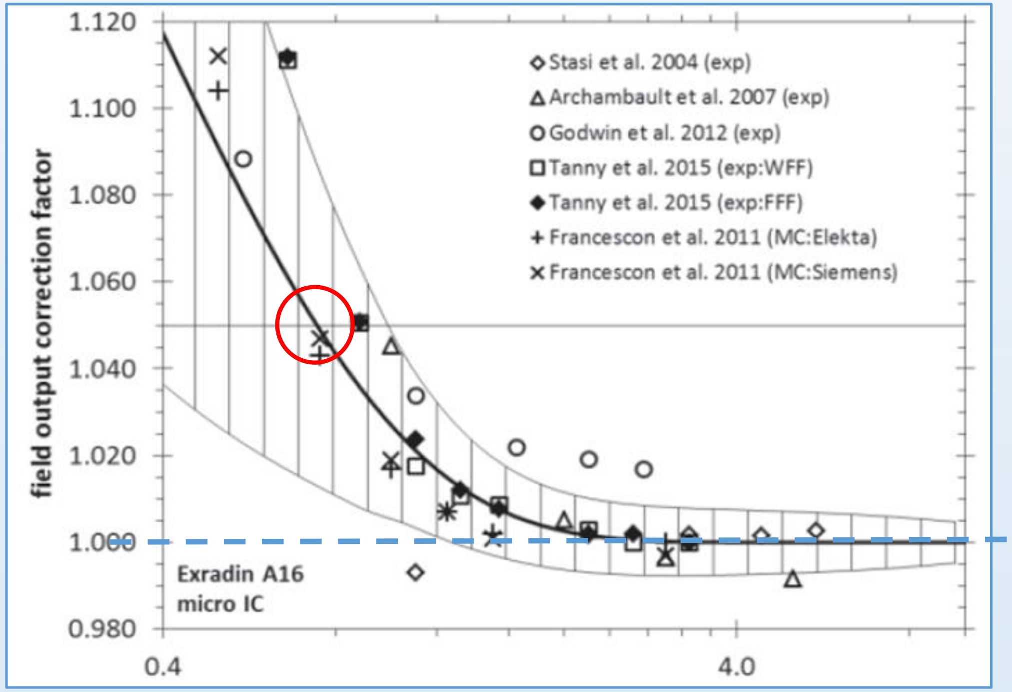
$k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ data for ionization chambers





Under-response for very small fields

$$\boxed{k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}} > 1}$$

ALWAYS!

6 MV LINAC

LINAC

Under-response for very small fields

$$\boxed{k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}} > 1}$$

ALWAYS!

$k^{f_{clin},f_{ref}}_{Q_{clin},Q_{ref}}$ data for ionization chambers

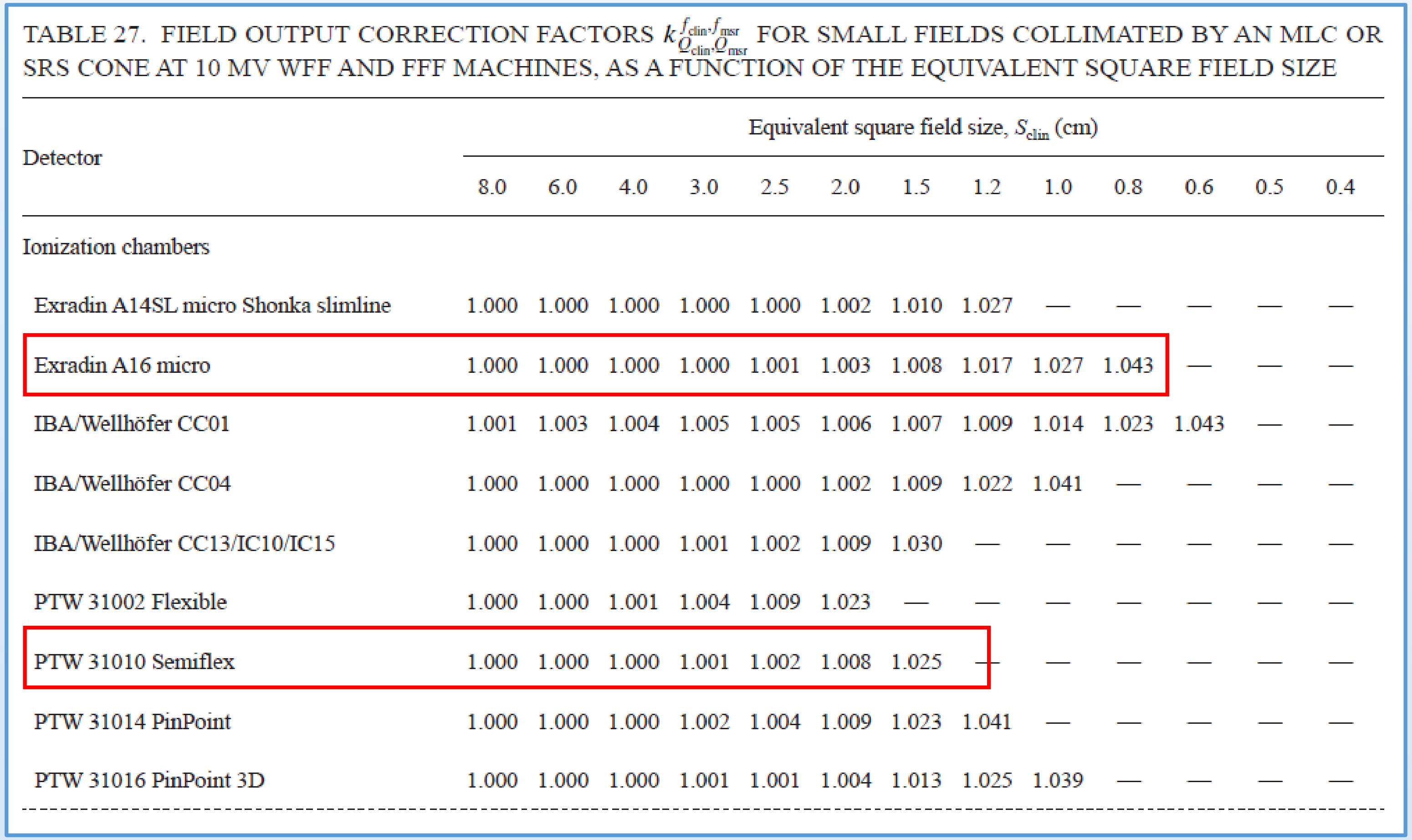
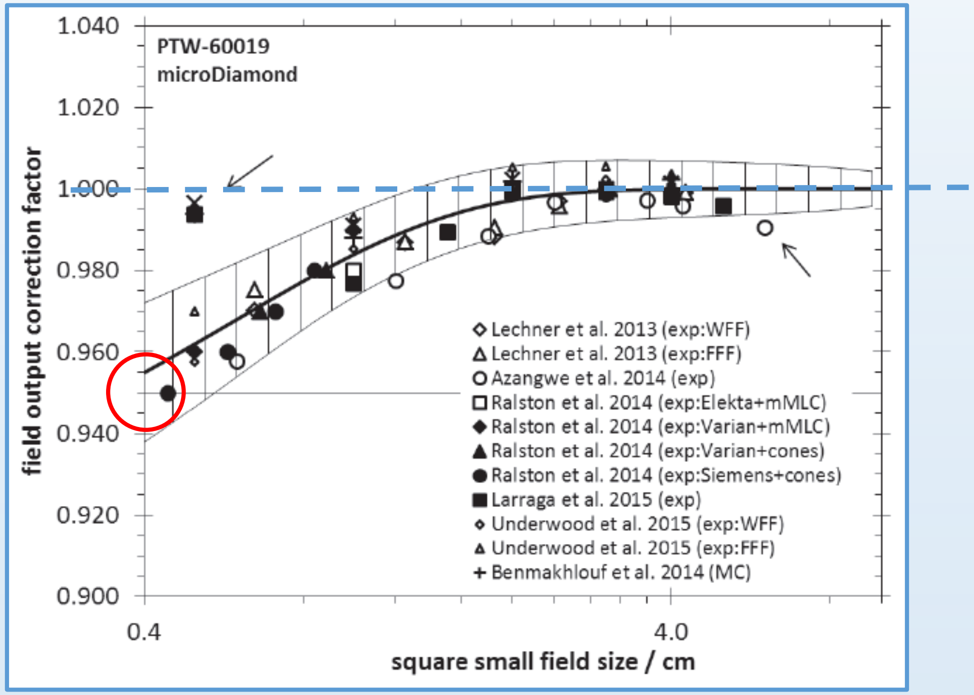
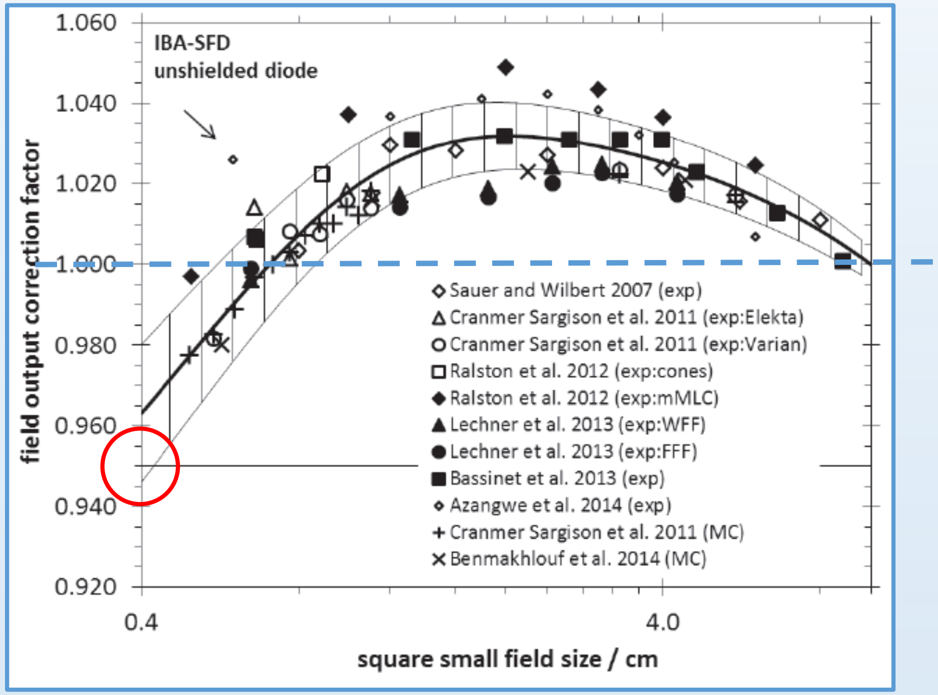


TABLE 27. FIELD OUTPUT CORRECTION FACTORS $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ FOR SMALL FIELDS COLLIMATED BY AN MLC OR SRS CONE AT 10 MV WFF AND FFF MACHINES, AS A FUNCTION OF THE EQUIVALENT SQUARE FIELD SIZE

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	1.001	1.003	1.004	1.005	1.005	1.006	1.007	1.009	1.014	1.023	1.043	—	—
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	—	—	—	—

$k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ data for solid state detectors





Over-response for very small fields

$$\boxed{k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}} < 1}$$

ALWAYS!

6 MV BEAM LINAC

Over-response for very small fields

$$\boxed{k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}} < 1}$$

NOT ALWAYS!

$k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ data for solid state detectors

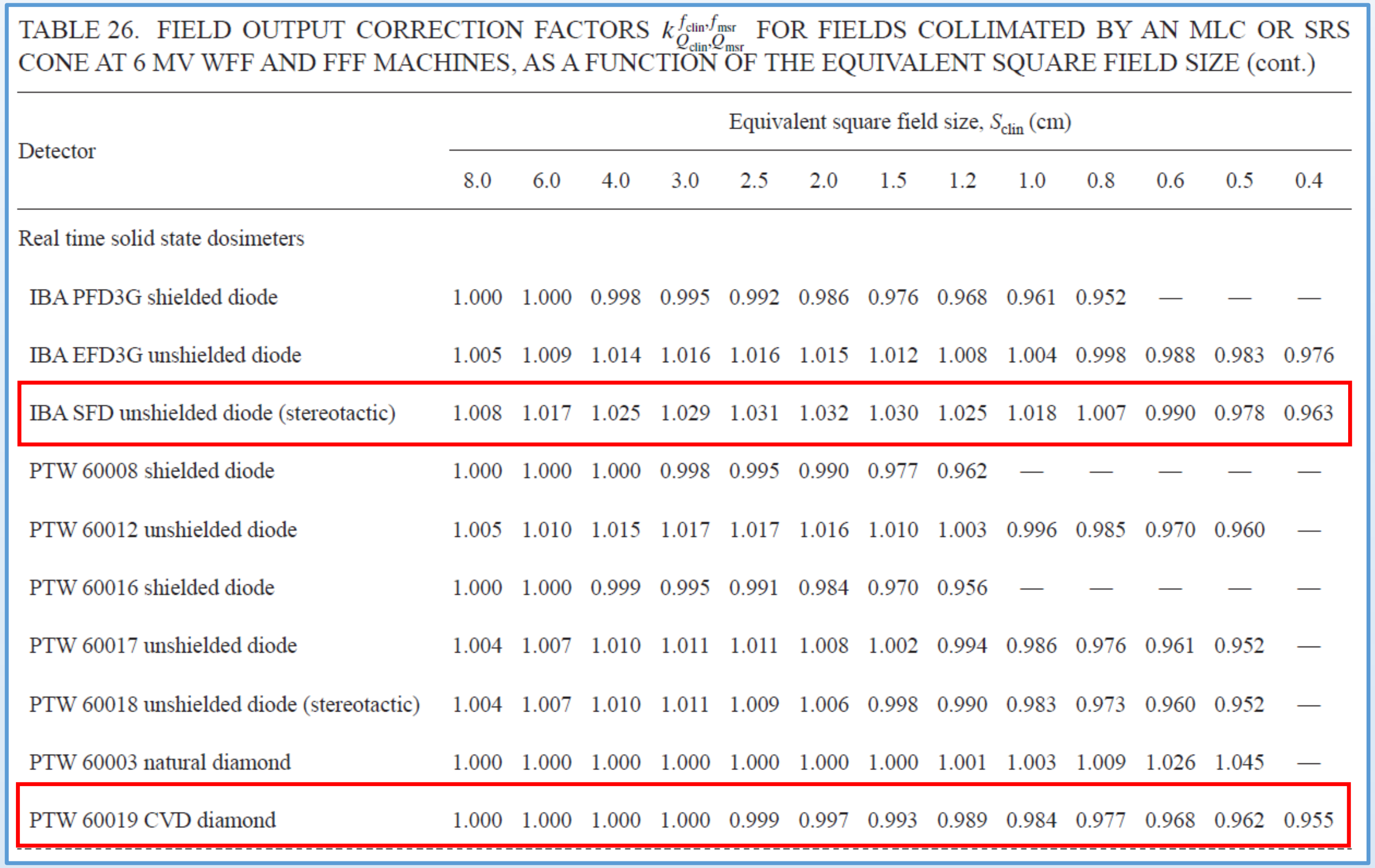


TABLE 26. FIELD OUTPUT CORRECTION FACTORS $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ FOR FIELDS COLLIMATED BY AN MLC OR SRS CONE AT 6 MV WFF AND FFF MACHINES, AS A FUNCTION OF THE EQUIVALENT SQUARE FIELD SIZE (cont.)

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

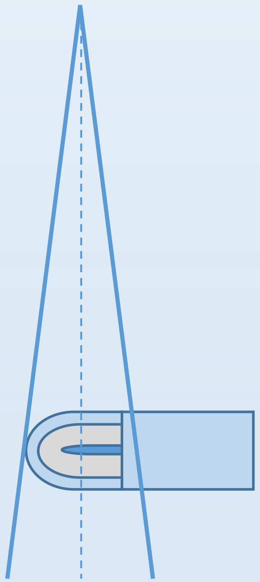
1. Background
2. Basic physics of small fields
3. TRS-483 CoP: concepts and formalism
4. Detector specific output correction factors
5. **On the orientation of the ionization chambers**
6. Acknowledgments

Orientation of the ionization chambers in the beam

Experimental part of the work was carried out **for two different orientations** of ionization chambers

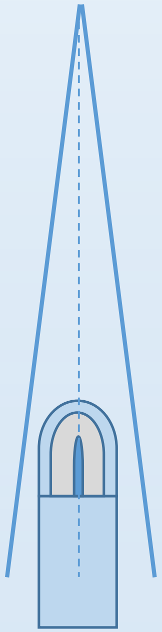
IC axis **perpendicular** to the beam axis

ADVISED IN THE TRS-483 FOR FOFs



IC axis **parallel** to the beam axis

NOT ADVISED IN THE TRS-483 FOR FOFs



DIFFERENCES OF $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$

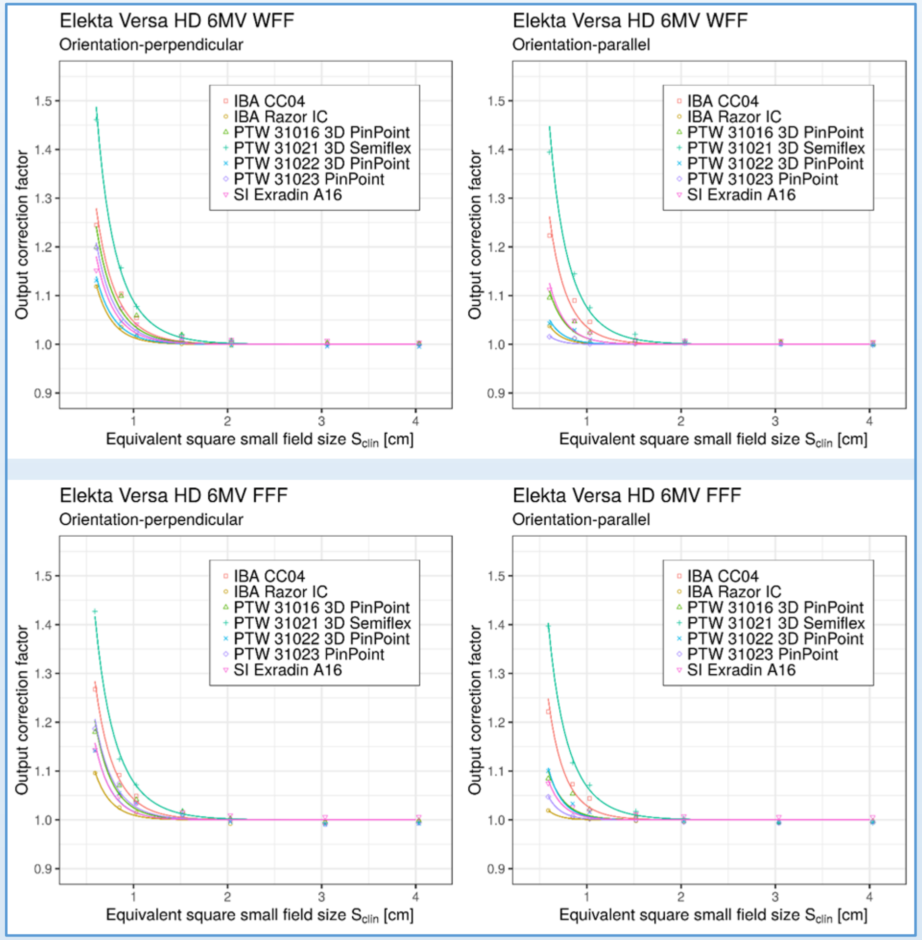
↓

ANALYSIS OF $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$

↓

RECOMMENDATIONS

$k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}(S_{clin})$ for seven ICs in two orientations (Elekta Versa HD)

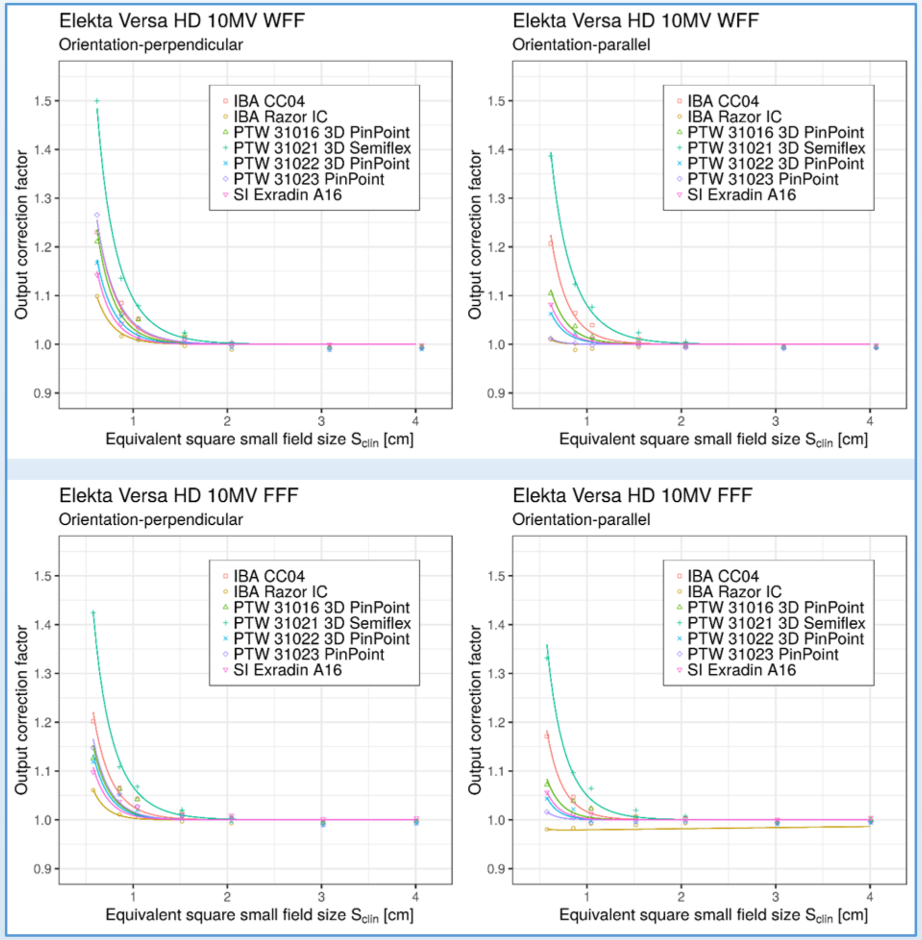


- Signal ratios were fitted by analytical function from TRS-483

$$k(S_{clin}) = \frac{1 - d \cdot e^{-\frac{10-a}{b}}}{1 - d \cdot e^{-\frac{S_{clin}-a}{b}}} + c \cdot (S_{clin} - 10)$$

- $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}(S_{clin})$ were always lower for parallel orientation of ionization chambers
- IBA Razor, PTW 31022 3D PinPoint and 31023 PinPoint chambers have correction factors close to 1 for field sizes down to 1 cm for parallel orientation. Significantly higher $k(S_{clin})$ were found for perpendicular orientation
- IBA CC04 has higher correction factors; for 0.5 cm $k(S_{clin}) > 1.2$

$k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}(S_{clin})$ for seven ICs in two orientations (Elekta Versa HD)

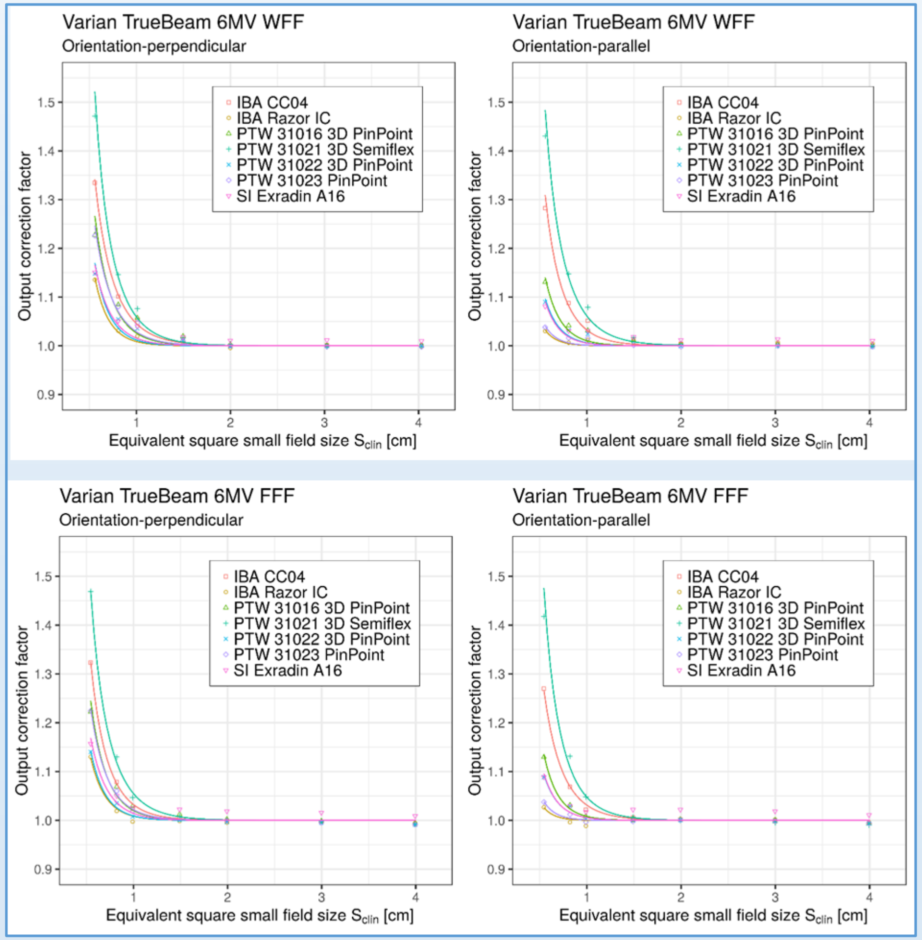


- Signal ratios were fitted by analytical function from TRS-483

$$k(S_{clin}) = \frac{1 - d \cdot e^{-\frac{10-a}{b}}}{1 - d \cdot e^{-\frac{S_{clin}-a}{b}}} + c \cdot (S_{clin} - 10)$$

- $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}(S_{clin})$ were always lower for parallel orientation of ionization chambers
- IBA Razor, PTW 31022 3D PinPoint and 31023 PinPoint chambers have correction factors close to 1 for field sizes down to 1 cm for parallel orientation. Significantly higher $k(S_{clin})$ were found for perpendicular orientation
- IBA CC04 has higher correction factors; for 0.5 cm $k(S_{clin}) > 1.2$

$k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}(S_{clin})$ for seven ICs in two orientations (Varian TrueBeam)

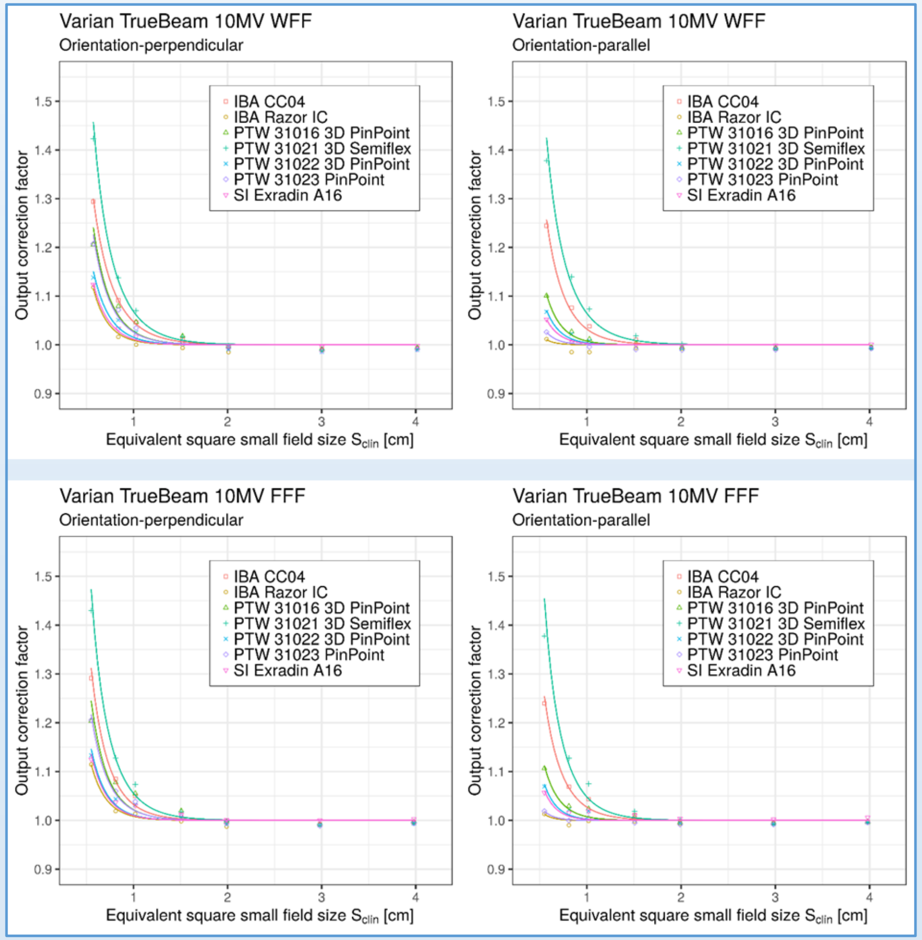


- Signal ratios were fitted by analytical function from TRS-483

$$k(S_{clin}) = \frac{1 - d \cdot e^{-\frac{10-a}{b}}}{1 - d \cdot e^{-\frac{S_{clin}-a}{b}}} + c \cdot (S_{clin} - 10)$$

- $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}(S_{clin})$ were always lower for parallel orientation of ionization chambers
- IBA Razor, PTW 31022 3D PinPoint and 31023 PinPoint chambers have correction factors close to 1 for field sizes down to 1 cm for parallel orientation. Significantly higher $k(S_{clin})$ were found for perpendicular orientation
- IBA CC04 has higher correction factors; for 0.5 cm $k(S_{clin}) > 1.2$

$k^{f_{clin},f_{ref}}_{Q_{clin},Q_{ref}}(S_{clin})$ for seven ICs in two orientations (Varian TrueBeam)

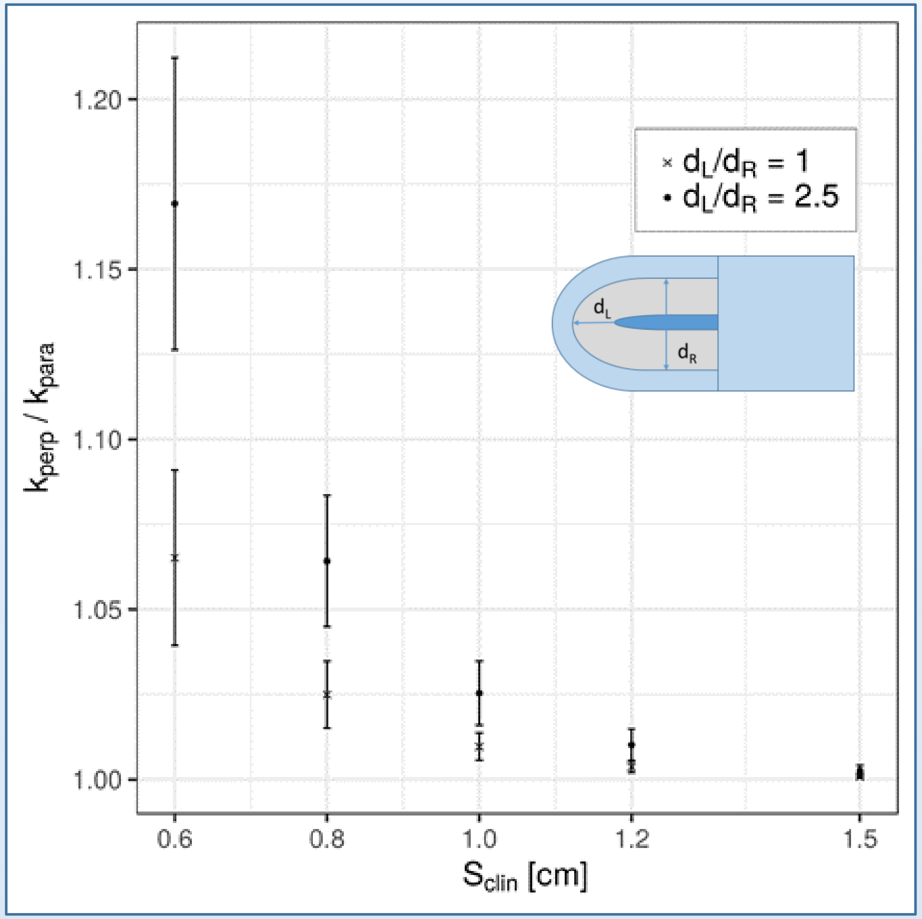


- Signal ratios were fitted by analytical function from TRS-483

$$k(S_{clin}) = \frac{1 - d \cdot e^{-\frac{10-a}{b}}}{1 - d \cdot e^{-\frac{S_{clin}-a}{b}}} + c \cdot (S_{clin} - 10)$$

- $k^{f_{clin},f_{ref}}_{Q_{clin},Q_{ref}}(S_{clin})$ were always lower for parallel orientation of ionization chambers
- IBA Razor, PTW 31022 3D PinPoint and 31023 PinPoint chambers have correction factors close to 1 for field sizes down to 1 cm for parallel orientation. Significantly higher $k(S_{clin})$ were found for perpendicular orientation
- IBA CC04 has higher correction factors; for 0.5 cm $k(S_{clin}) > 1.2$

k_{perp}/ k_{para} for two ionization chambers

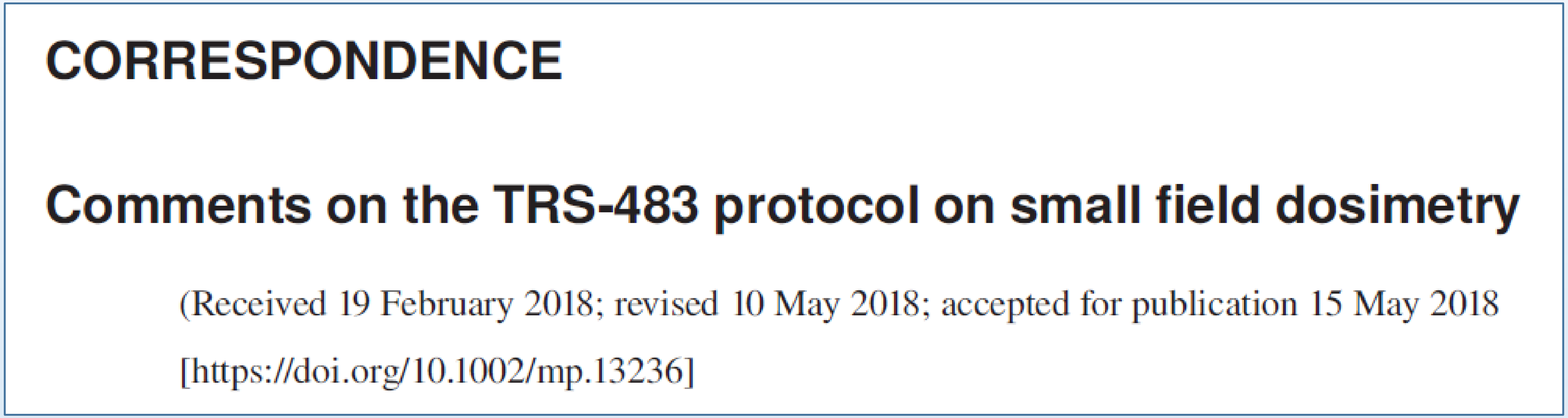


- $d_L/d_R = 1$ (PTW 31022 3D PinPoint chamber)
- $d_L/d_R = 2.5$ (PTW 31023 PinPoint chamber)

- Average values for output correction factors for all investigated beams were considered for the determination of k_{perp}/k_{para} values

- output correction factors for all ionization chambers included in the study are lower if the chambers are oriented with their main axis parallel to the central axis of the beam even if the length of the cavity is equal to the cavity diameter as it is in the case of 3D ionization chambers

On the orientation of ICs (Das & Francescon)



CORRESPONDENCE

Comments on the TRS-483 protocol on small field dosimetry

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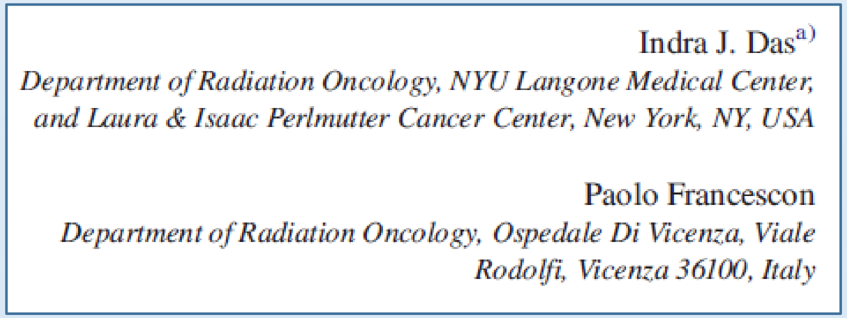
[https://doi.org/10.1002/mp.13236]



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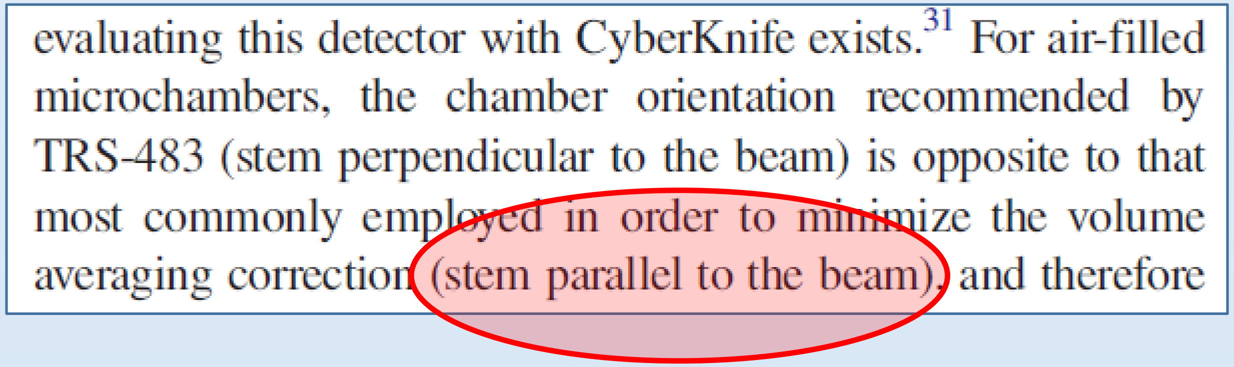
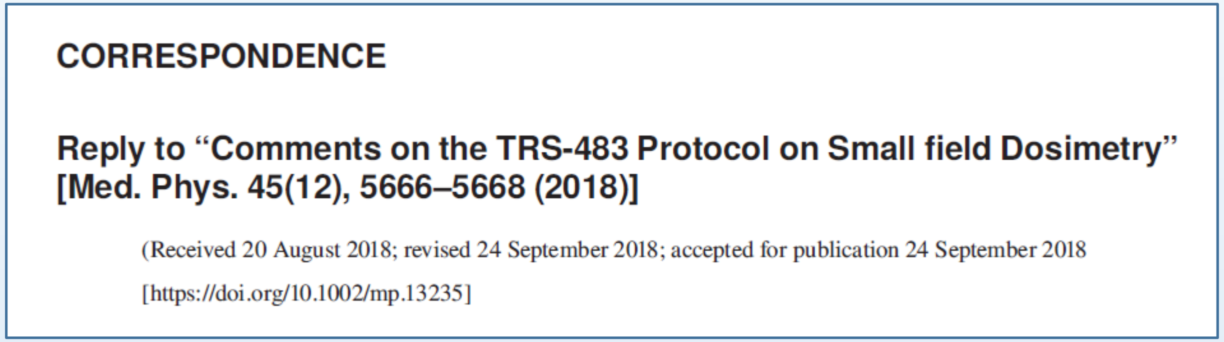


evaluating this detector with CyberKnife exists.[31] For air-filled microchambers, the chamber orientation recommended by TRS-483 (stem perpendicular to the beam) is opposite to that most commonly employed in order to minimize the volume averaging correction (stem parallel to the beam), and therefore

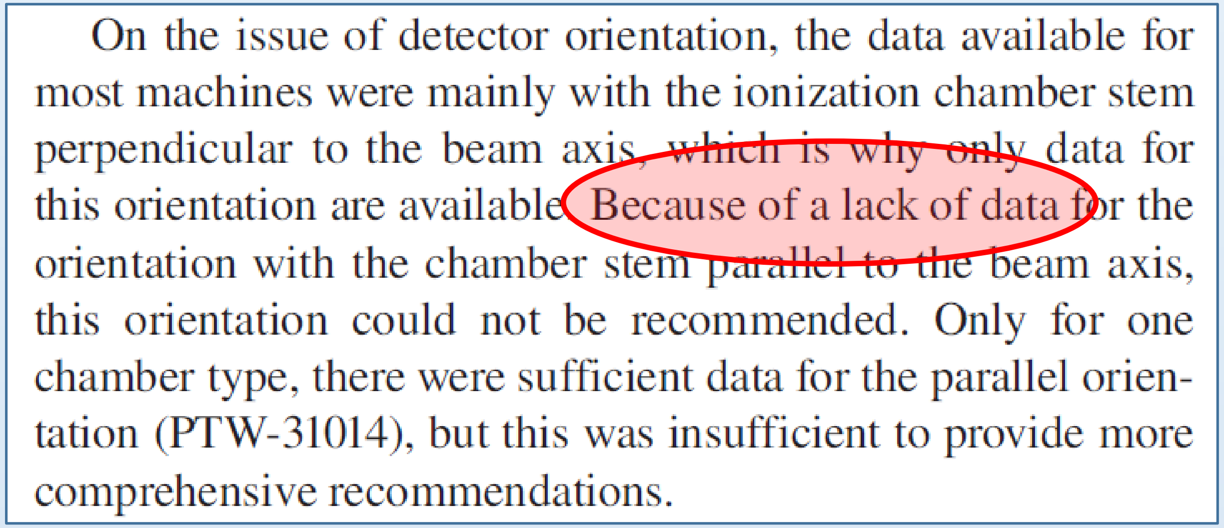
On the orientation of ICs (TRS-483 authors)



CORRESPONDENCE

Reply to "Comments on the TRS-483 Protocol on Small field Dosimetry" [Med. Phys. 45(12), 5666–5668 (2018)]

(Received 20 August 2018; revised 24 September 2018; accepted for publication 24 September 2018
[https://doi.org/10.1002/mp.13235]



On the issue of detector orientation, the data available for most machines were mainly with the ionization chamber stem perpendicular to the beam axis, which is why only data for this orientation are available. Because of a lack of data for the orientation with the chamber stem parallel to the beam axis, this orientation could not be recommended. Only for one chamber type, there were sufficient data for the parallel orientation (PTW-31014), but this was insufficient to provide more comprehensive recommendations.

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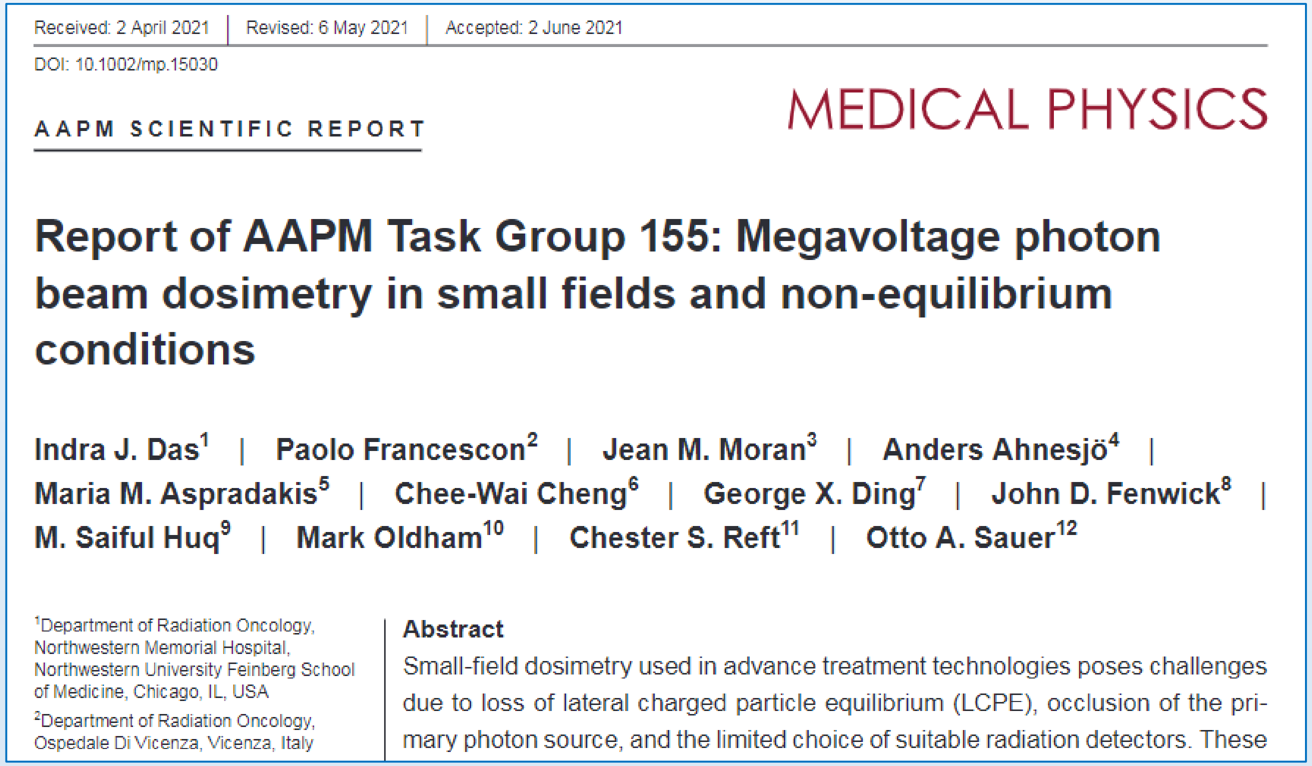
Report of AAPM TG 155



Received: 2 April 2021 | Revised: 6 May 2021 | Accepted: 2 June 2021
DOI: 10.1002/mp.15030

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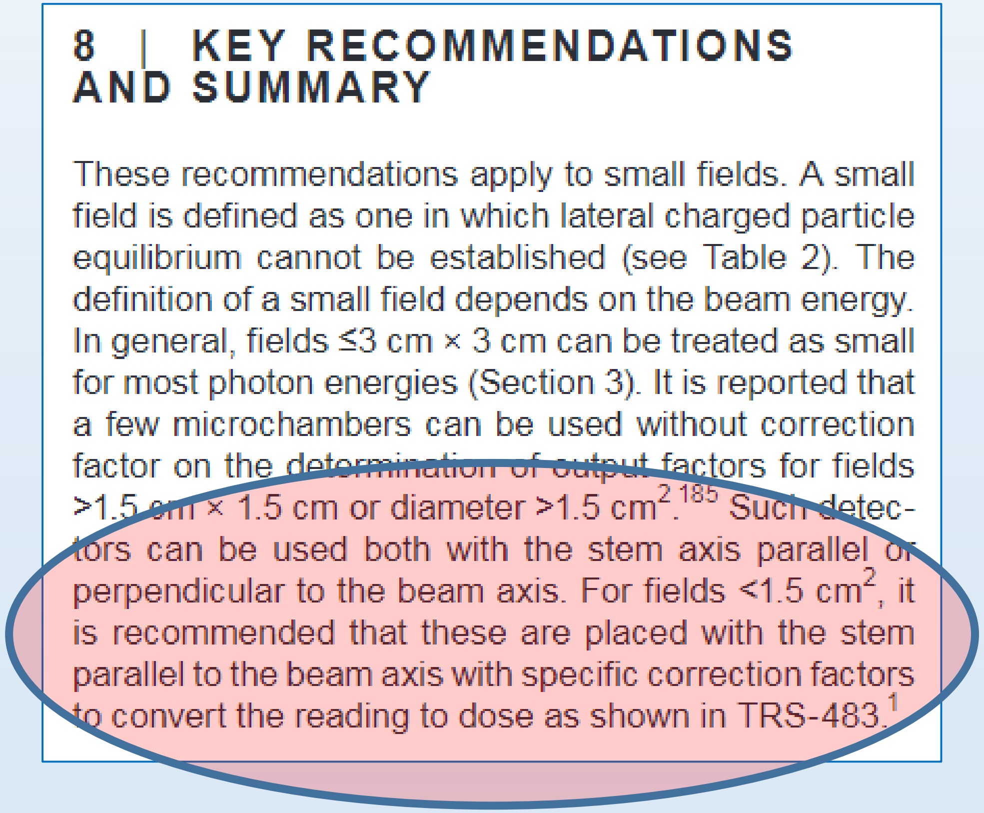
Abstract
Small-field dosimetry used in advance treatment technologies poses challenges due to loss of lateral charged particle equilibrium (LCPE), occlusion of the primary photon source, and the limited choice of suitable radiation detectors. These



8 | KEY RECOMMENDATIONS AND SUMMARY

These recommendations apply to small fields. A small field is defined as one in which lateral charged particle equilibrium cannot be established (see Table 2). The definition of a small field depends on the beam energy. In general, fields ≤3 cm × 3 cm can be treated as small for most photon energies (Section 3). It is reported that a few microchambers can be used without correction factor on the determination of output factors for fields >1.5 cm × 1.5 cm or diameter $>1.5\ \text{cm}^2$.[2,185] Such detectors can be used both with the stem axis parallel or perpendicular to the beam axis. For fields $<1.5\ \text{cm}^2$, it is recommended that these are placed with the stem parallel to the beam axis with specific correction factors to convert the reading to dose as shown in TRS-483.[1]

For further reading …

Check for updates

A novel method for the determination of field output factors and output correction factors for small static fields for six diodes and a microdiamond detector in megavoltage photon beams

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(Received 17 August 2018; revised 21 November 2018; accepted for publication 21 November 2018; published 24 December 2018)

Purpose: The goal of this work is to provide a large and consistent set of data for detector-specific output correction factors, $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$, for small static fields for seven solid-state detectors and to determine field output factors, $\Omega_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$, using EBT3 radiochromic films and W1 plastic scintillator as reference detectors on two different linear accelerators and four megavoltage photon beams. Consistent measurement conditions and recommendations given in the International Code of Practice TRS-483 for small-field dosimetry were followed throughout the study.
Methods: $\Omega_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ were determined on two linacs, Elekta Versa HD and Varian TrueBeam, for 6 and 10 MV beams with and without flattening filter and for nine fields ranging from $0.5 \times 0.5\ \mathrm{cm}^2$ to $10 \times 10\ \mathrm{cm}^2$. Signal readings obtained with EBT3 radiochromic films and W1 plastic scintillator were fitted by an analytical function. Volume averaging correction factors, determined from two-dimensional (2D) dose matrices obtained with EBT3 films and fitted to bivariate Gaussian function, were used to correct measured signals. $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ were determined empirically for six diodes, IBA SFD, IBA Razor, PTW 60008 P, PTW 60012 E, PTW 60018 SRS, and SN EDGE, and a PTW 60019 microDiamond detector.
Results: Field output factors and detector-specific $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ are presented in the form of analytical functions as well as in the form of discrete values. It is found that in general, for a given linac, small-field output factors need to be determined for every combination of beam energy and filtration (WFF or FFF) and field size as the differences between them can be statistically significant ($P < 0.05$). For different beam energies, the present data for $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ are found to differ significantly ($P < 0.05$) from the corresponding data published in TRS-483 mostly for the smallest fields (<1.5 cm). For the PTW microDiamond detector, statistically significant differences ($P < 0.05$) between $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ values were found for all investigated beams on an Elekta Versa HD linac for field sizes $0.5 \times 0.5\ \mathrm{cm}^2$ and $0.8 \times 0.8\ \mathrm{cm}^2$. Significant differences in $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ between beams of a given energy but with and without flattening filters are found for measurements made in small fields (<1.5 cm) at a given linac. Differences in $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ are also found when measurements are made at different linacs using the same beam energy filtration combination; for the PTW microDiamond detector, these differences were found to be around 6% and were considered as significant.
Conclusions: Selection of two reference detectors, EBT3 films and W1 plastic scintillator, and use of an analytical function, is a novel approach for the determination of $\Omega_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ for small static fields in megavoltage photon beams. Large set of $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ data for seven solid-state detectors and four beam energies determined on two linacs by a single group of researchers can be considered a valuable

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Output correction factors for small static fields in megavoltage photon beams for seven ionization chambers in two orientations — perpendicular and parallel

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Purpose: The goal of the present work was to provide a large set of detector-specific output correction factors for seven small volume ionization chambers on two linear accelerators in four megavoltage photon beams utilizing perpendicular and parallel orientation of ionization chambers in the beam for nominal field sizes ranging from $0.5\ \mathrm{cm}^2 \times 0.5\ \mathrm{cm}^2$ to $10\ \mathrm{cm}^2 \times 10\ \mathrm{cm}^2$. The present study is the second part of an extensive research conducted by our group.
Methods: Output correction factors $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ were experimentally determined on two linacs, Elekta Versa HD and Varian TrueBeam for 6 and 10 MV beams with and without flattening filter for nine square fields ranging from $0.5\ \mathrm{cm}^2 \times 0.5\ \mathrm{cm}^2$ to $10\ \mathrm{cm}^2 \times 10\ \mathrm{cm}^2$, for seven mini and micro ionization chambers, IBA CC04, IBA Razor, PTW 31016 3D PinPoint, PTW 31021 3D Semiflex, PTW 31022 3D PinPoint, PTW 31023 PinPoint, and SI Exradin A16. An Exradin W1 plastic scintillator and EBT3 radiochromic films were used as the reference detectors.
Results: For all ionization chambers, values of output correction factors $k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}}$ were lower for parallel orientation compared to those obtained in the perpendicular orientation. Five ionization chambers from our study set, IBA Razor, PTW 31016 3D PinPoint, PTW 31022 3D PinPoint, PTW 31023 PinPoint, and SI Exradin A16, fulfill the requirement recommended in the TRS-483 Code of Practice, that is, $0.95 < k_{Q_{clin},Q_{ref}}^{f_{clin},f_{ref}} < 1.05$, down to the field size $0.8\ \mathrm{cm}^2 \times 0.8\ \mathrm{cm}^2$, when they are positioned in parallel orientation; two of the ionization chambers, IBA Razor and PTW 31023 PinPoint, satisfy this condition down to the field size of $0.5\ \mathrm{cm}^2 \times 0.5\ \mathrm{cm}^2$.
Conclusions: The present paper provides experimental results of detector-specific output correction factors for seven small volume ionization chambers. Output correction factors were determined in 6 and 10 MV photon beams with and without flattening filter down to the square field size of $0.5\ \mathrm{cm}^2 \times 0.5\ \mathrm{cm}^2$ for two orientations of ionization chambers — perpendicular and parallel. Our main finding is that output correction factors are smaller if they are determined in a parallel orientation compared to those obtained in a perpendicular orientation for all ionization chambers regardless of the photon beam energy, filtration, or linear accelerator being used. Based on our findings, we recommend using ionization chambers in parallel orientation, to minimize corrections in the experimental determination of field output factors. Latter holds even for field sizes below $1.0\ \mathrm{cm}^2 \times 1.0\ \mathrm{cm}^2$, whenever necessary corrections remain within 5%, which was the case for several ionization chambers from our set.

TRS-483 recommended perpendicular orientation of ionization chambers for the determination of field output factors. The present study presents results for both perpendicular and parallel orientation of ionization chambers. When validated by other researchers, the present results for parallel orientation can be considered as a complementary dataset to those given in TRS-483. © *2019 The Authors. Medical Physics published by Wiley Periodicals, Inc. on behalf of American Association of Physicists in Medicine.* [https://doi.org/10.1002/mp.13894]

1. Background
2. Basic physics of small fields
3. TRS-483 CoP: concepts and formalism
4. Detector specific output correction factors
5. On the orientation of the ionization chambers

6. Acknowledgments

To my friends and fellow researchers

Eduard Gershkevitsh (Estonia)

Ignasi Mendez (Slovenia/Spain)

Slaven Jurković (Croatia)

Saiful Huq (United States)

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