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School on Medical Physics for Radiation Therapy:
Dosimetry and Treatment Planning for Basic and Advanced Applications

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Dosimetry of small photon beams (TRS 483)

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Content:

(1) Introduction: Characteristics of small field

(2) TRS 483 Code of Practice: The two-steps-approach:
- The **machine specific reference** (msr) field
- Transition to **clinical fields** smaller than the (msr) field

(3) **Reference dosimetry traceable to PSDL** for the machine specific reference field

(4) **Relative dosimetry** for clinical small fields

(5) Suitable detectors for relative dosimetry

In radiotherapy it is essential that the dose delivered to the patient be known **accurately** so that patients receive the correct amount of radiation.

The key for that is a consistent reference dosimetry which

- is **traceable to primary standards**
- enables **common procedures** to be followed.

For conventional radiotherapy this has been achieved by universally adopted codes of practice,

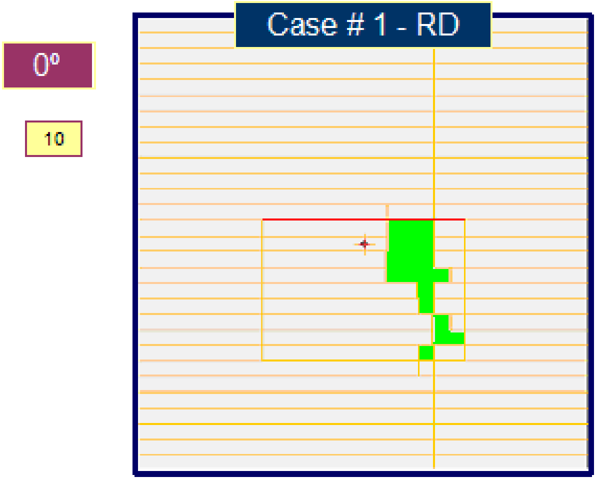
for instance by IAEA TRS 398:

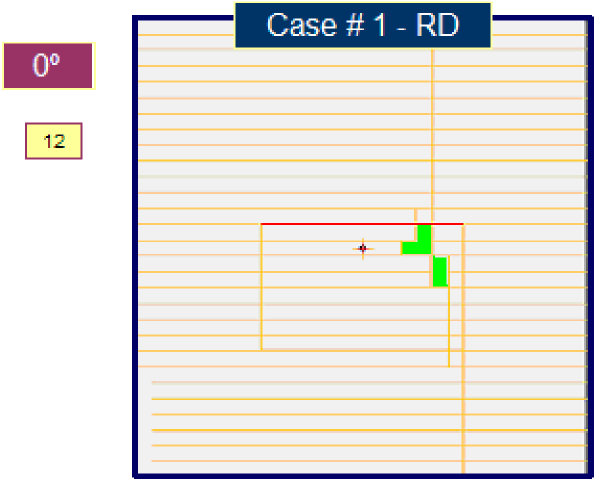
$$\boxed{D_{w,Q} = M_Q \; N_{D,w,Q_o} \; k_{Q,Q_o}}$$

However, recent developments in radiotherapy have resulted in a more frequent use of **small static photon beams**

- stereotactic **radiotherapy**
- stereotactic body radiotherapy
- stereotactic **radiosurgery** using circular collimators for narrow beams

- intensity modulated radiotherapy.





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● *Original Contribution*

CEREBRAL RADIATION SURGERY USING MOVING FIELD IRRADIATION AT A LINEAR ACCELERATOR FACILITY

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A modified irradiation technique at a linear accelerator fac consisting of several moving field irradiations in non-c localization system and special computer programs for pr within small, well circumscribed volumes is obtained. Re and by calculations. A simple algorithm for treatment Radiation surgery within the brain is now technically feas now been treated.

Radiosurgery, Linear accelerator, Brain, Single dose treat

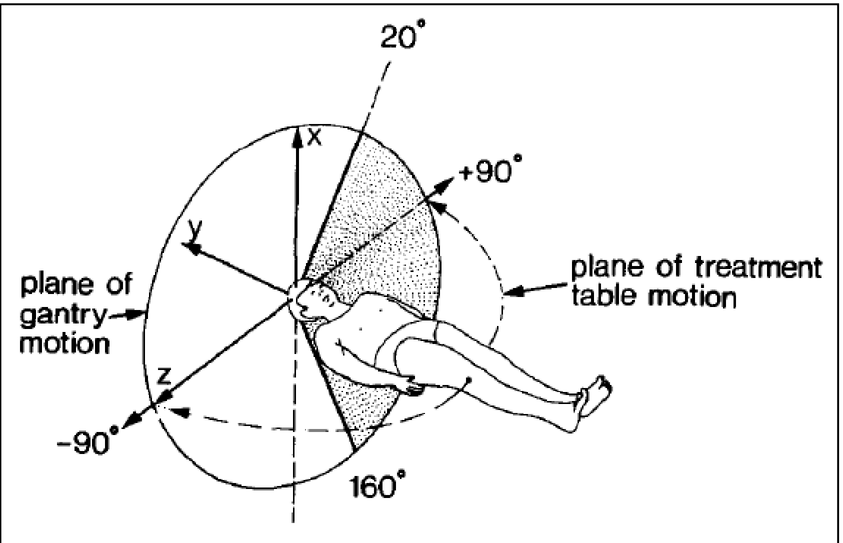


Fig. 1. Schematic illustration of the three dimensional cross fire irradiation. The shadowed area represents the moving field angle (20°–160°). Each of the 11 irradiations is performed at a different angle of the treatment table varying between −90° and +90°.

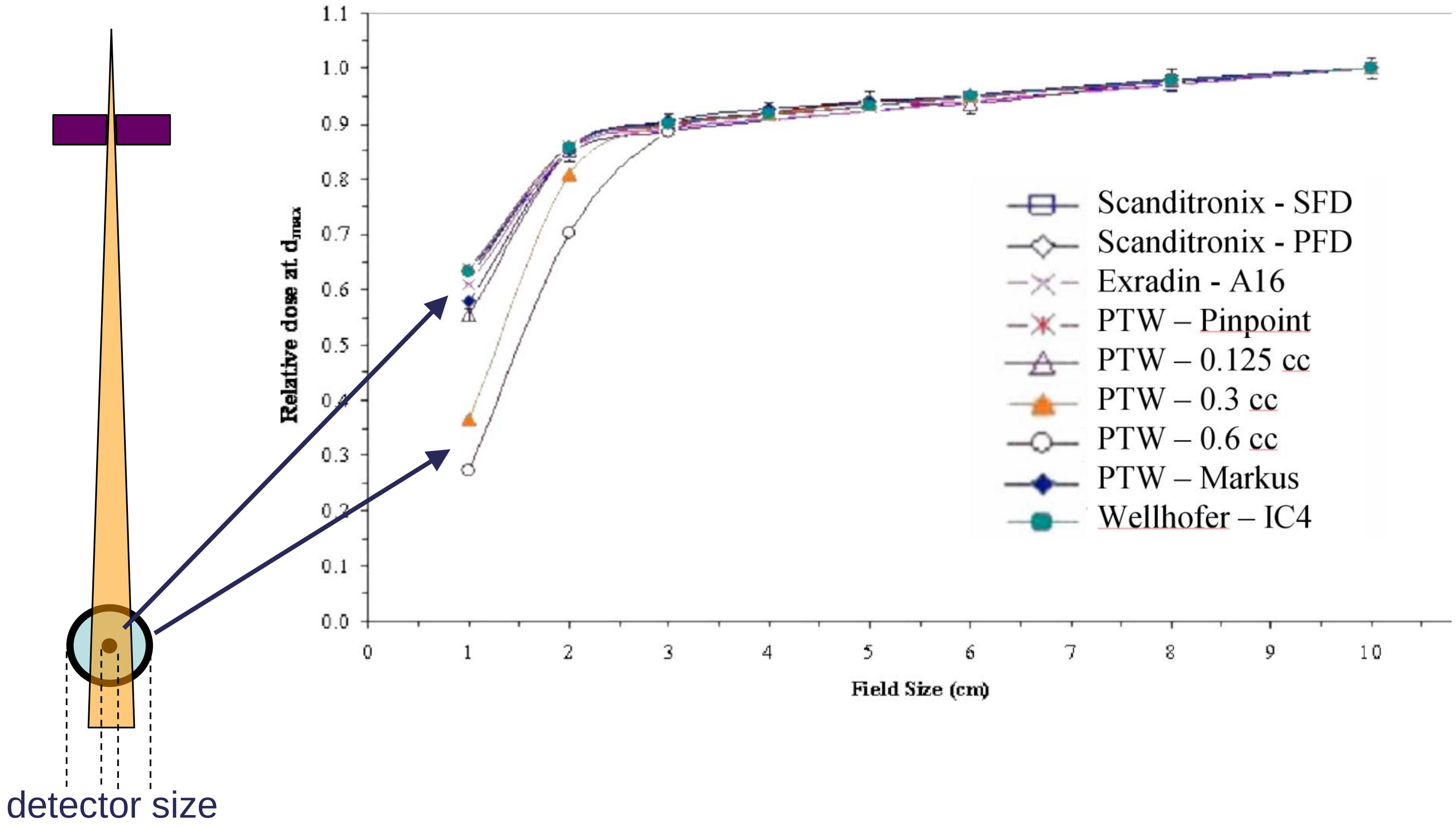
At the same time, dosimetrical errors have become considerably larger than with conventional beams, because:

- The well known **reference field size of 10 cm x 10 cm for beam calibration** cannot be realized in some machines;
- The measurement procedures for determination of absorbed dose to water in small fields **are not standardized**.

Accidents have really occurred owing to the use

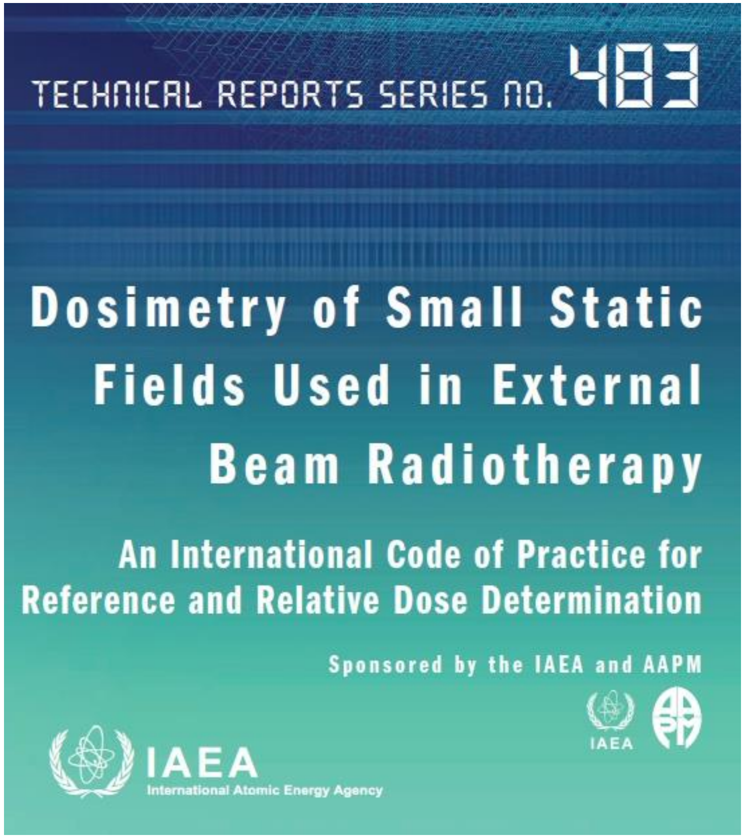
- of methods that are appropriate for large fields but not for small fields
- particularly of **detectors** appropriate for large fields but not for small fields

Influence of the size of the detector



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

Facing this problem, an IAEA & AAPM working group published in 2008 a formalism for the dosimetry of small and composite fields known as TRS 483.



This Code of Practice (also already Alfonso et al. 2008) introduced the following concept consisting of a separation into two steps:

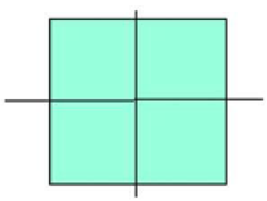
Step 1:

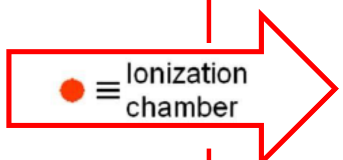
machine specific **reference field**

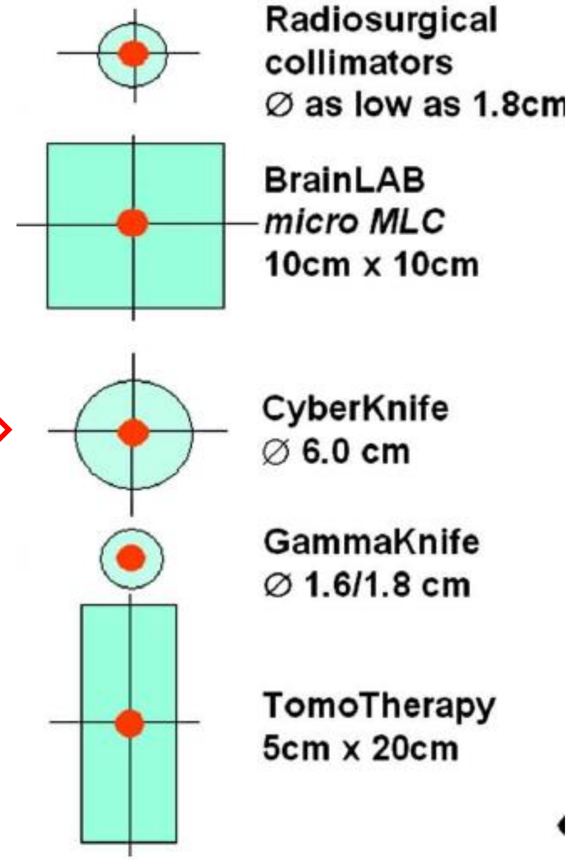
$\boldsymbol{f}_{\mathbf{msr}}$

10 cm x 10 cm reference field

$\boldsymbol{f}_{\mathbf{ref}}$







$$\boxed{D_{w,Q} = M_Q \; N_{D,w,Q_o} \; k_{Q,Q_o}}$$

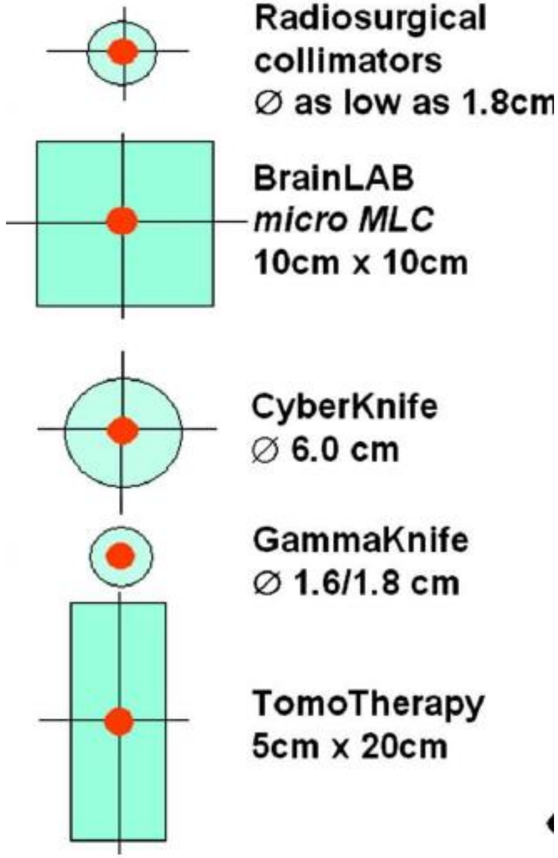
TABLE 2. msr FIELDS FOR COMMON RADIOTHERAPY MACHINES

Machine type	msr field
CyberKnife	6 cm diameter fixed collimator
TomoTherapy	5 cm × 10 cm field
Gamma Knife	1.6 cm or 1.8 cm diameter collimator helmet, all sources simultaneously out
Brainlab micro MLC add-on	For example 9.8 cm × 9.8 cm or 9.6 cm × 10.4 cm
SRS cone add-ons	The closest to a 10 cm × 10 cm equivalent square msr field achievable

Step 2:

machine specific reference field

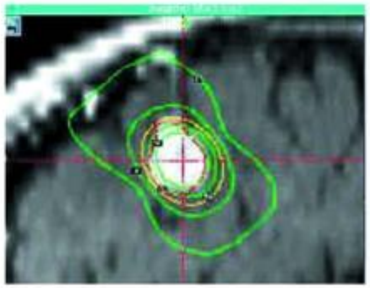
f_{msr}



relative dosimetry

clinical field

f_{clin}



e.g. a GammaKnife clinical plan

Some words on the characteristics of small fields

If a field is to be considered as a small field, at least one of the following three physical conditions should be fulfilled for an external photon :

1) There is a loss of **lateral charged particle equilibrium** (=LCPE) on the beam axis

- Loss of LCPE in photon beams occurs if the radius is smaller than the maximum range of secondary electrons.

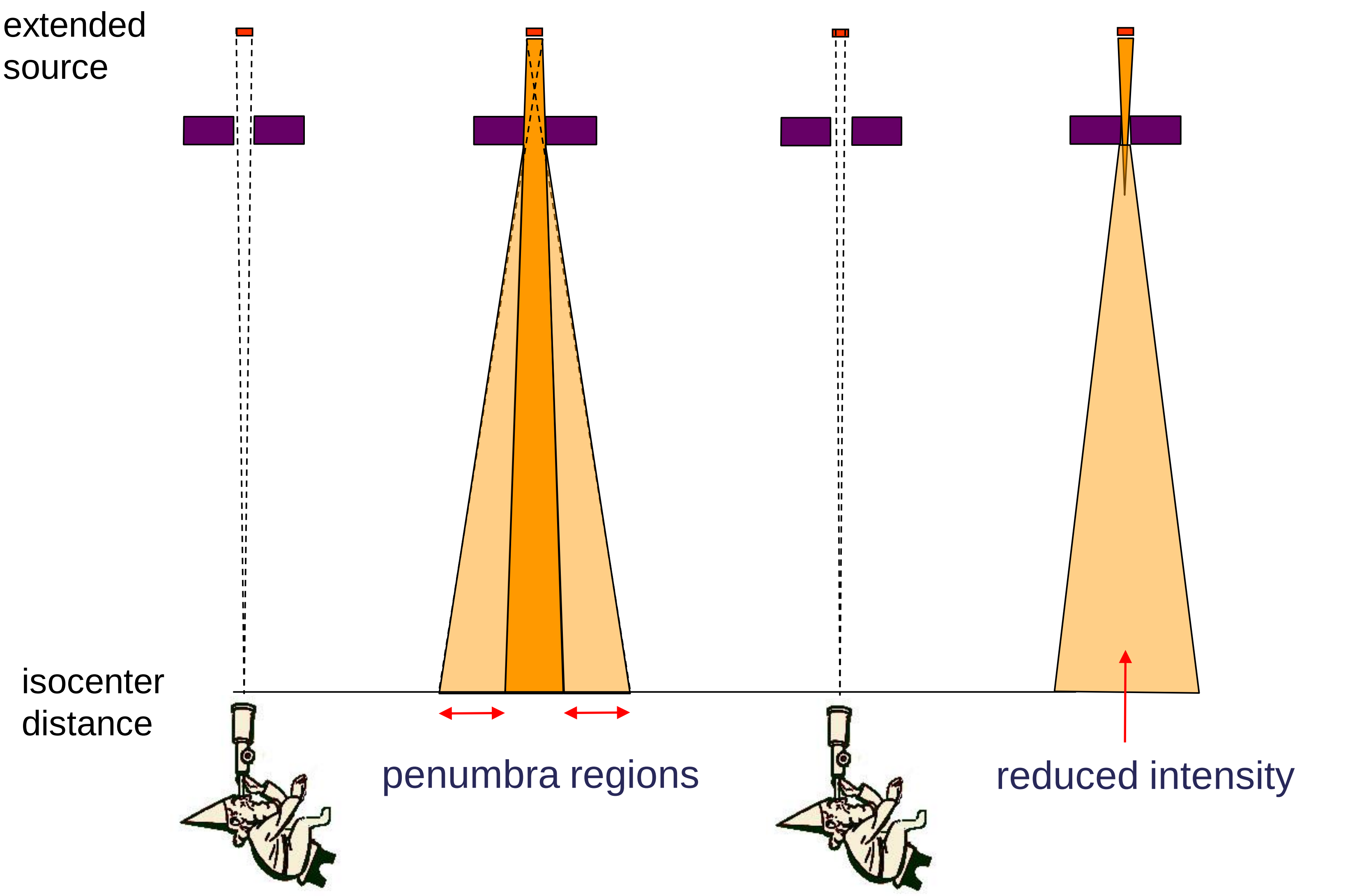
- A practical parameter for that is the **LCPE range r_{LCPE}.**
  It is defined as the minimum radius of a circular photon field for which at the centre of the field

collision kerma in water = absorbed dose to water

- r_{LCPE} can be expressed as a function of the quality parameter $TPR_{20,10}$

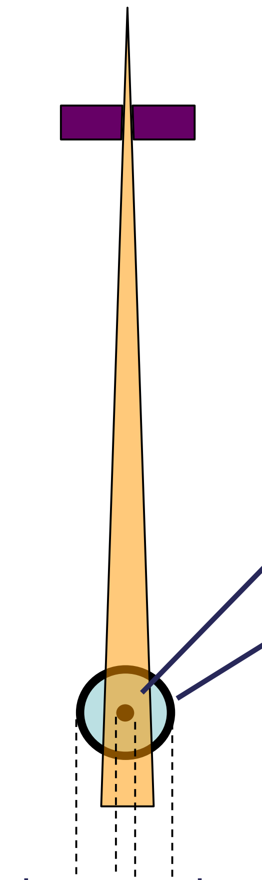
$$r_{\mathrm{LCPE}} = 8.369 \times \mathrm{TPR}_{20,10}(10) - 4.382$$

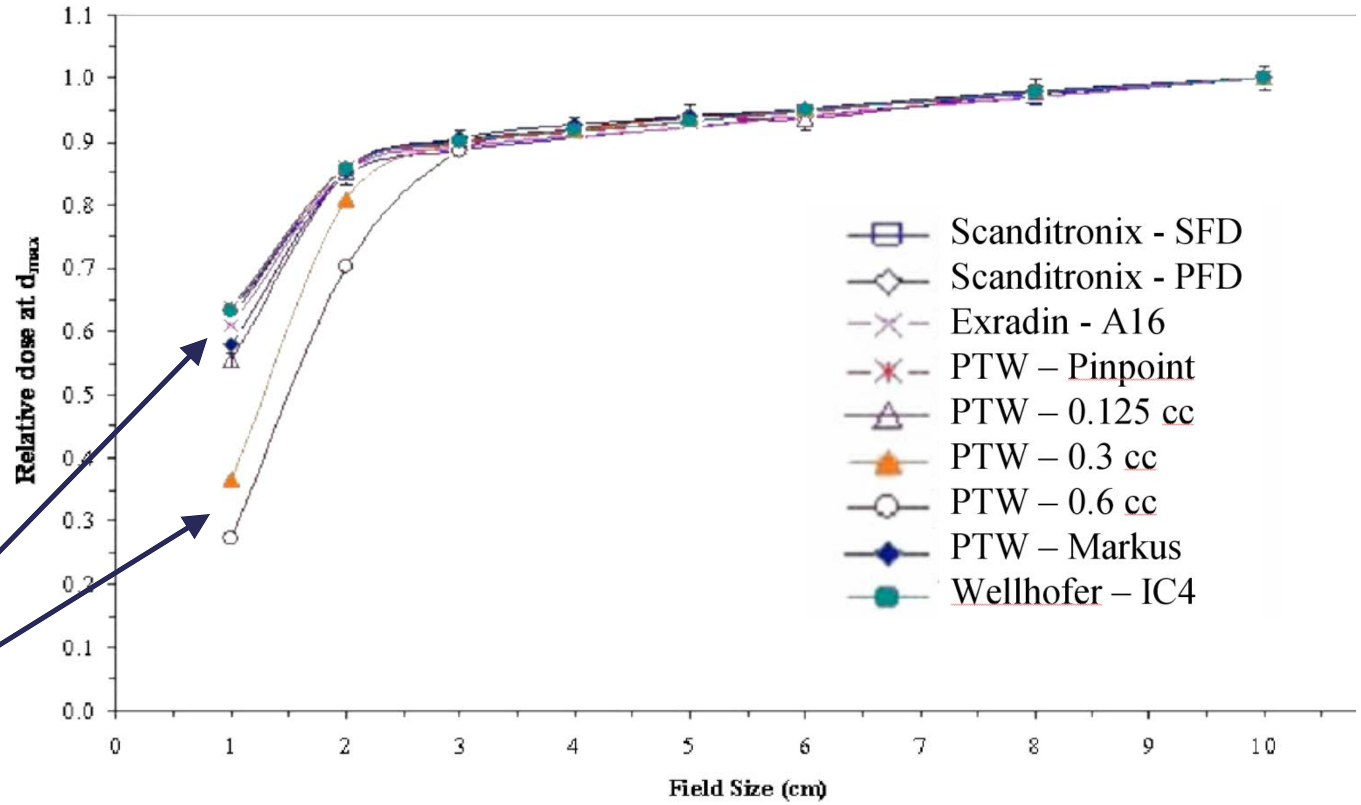
2) There is **partial occlusion of the primary photon source** by the collimater



3) The size of the detector is large compared to the beam size

While the first two conditions are beam related, this third condition is detector related for a given field size.





Definition of field size

There are two possibilities:

1. The geometrical field size is defined as the **geometrical projection** of the collimator opening by the radiation source on a plane perpendicular to the axis of the beam;

2. The irradiation field size is defined by the area in a plane perpendicular to the radiation beam axis defined by a specified isodose line.

   An example is at the 50% level.
   This is called the Full Width at Half Maximum FWHM

TRS 483 advises that for small field dosimetry

- field size is reported as the **FWHM** of the field
- This field size definition is also used for the **detector perturbations and associated correction factors** as a function of field size.

TRS 483 Step1: Formalism

Subscript notation used throughout in TRS 483:

Well known TRS 398 notation used for the reference dosismetry:

$$D_{\mathrm{w,Q}} = M_{\mathrm{Q}} \cdot N_{\mathrm{D,w,Q_0}} \cdot k_{\mathrm{Q}(,\mathrm{Q_0})}$$

TRS 483 notation used for the same purpose:

$$D_{\mathrm{w,Q_{ref}}} = M_{\mathrm{Q_{ref}}}^{f_{ref}} \cdot N_{\mathrm{D,w,Q_0}}^{f_{ref}} \cdot k_{\mathrm{Q_{ref}}(,\mathrm{Q_0})}^{f_{ref}}$$

Now we need the application of this formalism for the machine specific reference field f_{msr}

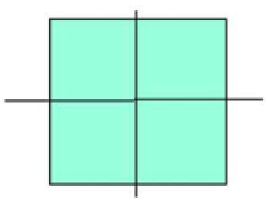
Step 1:

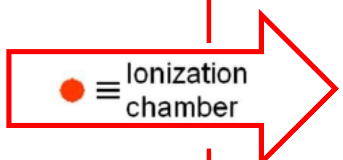
machine specific **reference field**

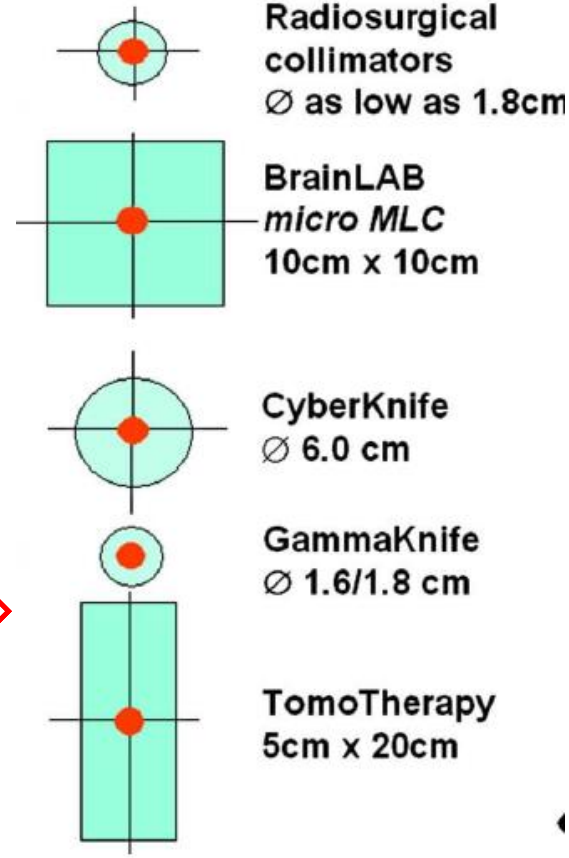
f $_{msr}$

10 cm x 10 cm reference field

f $_{ref}$







$$D_{w,Q_{ref}} = M_{Q_{ref}}^{f_{ref}} \cdot N_{D,w,Q_0}^{f_{ref}} \cdot k_{Q_{ref}(,Q_0)}^{f_{ref}}$$

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q_{msr}(,Q_0)}^{f_{msr},f_{ref}}$$

TRS 483 Step1: Machine specific reference (msr) dosimetry

Formalism

This is the main formula in TRS 483 for the msr dosimetry:

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q_{msr}(,Q_0)}^{f_{msr},f_{ref}}$$

chamber calibration factor valid for conventional reference conditions!!

There are three alternative situations and formulations:

1) A chamber calibration factor in the msr field is **directly available**

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w(,Q_0)}^{f_{msr}}$$

(very rarely, not addressed here)

2) The chamber is **calibrated for a conventional reference field**,
a **generic beam quality correction factor for the msr field is available**

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q_{msr}(,Q_0)}^{f_{msr},f_{ref}}$$

3) The chamber is **calibrated for a conventional reference field**,
a generic beam quality correction factor for the msr field is **not** available

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q(,Q_0)}^{f_{ref}} \cdot k_{Q_{msr},Q}^{f_{msr},f_{ref}}$$

TRS 483 Step1:

Code of Practice for reference dosimetry of machine specific reference fields f_{msr}

- Dosimetry equipment: Ionization chambers
- Phantoms (same recommendations as in TRS 398)
- Reference conditions
- Machine specific determination of absorbed dose to water:
  - Determination when the conventional f_{ref} (10 x 10 cm^2) can be realized
  - Determination when the conventional f_{ref} **cannot** be realized
- Measurement in plastic water substitute phantoms

Code of Practice for reference dosimetry of machine specific reference fields f_{msr}

Dosimetry equipment

For the msr field it is advised to use an ionization chamber calibrated in terms of absorbed dose to water.

The size restriction on an ionization chamber for msr dosimetry is that the outer boundaries of the detector are at least a lateral charged particle distance r_{LCPE} away from the field edges (at 50% absorbed dose level).

For small fields with **equivalent square field size equal to or larger than 6 cm × 6 cm**, Farmer type chambers or other reference class chambers such as those listed in the **Table 1** used.

For small fields with **equivalent square field size smaller than 6 cm × 6 cm**, smaller ionization chambers such as those listed in **Table 2** are used to ensure that the outer edges of the detector volume are at least a distance r_{LCPE} **away from the field edges.**

Table 1: CHARACTERISTICS OF IONIZATION CHAMBERS SUITABLE FOR REFERENCE DOSIMETRY OF msr FIELDS *fmsr* $\geq$ 6 cm × 6 cm

Ionization chamber type	Cavity volume (cm^3)	Cavity length (mm)	Cavity radius (mm)	Wall material	Wall thickness (g/cm^2)	Central electrode material	Waterproof
Capintec PR-06C/G Farmer	0.65	22.0	3.2	C-552	0.050	C-552	N
Exradin A2 Spokas	0.53	11.4	4.8	C-552	0.176	C-552	Y
Exradin A12 Farmer	0.65	24.2	3.1	C-552	0.088	C-552	Y
Exradin A12S	0.25	11.6	3.1	C-552	0.088	C-552	Y
Exradin A19	0.63	25.0	3.1	C-552	0.088	C-552	Y
FZH TK 01	0.4	12.0	3.5	Delrin	0.071	(no data)	Y
Nuclear Assoc 30-751 Farmer	0.69	23.0	3.1	Delrin	0.056	Aluminium	Y
Nuclear Assoc 30-752 Farmer	0.69	23.0	3.1	Graphite	0.072	Aluminium	Y
NE 2505/3, 3A Farmer	0.6	24.0	3.2	Graphite	0.065	Aluminium	N
NE 2571 Farmer	0.6	24.0	3.2	Graphite	0.065	Aluminium	N
NE 2611	0.33	9.2	3.7	Graphite	0.090	Aluminium (hollow)	N
PTW 23331 rigid	1.0	22.0	4.0	PMMA	0.060	Aluminium	N
PTW 23332 rigid	0.3	18.0	2.5	PMMA	0.054	Aluminium	N
PTW 23333 (3 mm cap)	0.6	21.9	3.1	PMMA	0.059	Aluminium	N
PTW 30001 Farmer	0.6	23.0	3.1	PMMA	0.045	Aluminium	N
PTW 30010 Farmer	0.6	23.0	3.1	PMMA	0.057	Aluminium	N
PTW 30002/30011 Farmer	0.6	23.0	3.1	Graphite	0.079	Graphite	N
PTW 30004/30012 Farmer	0.6	23.0	3.1	Graphite	0.079	Aluminium	N
PTW 30006/30013 Farmer	0.6	23.0	3.1	PMMA	0.057	Aluminium	Y
PTW 31003/31013 Semiflex	0.3	16.3	2.8	PMMA	0.078	Aluminium	Y
SNC 100700-0 Farmer	0.6	24.4	3.1	PMMA	0.060	Aluminium	N
SNC 100700-1 Farmer	0.6	24.4	3.1	Graphite	0.085	Aluminium	N
Victoreen Radocon II 555	0.1	23.0	2.4	Polystyrene	0.117	(no data)	N
Victoreen 30-348	0.3	18.0	2.5	PMMA	0.060	(no data)	N
Victoreen 30-351	0.6	23.0	3.1	PMMA	0.060	(no data)	N
Victoreen 30-349	1.0	22.0	4.0	PMMA	0.060	(no data)	N
Victoreen 30-361	0.4	22.3	2.4	PMMA	0.144	(no data)	N
IBA FC-65P Farmer	0.65	23.1	3.1	Delrin	0.057	Aluminium	Y
IBA FC-65G Farmer	0.65	23.1	3.1	Graphite	0.073	Aluminium	Y
IBA FC-23C Farmer	0.23	8.8	3.1	C-552	0.070	C-552	Y
IBA CC13	0.25	10.0	3.0	C-552	0.070	C-552	Y

Table 2: CHARACTERISTICS OF IONIZATION CHAMBERS SUITABLE FOR REFERENCE DOSIMETRY OF msr FIELDS *fmsr* < 6 cm × 6 cm

Ionization chamber type	Cavity volume (cm^3)	Cavity length (mm)	Cavity radius (mm)	Wall material	Wall thickness (g/cm^2)	Central electrode material	Waterproof
Capintec PR-05P minia	0.07	5.5	2.0	C-552	0.220	C-552	N
Exradin A1 mini Shonka (2 mm cap)	0.057	5.7	2.0	C-552	0.176	C-552	Y
Exradin A1SL mini Shonka slimlinea	0.057	5.7	2.1	C-552	0.176	C-552	Y
Exradin A14 micro Shonkaa	0.016	2.0	2.0	C-552	0.176	C-552	Y
Exradin A14SL micro Shonka slimlinea	0.016	2.1	2.1	C-552	0.194	C-552	Y
Exradin A14P micro planar	0.002	1.0	2.0	C-552	0.176	C-552	Y
Exradin A16 micro	0.007	1.7	1.2	C-552	0.088	C-552	Y
Exradin A18 thimble	0.125	4.9	2.5	C552	0.176	C-552	Y
IBA CC01a	0.01	3.6	1.0	C-552	0.088	Steel	Y
IBA CC04a	0.04	3.6	2.0	C-552	0.070	C-552	Y
IBA CC08	0.08	4.0	3.0	C-552	0.070	C-552	Y
IBA CC13	0.13	5.8	3.0	C-552	0.070	C-552	Y
IBA CC13-S	0.13	5.8	3.0	PEEK/ C-552	0.154	C-552	Y
Nuclear Assoc 30-750	0.03	3.6	2.0	C-552	0.068	C-552	Y
Nuclear Assoc 30-749	0.08	4.0	3.0	C-552	0.068	C-552	Y
Nuclear Assoc 30-744	0.13	5.8	3.0	C-552	0.068	C-552	Y
PTW 31010 Semiflex	0.125	6.5	2.8	PMMA	0.078	Aluminium	Y
PTW 31014 PinPointa	0.015	5.0	1.0	PMMA	0.085	Aluminium	Y
PTW 31015 PinPoint	0.030	5.0	1.45	PMMA	0.085	Aluminium	Y
PTW 31016 PinPoint 3D	0.016	2.9	1.45	PMMA	0.085	Aluminium	Y
Victoreen Radocon II 555	0.1	4.3	2.5	Delrin	0.529	(no data)	N

Code of Practice for reference dosimetry of machine specific reference fields f_{msr}

Reference conditions

Reference conditions are **machine dependent**:

1. In high energy photon beams (general)
2. In high energy photon beams on cyberknife machines
3. In high energy photon beams on tomotherapy machines
4. On Gamma Knife machines

TABLE 8. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN HIGH ENERGY PHOTON BEAMS

Influence quantity	Reference value or reference characteristics
Phantom material	Water
Phantom shape and size	At least 30 cm × 30 cm × 30 cm
Chamber type	Cylindrical
Measurement depth z_{ref}	10 g/cm^2
Reference point of chamber	On the central axis at the centre of the cavity volume
Position of reference point of chamber	At the measurement depth z_{ref}
SSD/SDD	100 cm or the closest achievable[a]
Field size	10 cm × 10 cm[b] or size of the msr field[c]

TABLE 9. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN HIGH ENERGY PHOTON BEAMS ON CYBERKNIFE MACHINES

Influence quantity	Reference value or reference characteristics
Phantom material	Water
Phantom shape and size	At least 30 cm × 30 cm × 30 cm
Chamber type	Cylindrical
Measurement depth z_{ref}	10 g/cm^2
Reference point of chamber	On the central axis at the centre of the cavity volume
Position of reference point of chamber	At the measurement depth z_{ref}
SDD	80 cm
Field shape and size	Circular, maximum available, fixed collimator (6 cm diameter)

TABLE 10. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER IN HIGH ENERGY PHOTON BEAMS ON TOMOTHERAPY MACHINES

Influence quantity	Reference value or reference characteristics
Phantom material	Water
Phantom shape and size	At least 30 cm × 30 cm × 30 cm
Chamber type	Cylindrical
Measurement depth z_{ref}	10 g/cm^2
Reference point of chamber	On the central axis at the centre of the cavity volume
Position of reference point of chamber	At the measurement depth z_{ref}
SSD/SDD	85 cm[a]
Field shape and size	Rectangular (5 cm × 10 cm for TomoTherapy HiArt)

[a] The reference SSD or SDD (for source-to-axis distance set-up) is that used for clinical treatments.

TABLE 11. REFERENCE CONDITIONS FOR THE DETERMINATION OF ABSORBED DOSE TO WATER ON GAMMA KNIFE MACHINES

Influence quantity	Reference value or reference characteristics
Phantom material	Water or plastic (polystyrene, ABS, Solid Water, etc.)[a]
Phantom shape and size	Hemispherical atop a cylinder, 16 cm diameter
Chamber type	Microchamber, cylindrical
Measurement depth z_{ref}	Centre of the hemisphere[b]
Reference point of chamber	On the central axis at the centre of the cavity volume
Position of reference point of chamber	At the centre of the hemisphere
SSD	32 cm
Field size	Circular, maximum available (1.6 or 1.8 cm diameter)[c]

Code of Practice for reference dosimetry of machine specific reference fields f_{msr}

Machine specific determination of absorbed dose to water when the conventional f_{ref} (10 x 10 cm^2) can be realized

Basic formula: $$D_{\mathrm{w,Q_{msr}}}^{f_{msr}} = M_{\mathrm{Q_{msr}}}^{f_{\mathrm{msr}}} \cdot N_{\mathrm{D,w}(,\mathrm{Q_0})}^{f_{ref}} \cdot k_{\mathrm{Q_{msr}}(,\mathrm{Q_0})}^{f_{\mathrm{msr}},f_{ref}}$$

If the conventional reference field f_{ref} *= 10 cm × 10 cm can be established at the machine, then:*

- ***f_{msr} will be replaced by f_{ref}***
- ***beam quality Q_{msr} will be replaced by Q.***

$$D_{w,Q}^{f_{ref}} = M_{Q_{msr}}^{f_{ref}} \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q(,Q_0)}^{f_{ref}} = M \cdot N_{D,w} \cdot k_Q$$

Tables for k_Q:

For machines with flattening filter (WFF):	Table 12 of TRS 483
For flattening filter free machines (FFF):	Table 13
For the Gamma Knife:	Table 14

TABLE 12. $k_Q^{f_{ref}}$ DATA FOR THE CONVENTIONAL f_{ref} FIELD (10 cm × 10 cm) FOR REFERENCE IONIZATION CHAMBERS IN WFF LINACS, AS A FUNCTION OF THE BEAM QUALITY INDICES $TPR_{20,10}(10)$ AND $\%dd(10,10)_x$

Ion chamber ↓	$TPR_{20,10}(10)$ = $\%dd(10,10)_x$ =	0.630 63.4	0.660 65.2	0.690 67.6	0.720 70.5	0.750 73.9
Capintec PR-06C/G Farmer		0.997	0.994	0.991	0.988	0.982
Exradin A2 Spokas		0.998	0.997	0.995	0.992	0.988
Exradin A12 Farmer		0.998	0.996	0.993	0.990	0.984
Exradin A12S		0.996	0.994	0.991	0.987	0.981
Exradin A19		0.996	0.993	0.990	0.985	0.980
Nuclear Assoc 30-751 Farmer		0.996	0.993	0.990	0.985	0.979
Nuclear Assoc 30-752 Farmer		0.997	0.995	0.992	0.989	0.983
NE 2505/3, 3A Farmer		0.996	0.994	0.992	0.989	0.984
NE 2571 Farmer		0.997	0.994	0.992	0.989	0.984
NE 2611		0.996	0.993	0.991	0.988	0.984
PTW 23331 rigid		0.996	0.992	0.989	0.985	0.980

(continued)

TABLE 13. $k_{Q_{msr}}^{f_{msr},f_{ref}}$ DATA FOR THE CONVENTIONAL f_{ref} FIELD (10 cm × 10 cm) FOR REFERENCE IONIZATION CHAMBERS IN FFF LINACS, AS A FUNCTION OF THE BEAM QUALITY INDICES $TPR_{20,10}(10)$ AND $\%dd(10,10)_x$, AND FOR THE CYBERKNIFE AND TOMOTHERAPY MACHINES

Ion chamber ↓	$TPR_{20,10}(10)$ = $\%dd(10,10)_x$ =	0.63 63.8	0.66 65.6	0.69 68.2	0.72 71.7	0.75 76.1	CyberKnife	TomoTherapy
Capintec PR-06C/G Farmer		0.996	0.995	0.992	0.988	0.981	1.000	0.996
Exradin A2 Spokas		0.996	0.996	0.993	0.989	0.983	0.997	0.996
Exradin A12 Farmer		0.998	0.997	0.994	0.991	0.984	1.004	0.998
Exradin A12S		0.994	0.993	0.989	0.984	0.977	0.993	0.994
Exradin A19		0.995	0.995	0.991	0.987	0.981	1.002	0.995
Nuclear Assoc 30-751 Farmer		0.995	0.994	0.991	0.986	0.979	1.000	0.995
Nuclear Assoc 30-752 Farmer		0.997	0.996	0.993	0.990	0.983	1.002	0.997
NE 2505/3, 3A Farmer		0.996	0.996	0.993	0.990	0.985	1.003	0.996
NE 2571 Farmer		0.996	0.995	0.993	0.990	0.985	1.003	0.996
NE 2611		0.994	0.992	0.989	0.985	0.979	0.993	0.993

(continued)

TABLE 14. CORRECTION FACTORS $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ FOR THE GAMMA KNIFE MODELS PERFEXION AND 4C [110, 153]

Chamber type	Perfexion f_{msr} = 16 mm ∅			4C f_{msr} = 18 mm ∅		
	Solid Water	ABS	Water	Solid Water	ABS	Water
PTW T31010	1.0037	1.0146	1.0001	0.9958	0.9990	0.9924
PTW T31016	1.0040	1.0110	0.9991	1.0014	1.0025	0.9964
Exradin A1SL	1.0046	1.0138	1.0006	1.0009	1.0014	0.9967
Exradin A14SL	1.0154	1.0194	1.0112	1.0116	1.0060	1.0058
Exradin A16	1.0167	1.0295	1.0127	1.0163	1.0217	1.0104
IBA CC01	1.0213	1.0292	1.0169	1.0203	1.0208	1.0157
IBA CC04	1.0107	1.0117	1.0062	1.0086	1.0049	1.0040
Capintec PR05-P 4.7	1.0059	1.0070	1.0010	1.0007	0.9960	0.9951
Capintec PR05-P 7.6	1.0025	1.0126	0.9976	0.9885	0.9972	0.9844

Machine specific determination of absorbed dose to water when the conventional f_{ref} (10 x 10 cm^2) **cannot** be realized

Basic formula: $$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q(,Q_0)}^{f_{ref}} \cdot k_{Q_{msr}Q}^{f_{msr},f_{ref}}$$

However, based on current knowledge and uncertainty estimates, it can be assumed that: $$k_{Q_{msr}Q}^{f_{msr},f_{ref}} = 1$$

$$\Rightarrow \quad D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q(,Q_0)}^{f_{ref}}$$

WFF machines: Table 12 of TRS 483

FFF machines: Table 13

However, the question remains:

Which radiation quality Q has to taken??

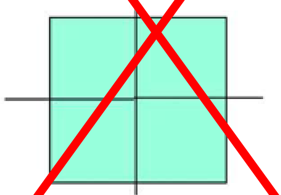
Remember:
A 10 x 10 cm^2 field cannot be realized, however it would be required to determine $TPR_{20,10}(10)$

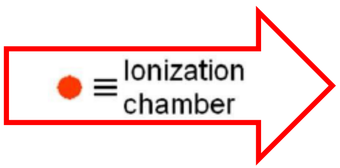
TRS 483 Step 1:

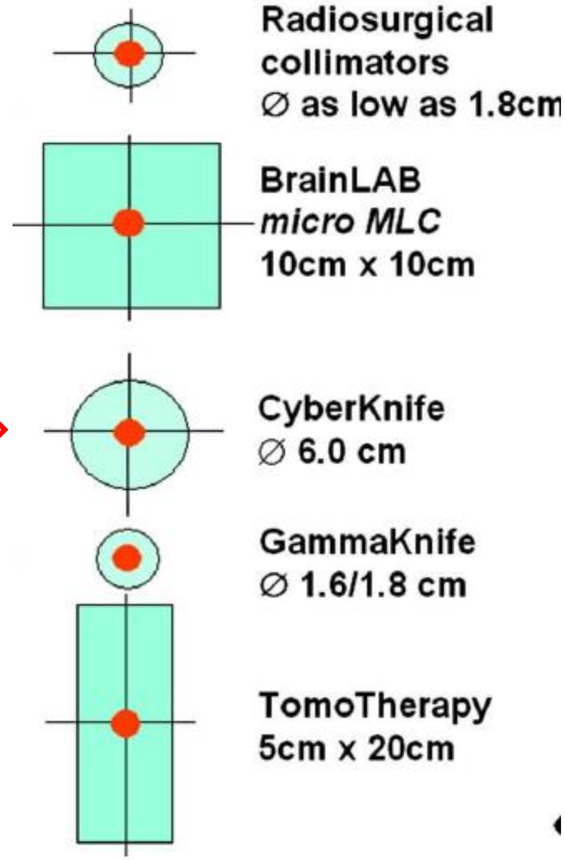
machine specific reference field

f_{msr}

$$D_{w,Q} = M_Q \, N_{D,w,Q_o} \, k_{Q,Q_o}$$







Two further steps are required to arrive at Q:

1. Determination of an equivalent square msr field size, denoted as S (see TRS 483, Table 15, 16 and 17

2. Experimental determination of $TPR_{20,10}(10)$

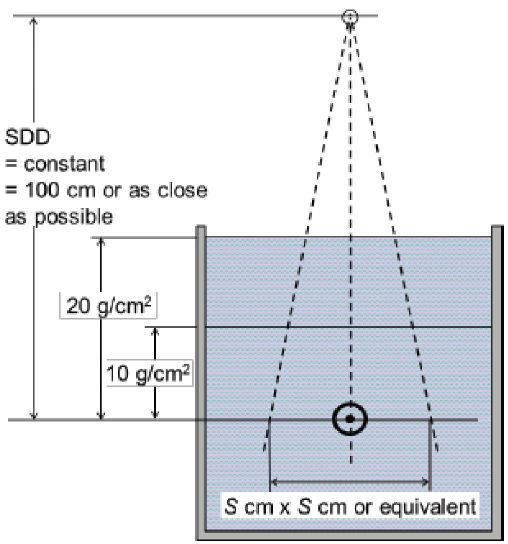


FIG. 14. Experimental set-up for the measurement of $TPR_{20,10}$(S). The SDD is kept constant at 100 cm or as close to that distance as possible, and measurements are made with 10 g/cm² and 20 g/cm² of water over the reference point of the chamber. The field at the position of the reference point of the chamber has an equivalent square msr field size S. Either a cylindrical or a plane-parallel ionization chamber can be used (reproduced from Ref. [1]).

$$TPR_{20,10}(S)$$

The beam quality index Q = $TPR_{20,10}(10)$ for the hypothetical conventional reference field 10 cm × 10 cm is then obtained by:

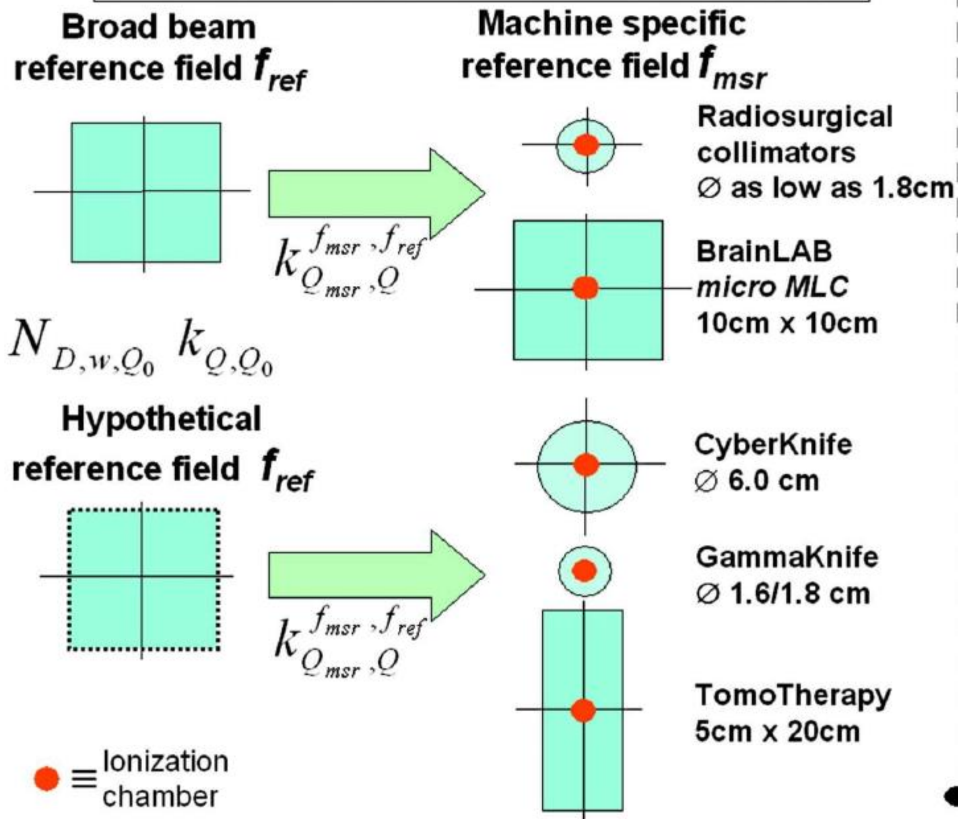
$$TPR_{20,10}(10) = \frac{TPR_{20,10}(S) + c \cdot (10 - S)}{1 + c \cdot (10 - S)}$$

where c = (16.15 ± 0.12) × 10^{-3}

1

REFERENCE DOSIMETRY

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}}\ N_{D,w,Q_0}\ k_{Q,Q_0}\ k_{Q_{msr},Q}^{f_{msr},f_{ref}}$$



Code of Practice for reference dosimetry of machine specific reference fields f_{msr}

Measurement in plastic water substitute phantoms

For some treatment units, the use of water phantoms for reference dosimetry is possible but highly inconvenient, and therefore plastic water substitute phantoms may be necessary.

Today, there are well appropriate plastic materials:

- polymethylmethacrylate (PMMA) (Lucite)
- acrylonitrile butadiene styrene (ABS)
- Solid Water® (Sun Nuclear Corp., Melbourne, FL)

TRS 483 gives a methodology for use of plastic water substitute phantoms that complements the dosimetry in the reference conditions.

Modified basic formula:

$$D_{w,Q_{msr}}^{f_{msr}}\left(z_{ref}\right) = M_{Q_{msr}}^{f_{msr}}\left(z_{eq.plastic}\right) \cdot N_{D,w(,Q_0)}^{f_{ref}} \cdot k_{Q_{msr}(,Q_0)}^{f_{msr},f_{ref}} \cdot k_{Q_{msr}}^{w,plastic}$$

TRS 483 Step 2:

A full dosimetrical characterization of small fields for clinical use requires not only the calibration of the beam under reference conditions (= step 1) but also the determination of:

- **field output factors**, necessary for the calculation of monitor units or treatment time
- central axis **percentage depth dose** (PDD) distributions
- **tissue phantom ratios** (TPR) or tissue maximum ratios (TMR)
- **lateral beam profiles**.

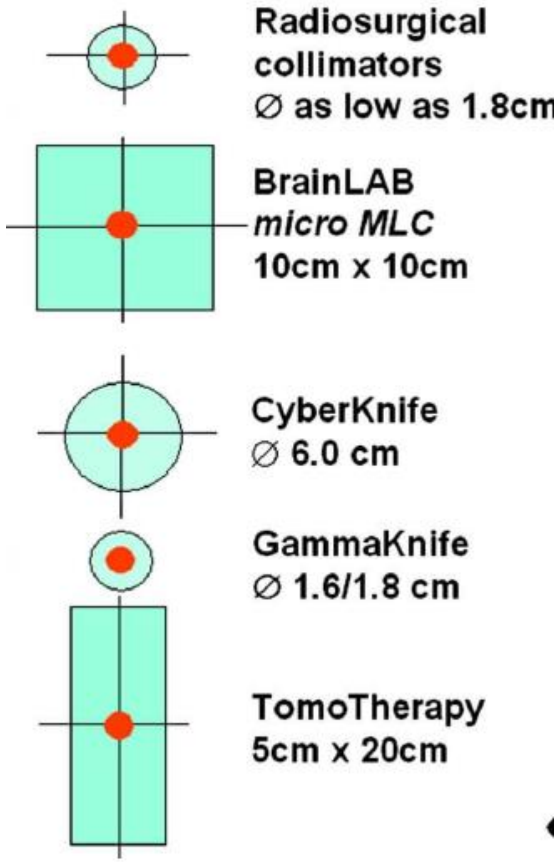
TRS 483 also provides a guide for measurements of field output factors and lateral beam profiles. The main aim is:

$$D_{w,Q_{msr}}^{f_{msr}} \xrightarrow{??} D_{w,Q_{clin}}^{f_{clin}}$$

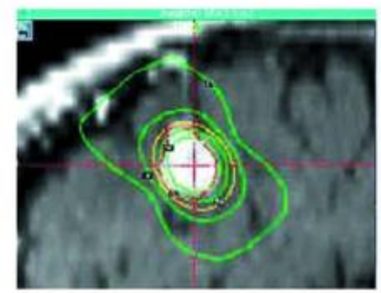
Step 2: **Relative dosimetry**

machine specific reference field f_{msr}

clinical field f_{clin}



relative dosimetry



e.g. a GammaKnife clinical plan

Step 2: Relative dosimetry

Formalism for the field output factor

Introduction of a field output factor Ω: $$D_{w,Q_{clin}}^{f_{clin}} = \Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} \cdot D_{w,Q_{msr}}^{f_{msr}}$$

Definition of the field output factor Ω as relative dose: $$\Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{D_{w,Q_{clin}}^{f_{clin}}}{D_{w,Q_{msr}}^{f_{msr}}}$$

Ω is derived as: $$\Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} \overset{??}{=} \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}}$$

This is valid only if

- the reading of the detector, ***M*** is directly proportional to the absorbed dose ***D*** to water
- the proportionality factor remains constant between f_{msr} and f_{clin}.

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

output correction factor

Step 2: Relative dosimetry: Formalism

The output correction factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ can be determined as:

$$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{D_{w,Q_{clin}}^{f_{clin}} \Big/ \overline{D}_{det,Q_{clin}}^{f_{clin}}}{D_{w,Q_{msr}}^{f_{msr}} \Big/ \overline{D}_{det,Q_{msr}}^{f_{msr}}}$$

$\overline{D}_{det}$ is the absorbed dose in the detector medium averaged over the detector volume

Methods for determination of $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ as:

- a directly measured value
- an experimental generic value
- a Monte Carlo calculated generic value

Step 2: Relative dosimetry: Formalism

The output correction factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ can also be expressed by the response of a detector

The response ***R*** of a detectors is generally defined as:

$$R = \frac{M}{D}$$

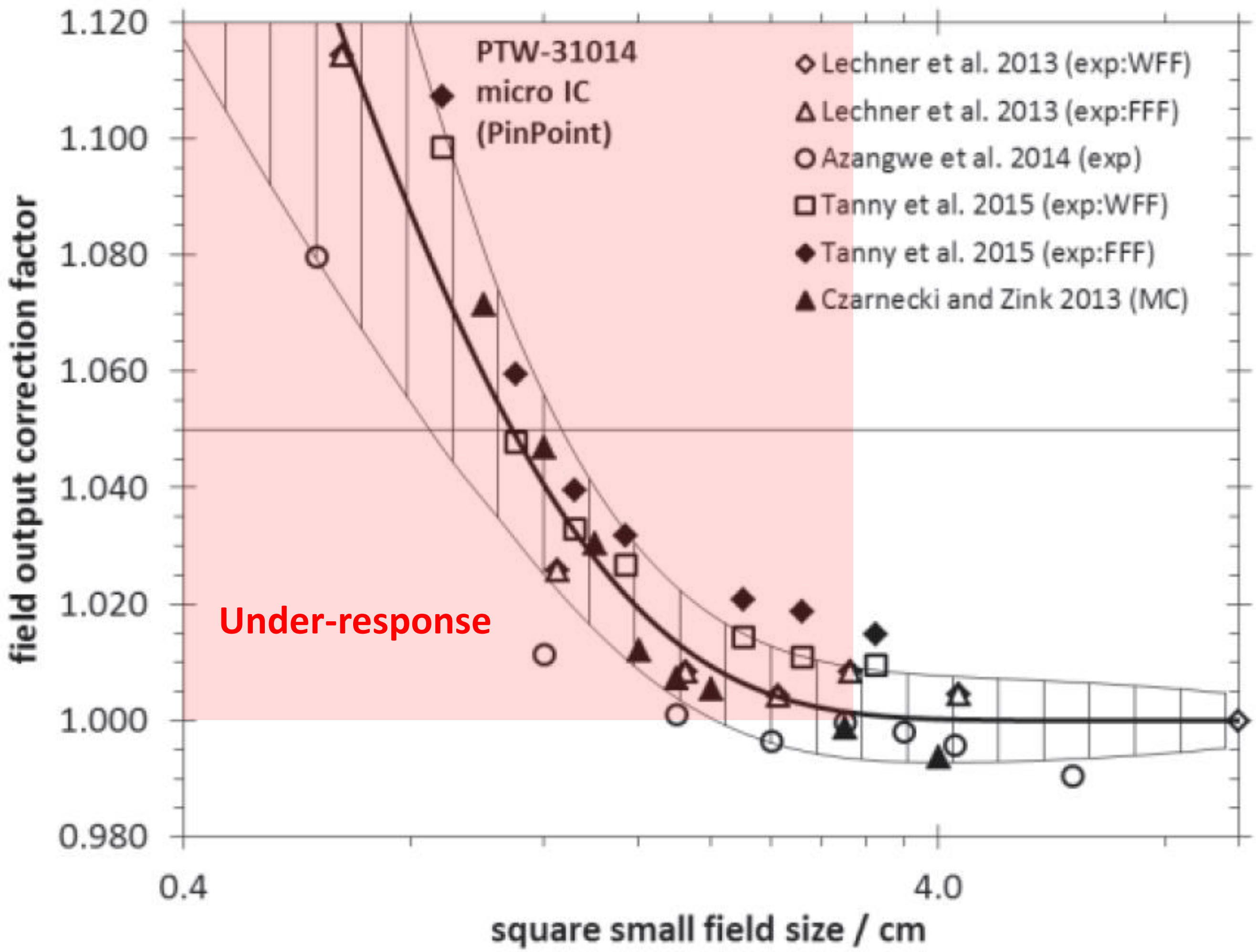
Substituting $D = M/R$ into $\Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{D_{w,Q_{clin}}^{f_{clin}}}{D_{w,Q_{msr}}^{f_{msr}}}$ yields:

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

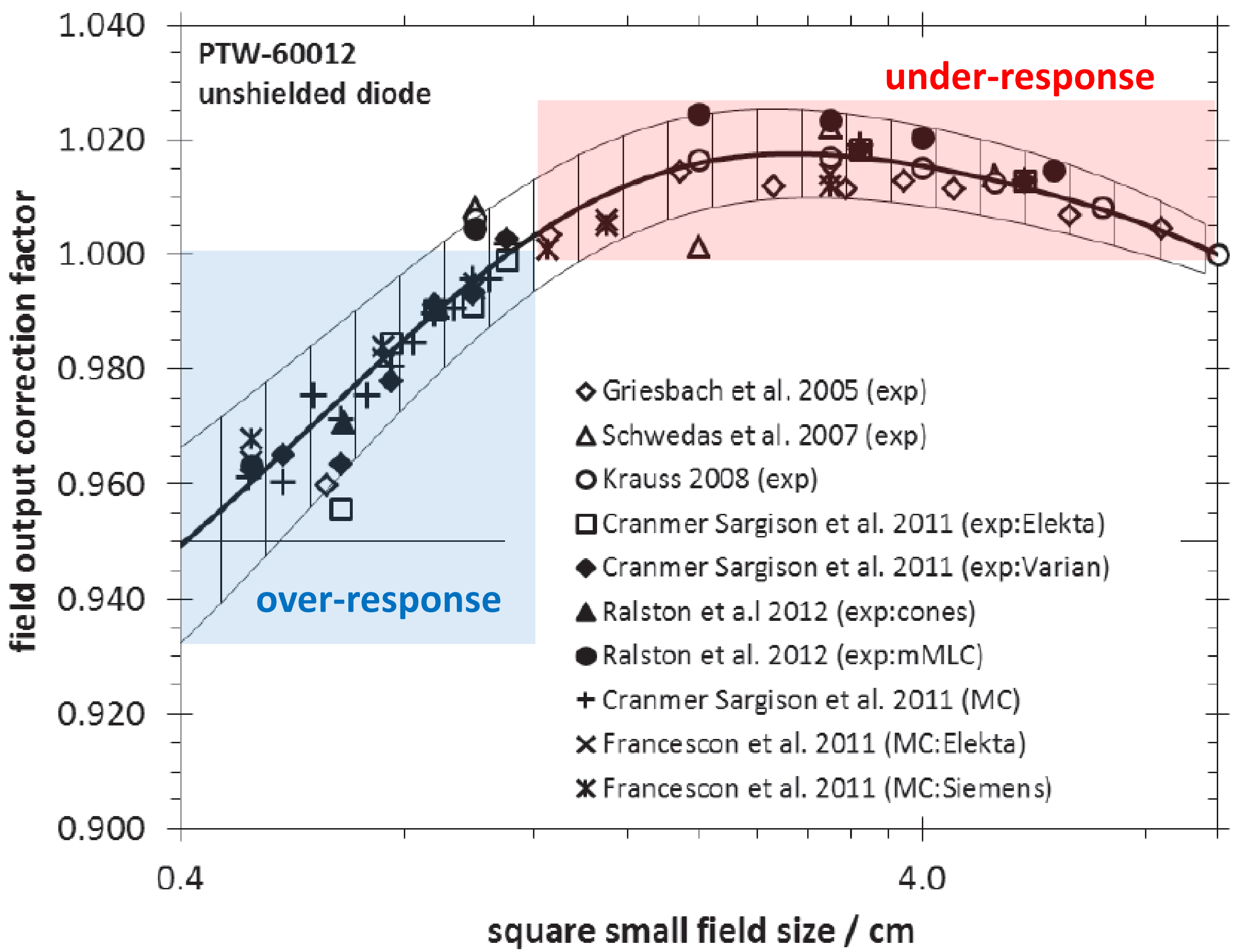
or, using $R_{\mathrm{rel}} = R_{clin}/R_{msr}$

$$\boxed{k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = 1/R_{\mathrm{rel}}}$$

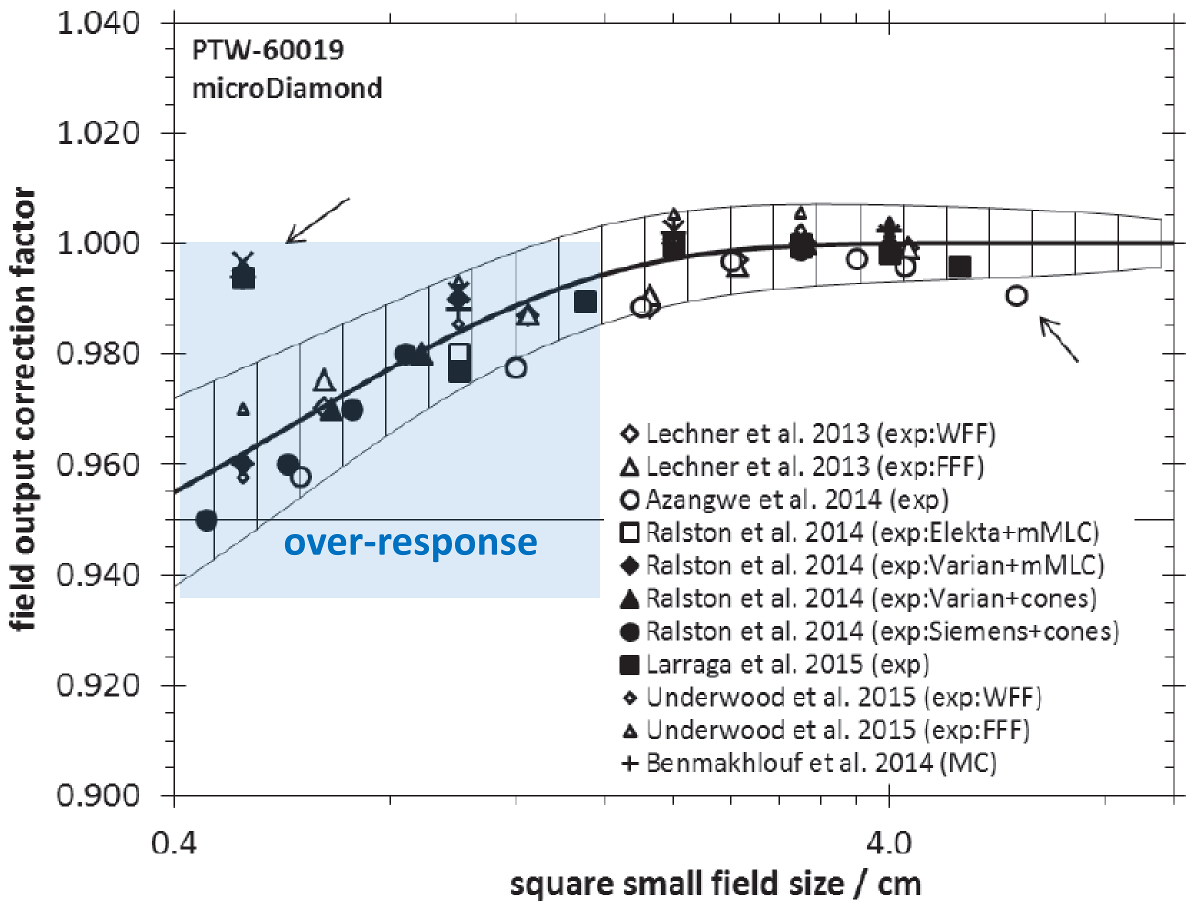
Three examples for the output correction factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$



Three examples for the output correction factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$



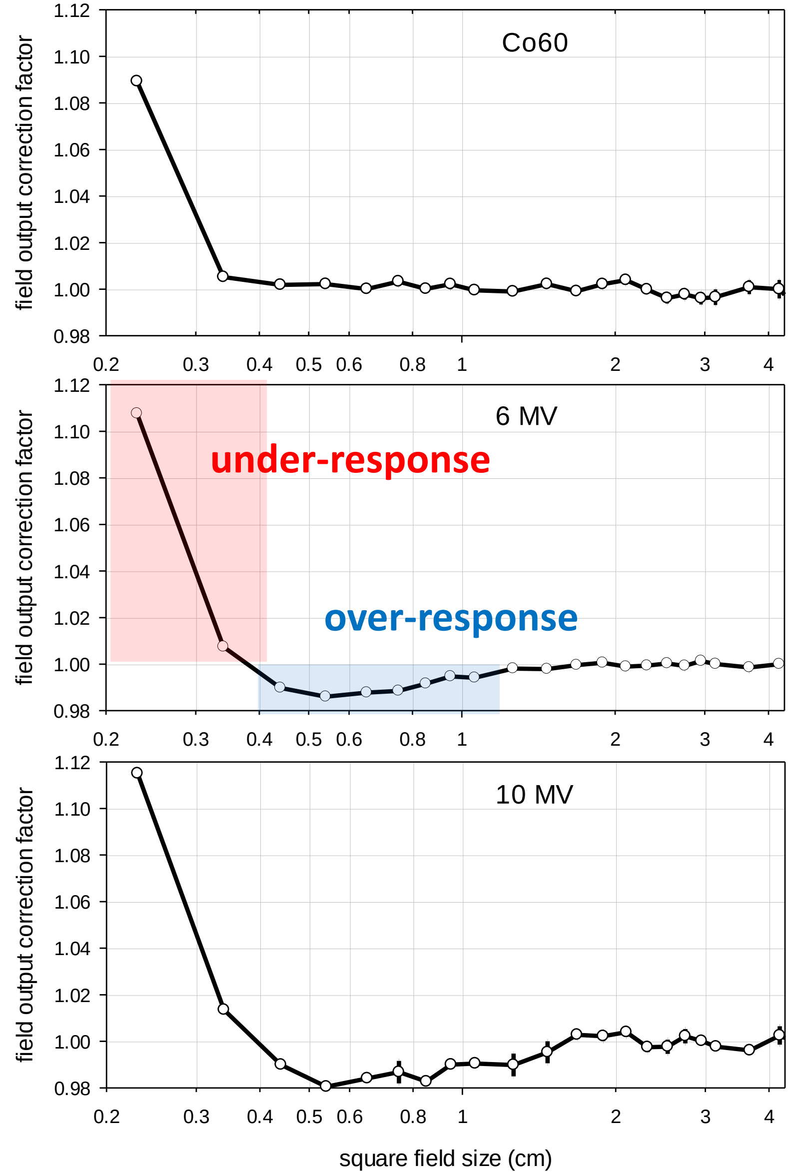
Three examples for the output correction factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$



Three examples for the output correction factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$

A Monte Carlo Study on the PTW 60019 MicroDiamond Detector

Günther H. Hartmann & Klemens Zink
(Med Phys, conditionally accepted)



Step 2: Relative dosimetry

Suitable detectors

Ideally, a detector should have a constant response which means $R_{rel} = 1$:

However, there is no ideal detector with a constant response for measurements in small fields.

For the determination of both field output factors and lateral beam profiles, the use of two or preferably three different types of suitable detectors is therefore advised.

Thus redundancy in the results can provide more confidence and assurance that no significant dosimetry errors are being made.

An example could be a combination of detectors with correction factors above and below unity (so that the product of these factors is close to one):

small air filled ionization chamber, radiochromic film & unshielded diode

diamond, liquid ion chamber & organic scintillator.

Suitable detectors

Again it must be emphasized that **no ideal detector** exists for measurements in small fields.

For this reason, in contrast to the situation for reference dosimetry, it is not possible to advise using a particular type of detector for particular relative measurements.

A wide range of detectors is described in the literature:

- vented air and liquid ionization chambers
- silicon diodes
- diamond detectors
- plastic and organic scintillators
- radiographic and radiochromic films
- metal oxide semiconductor field-effect transistors (MOSFETs)
- thermoluminescent dosimeters (TLDs)
- optically stimulated luminescence detectors (OSLDs)
- radio photoluminescence glass rods
- alanine

Suitable detectors

If a suitable detector for the entire range of field sizes from f_{msr} *to* f_{clin} is not available, it is advised to use an **ionization chamber** down to such a field size where the typical under-response of ionization chambers not yet sets in.

Such a field size is called the intermediate field, f_{int}.

The intermediate field should be as small as possible but without small field conditions. A typical field size is 5 cm x 5 cm.

Following this, one can use a suitable small field detector such as a diode only for measurements in smaller fields, thereby limiting the effect of the energy dependence.

Using this intermediate field method (IFM), the field output factor is obtained by:

$$\Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \left[\frac{M_{Q_{\text{int}}}^{f_{\text{int}}}}{M_{Q_{\text{msr}}}^{f_{\text{msr}}}}\right]_{\text{IC}} \cdot \left[\frac{M_{Q_{\text{clin}}}^{f_{\text{clin}}}}{M_{Q_{\text{int}}}^{f_{\text{int}}}} \cdot k_{Q_{\text{clin}},Q_{\text{int}}}^{f_{\text{clin}},f_{int}}\right]_{\text{det}} = \left[\frac{M_{Q_{\text{int}}}^{f_{\text{int}}}}{M_{Q_{\text{msr}}}^{f_{\text{msr}}}}\right]_{\text{IC}} \cdot \left[\frac{M_{Q_{\text{clin}}}^{f_{\text{clin}}}}{M_{Q_{\text{int}}}^{f_{\text{int}}}} \cdot \frac{1}{\left(R_{\text{clin}}/R_{\text{int}}\right)}\right]_{\text{det}}$$

Summary

The TRS 483 CoP advises to apply the two-steps-approach:

- Standard dosimetry at the msr field traceable to PSDL
- Relative dosimetry down to clinical fields using suitable detectors

Required $k_{Q_{\mathrm{msr}}(,Q_0)}^{f_{\mathrm{msr}},f_{ref}}$ values for the msr dosimetry are made available in TRS 483 for a variety of ionization chambers and machines

A variety of detectors and their response characteristics suitable for relative dosimetry are described.

Using the intermediate field method (IFM), one can overcome the problem of response changes which applies at any detector. In particular one can avoid the considerably increasing under-response of ionization chambers at very small field sizes.