Challenges in small field MV photon dosimetry

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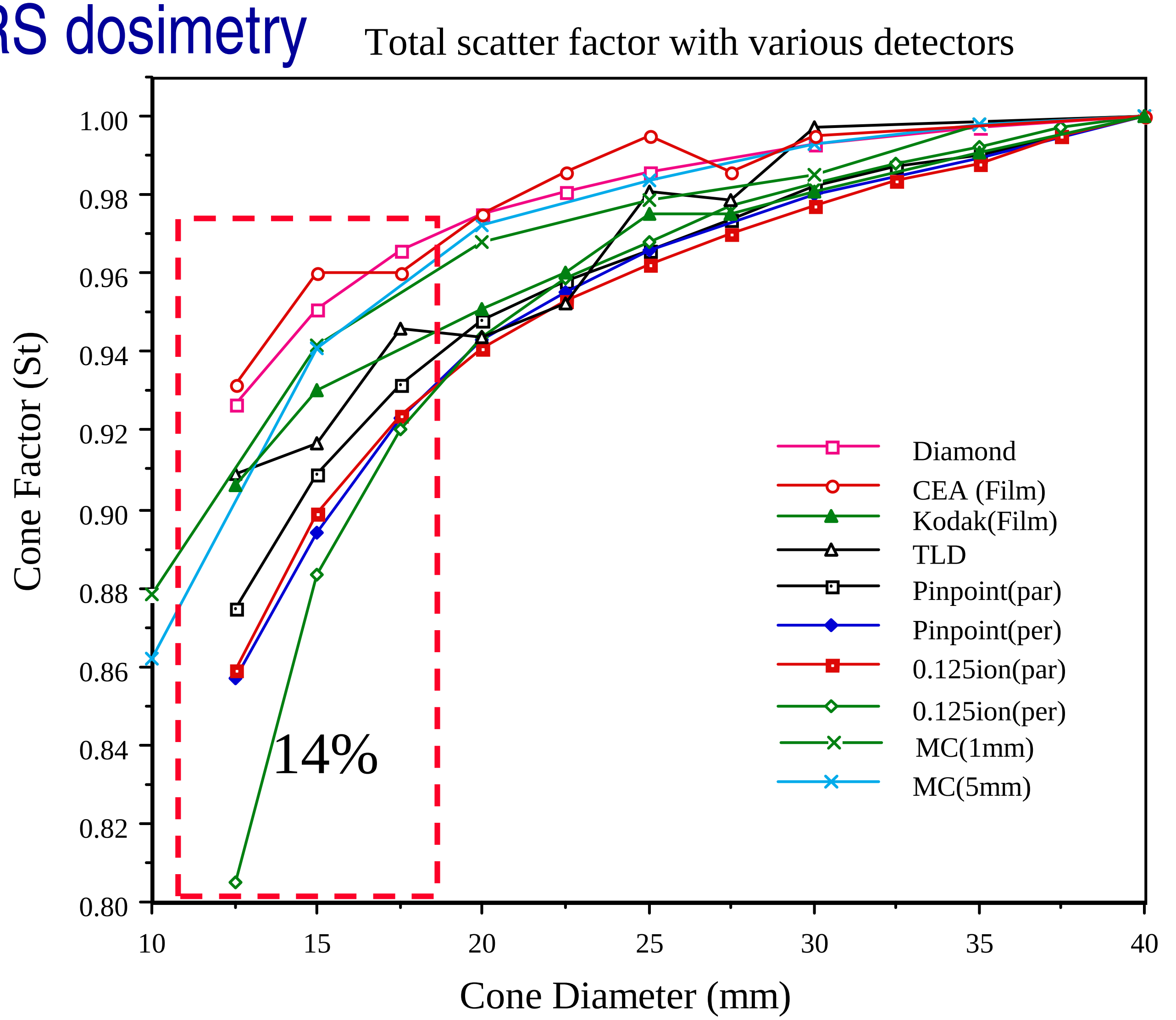
Why are we concerned with small MV photon fields?

SRS dosimetry



Which detector and measurement methodology?

Das et al, J Radiosurgery, 3, 177-186, 2000

Why are we concerned with small MV photon fields?

Incidents due to errors in dosimetry

AUTORITÉ DE SÛRETÉ NUCLÉAIRE

DIVISION DE BORDEAUX

RÉPUBLIQUE FRANÇAISE

Bordeaux, le 29 mai 2007

http://www.asn.fr/sites/default/files/files/Toulouse_ASN_report1.pdf?nocache=1225460993.4

REPORT

concerning the radiotherapy incident at the university hospital centre (CHU) in Toulouse – Rangueil Hospital

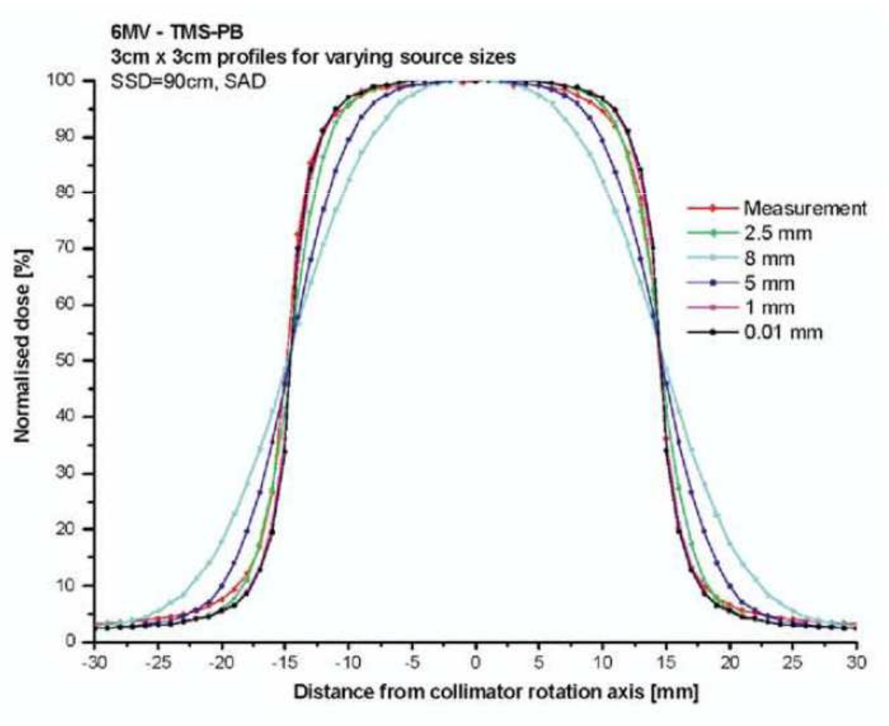
Although the origin of the event is clearly identified (use of a measuring device which was inappropriate for calibrating microbeams), the underlying causes remain to be determined; this, however, was not the main goal of the inspection. The letter following the inspection therefore asks the CHU to analyse the organisational and human factors, especially human resources, work load, skills and training.

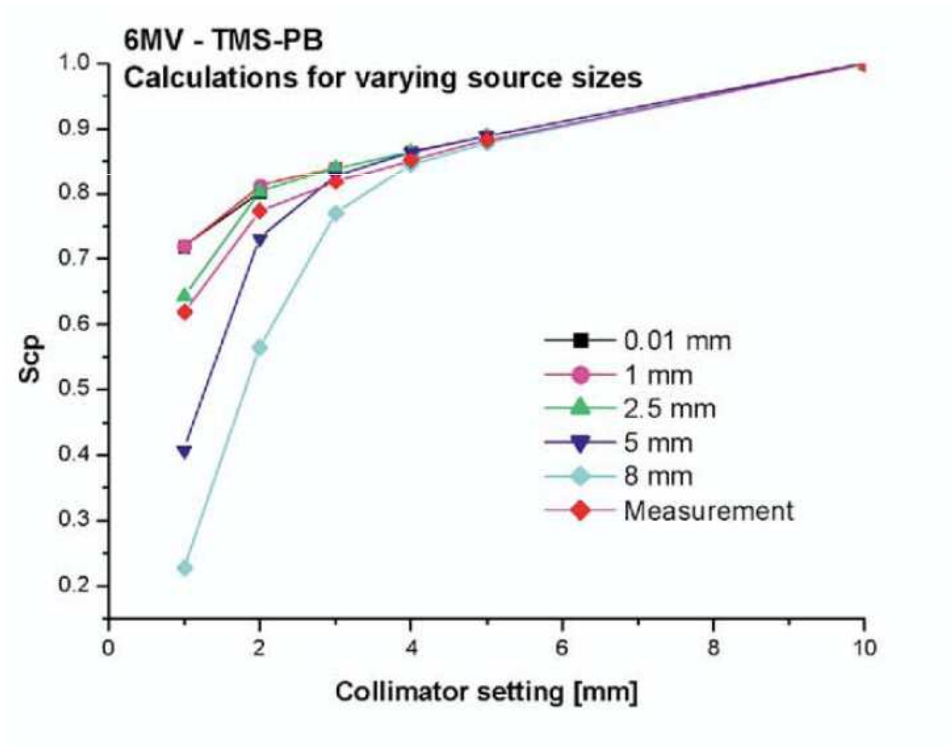
Is there enough education and training to carry out dosimetric measurements in small fields?

Why are we concerned with small MV photon fields?

Small MV photon fields on equipment originally designed and/or configured for treatments using broad photon fields

E.g. source size modelling on TPS



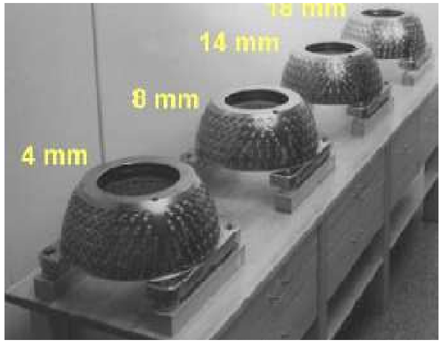


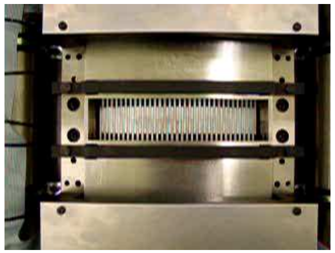
Aspradakis *et al* Med Dos 30, 233, 2005

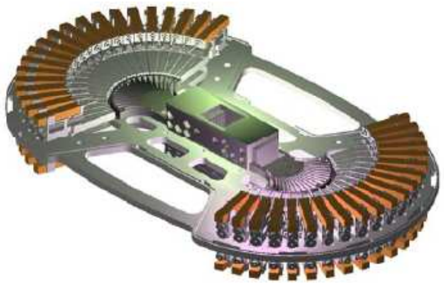
Appropriate fluence and dose models on TPSs?

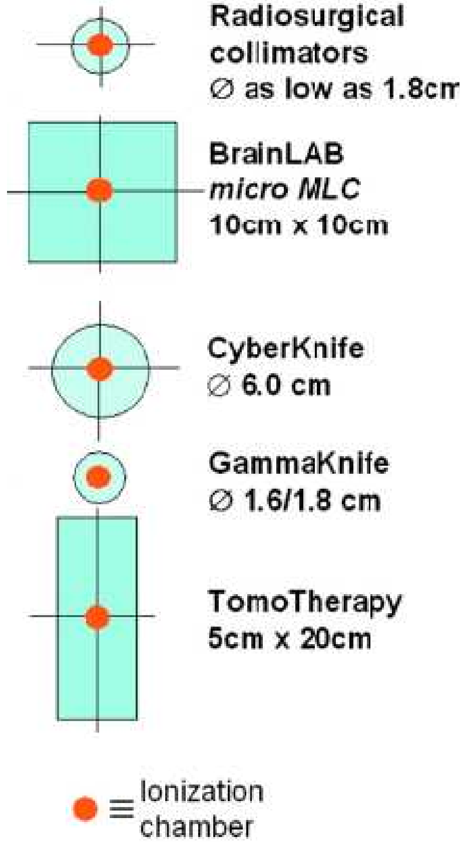
Why are we concerned with small MV photon fields?

Use of specialised equipment and techniques



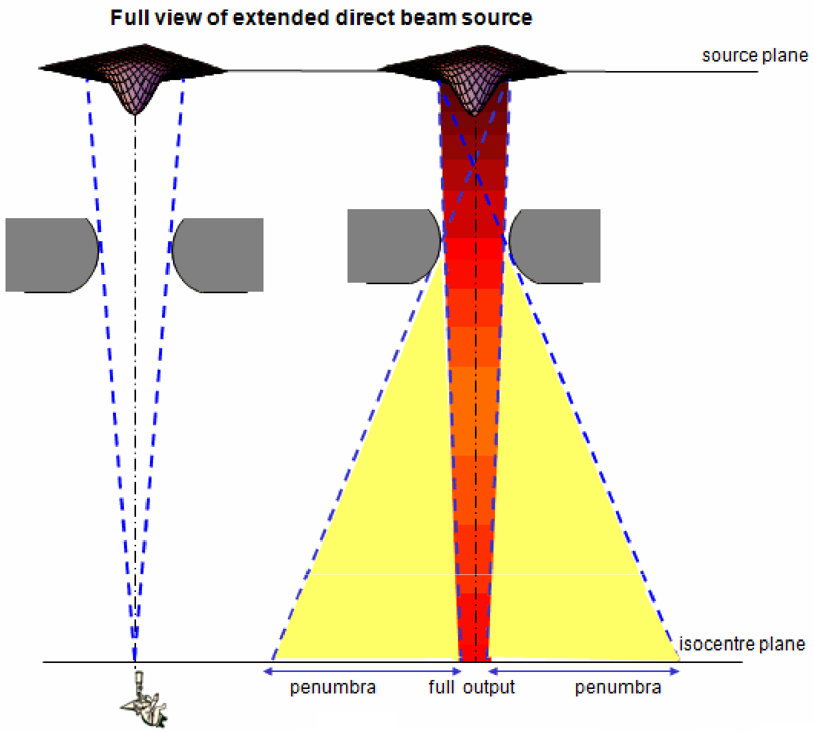


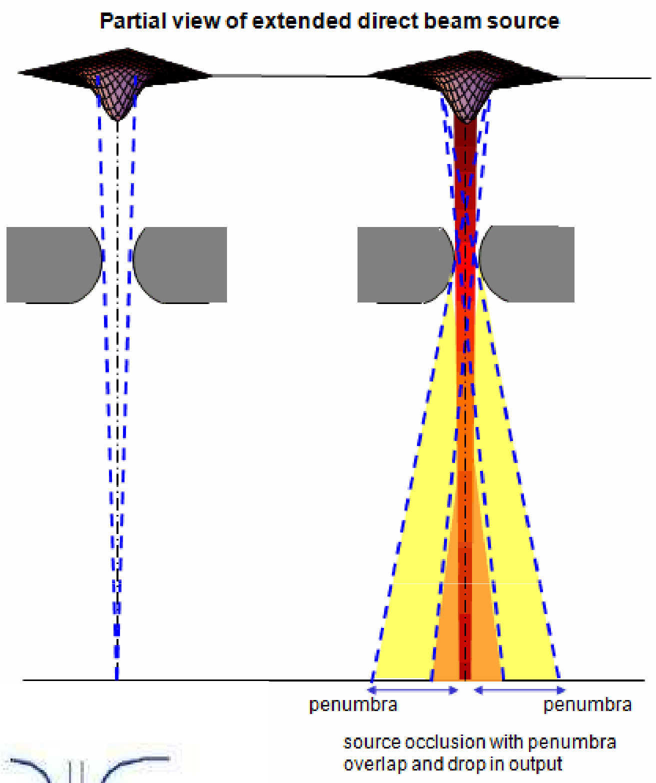


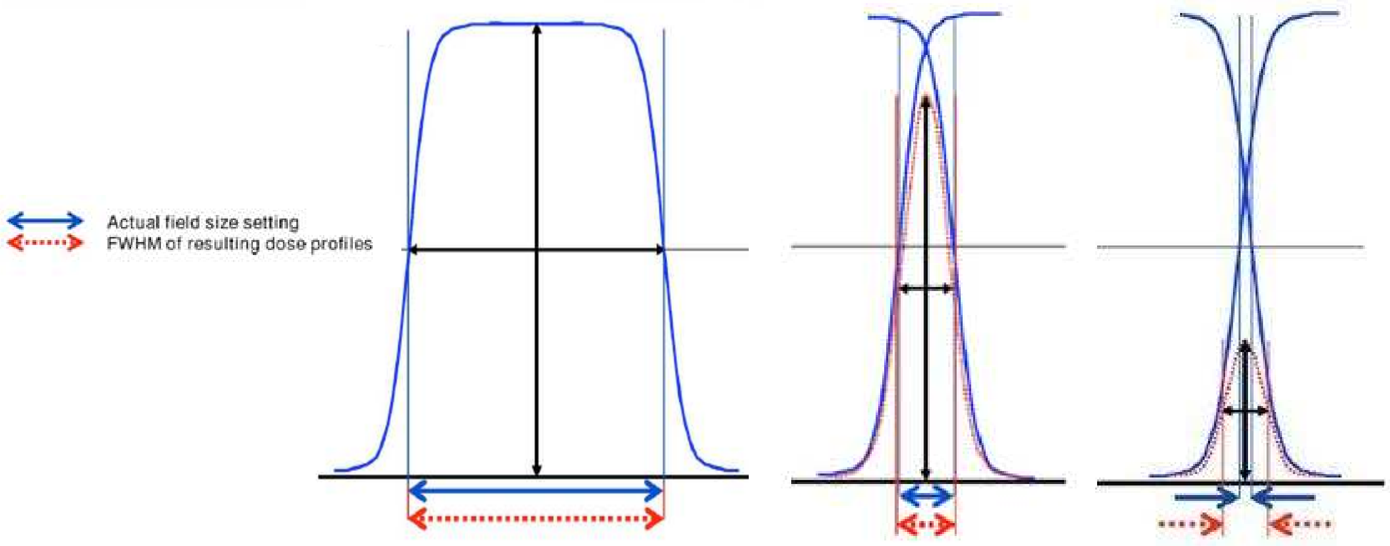


How to calibrate specialised equipment?

With decreasing field size:

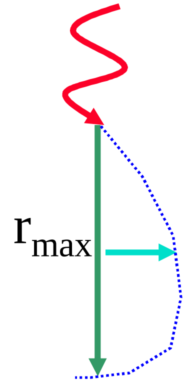


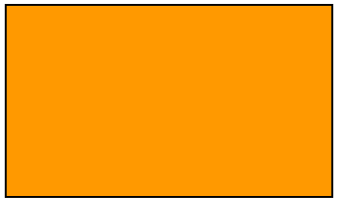




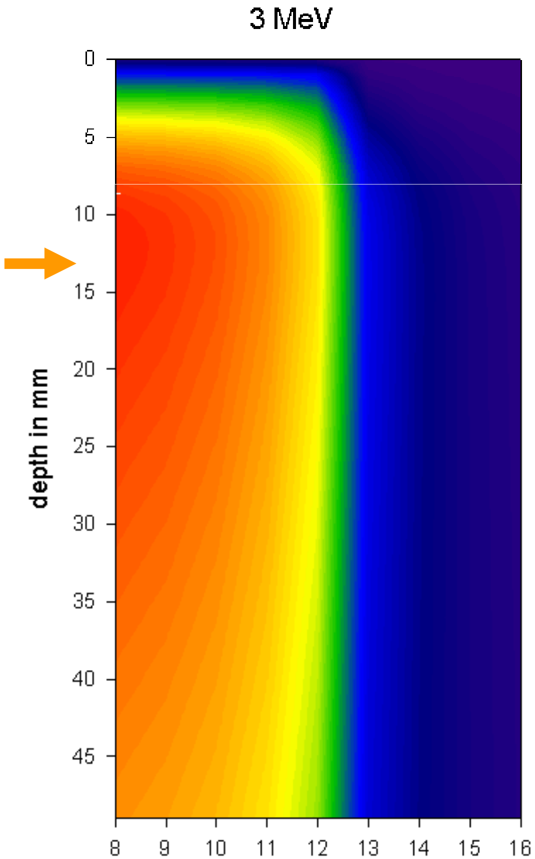
With decreasing field size:

The lateral range of the electrons compared to the field size influences dose in the **inner part** of the field.

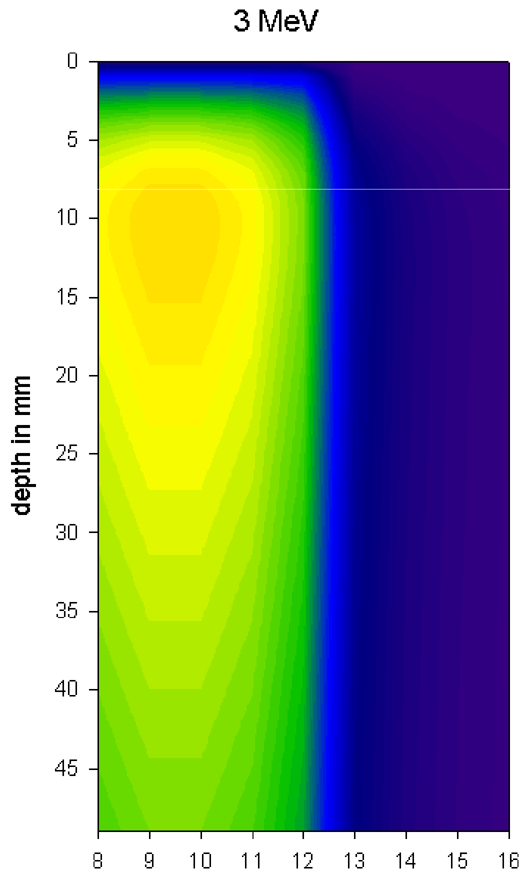




100 x 200 mm²



5 x 4 mm²



With decreasing field size:

1. Occlusion of the direct photon beam source
2. Drop in output and overlapping penumbrae
3. Lateral electron disequilibrium (depending on beam energy and irradiated medium)
4. Widening of FWHM of the dose profile $\rightarrow$**Is the FWHM an appropriate descriptor for field size in narrow collimated fields?**

5. $\Rightarrow$ The problem in dosimetric measurement? Detector size & construction
6. Detector becomes too large to resolve the penumbra and perturbs fluences at the position of measurement.

Definition of small MV photon field

- For the selected energy and medium, is the field size large enough to ensure CPE?
- Is the entire source in the detectors-eye-view?
- Is the detector small enough not to perturb fluence *significantly*?

Small MV photon fields

challenges

- Absolute dosimetry
- Reference dosimetry
- Relative dosimetry
- Modelling fluence and dose for small fields on treatment planning systems (TPS)
- Machine alignment & positional accuracy of collimating jaws

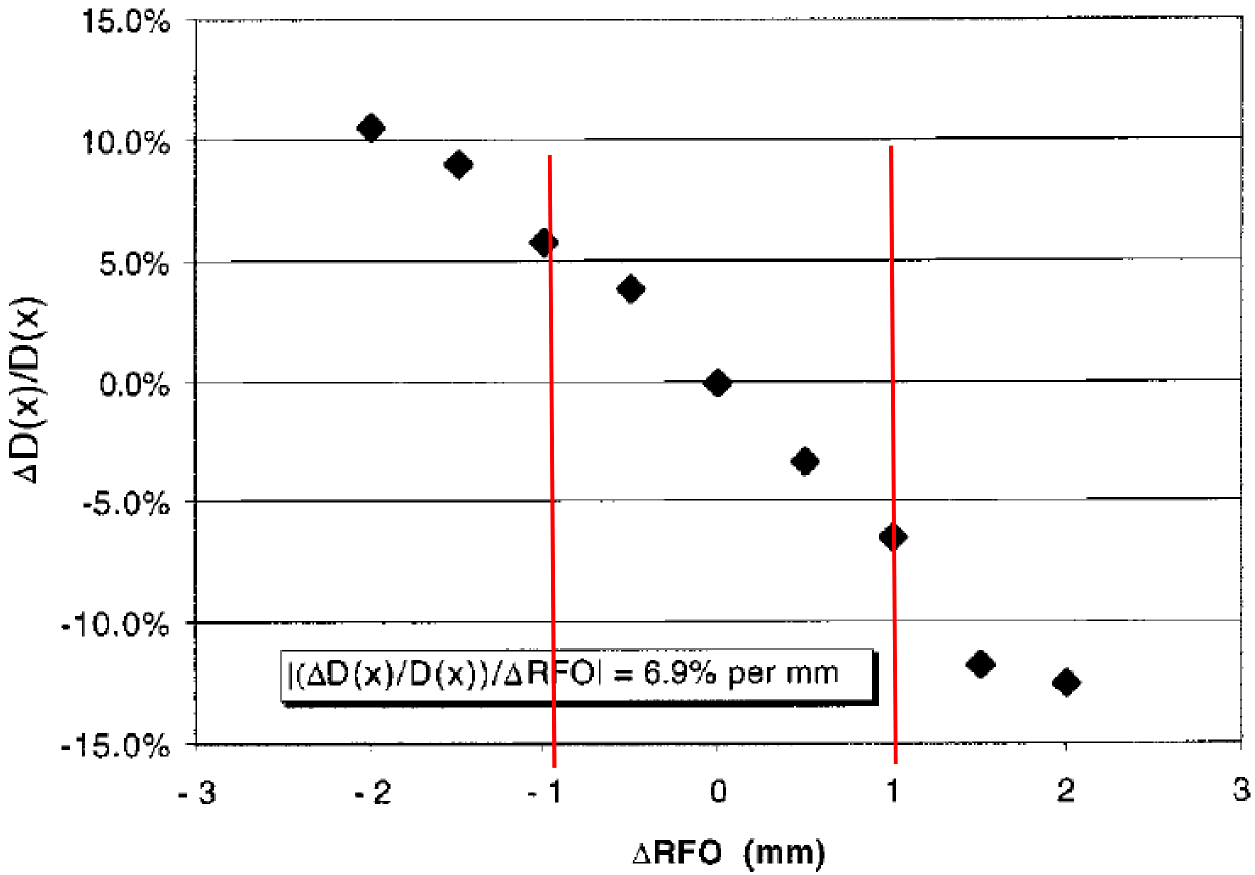
Machine alignment

- Standard linacs (gantry with collimating devices)
  - 0.5-1.5mm (1mm achievable)
    - IPEM Report 94 (2007)
    - AAPM report of Task Group 142 (2009) Med Phys 36(9)
- GammaKnife (convergence accuracy of 201 beams with the machine mechanical centre)
  - 0.5mm
    - Goetsch, S. J. (2008), Int J Radiat Oncol Biol Phys 71(1 Suppl): S118-21
- TomoTherapy (tolerance in all alignment checks)
  - 0.5^{o}/0.5mm
    - Balog and Soisson (2008). Int J Radiat Oncol Biol Phys 71(1 Suppl): S113-7
- CyberKnife (linac beam - laser beam coincidence)
  - better than 0.4mm
    - Antypas and Pantelis (2008). Phys Med Biol 53(17): 4697-718.

Calibration of collimating jaw

Implication of positional inaccuracy of collimating jaw

The fractional dose error to a position in the target volume per mm of RFO error



RFO: Radiation and light field offset at SAD for an MLC [mm]

An MLC leaf positional accuracy of 0.5mm needed, if the fractional dose error in the target is to be < 4%

Kung and Chen (2000), Med Phys 27(7): 1617-22

Reference dose measurement

with air-filled ionisation chambers

$$D_{water} = M\left[\left(\frac{\overline{W}_{air}}{e}\right)\frac{1}{m_{gas}}\right]\left[\left(\frac{\overline{S}}{\rho}\right)_{air}^{water} p_{det}\right]$$

$f_{water,air}$

conversion factor

To account for perturbations from B-G cavity theory:

$$p_{det} = p_{wall}\, p_{cel}\left(p_{gr}\, p_{fl}\right) = p_{wall}\, p_{cel}\, p_{repl}$$

under the reference conditions as defined in dosimetry codes of practice

$$D_{water,Q} = M_{water,Q}\, N_{D_w,Q_o}\, k_{Q,Q_o}$$

Reference dose measurement

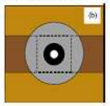
with air-filled ionisation chambers

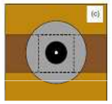
$$k_{Q,Q_o} = \frac{\left(\frac{W_{air}}{e}\right)_Q \left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_Q p_Q}{\left(\frac{W_{air}}{e}\right)_{Q_0} \left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_{Q_0} p_{Q_0}} \approx \frac{\left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_Q p_Q}{\left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_{Q_0} p_{Q_0}}$$

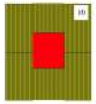
- *What is the influence of the spectral changes?*
- *How much does a detector perturb fluences?*

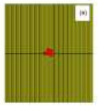
Spenser-Attix stopping power ratios on CAX at 5cm depth in water

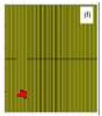

100 mm×100 mm


Beam ∅ 10 mm


Beam ∅ 3mm


100 mm×100 mm


20 mm×20 mm irregular on axis


20 mm×20 mm irregular off axis

		$s_{w,air}$			$s_{PMMA,air}$		
6 MV beams	Beam quality ($TPR_{20,10}$)	Andreo (1994)[a]	This work	Ratio this work/ Andreo	Andreo (1994)[a]	This work	Ratio this work/ Andreo
Elekta SL-18 radiosurgery							
10×10 cm^2	0.690	1.1187	1.1188	1.000	1.0853	1.0856	1.000
1.0 cm diameter			1.1155	0.997		1.0819	0.997
0.3 cm diameter			1.1153	0.997		1.0817	0.997
Siemens Primus MLC							
10×10 cm^2	0.677	1.1213	1.1221	1.001	1.0880	1.0892	1.001
2×2 cm^2 irregular on-axis			1.1203	0.999		1.0870	0.999
2×2 cm^2 irregular 8 cm off-axis			1.1250	1.003		1.0922	1.004
MLC transmission			1.1300	1.008			
IMRT beam (10×10 cm^2 approx)			1.1201	0.999			

[a] These are the values in the IAEA TRS-398 code of practice (Andreo *et al* 2000).

0.3%

0.5%

< 0.2%

Sanchez-Doblado et al (2003), PMB 48: 2081

Reference dose measurement

with air-filled ionisation chambers

$$k_{Q,Q_o} = \frac{\left(\frac{W_{air}}{e}\right)_Q \left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_Q p_Q}{\left(\frac{W_{air}}{e}\right)_{Q_0} \left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_{Q_0} p_{Q_0}} \approx \frac{\left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_Q p_Q}{\left[\left(\frac{\bar{S}}{\rho}\right)_{air}^{water}\right]_{Q_0} p_{Q_0}}$$

Conclusion: *Existing water to air ratios of Spencer-Attix restricted mass collision stopping powers published for broad (10cm x 10cm) fields can be used for dosimetry in small and composite fields.*

Challenge: derivation of perturbation factors for available small field (mini- and micro-) ionisation chambers

Challenge: derivation of perturbation factors for ionisation chambers

TABLE IV. Wall correction factors, replacement correction factors, and calculated k_Q of cylindrical ion chambers for a Cyberknife system and a linear accelerator.

$p_{det} \approx p_{wall} \, p_{repl}$

	P_{wall}		P_{repl}		k_Q	
Chamber type	Linac	Cyberknife	Linac	Cyberknife	Linac	Cyberknife
PTW 31002 flexible	1.0005	1.0004	0.9905	0.9893	0.9914	0.9887
PTW 30001 Farmer	1.0007	1.0006	0.9895	0.9881	0.9913	0.9885
PTW 30002 Farmer	0.9947	0.9945	0.9895	0.9881	0.9949	0.9921
PTW 30004 Farmer	0.9947	0.9945	0.9895	0.9881	0.9959	0.9930
PTW 30013 Farmer	1.0004	1.0003	0.9895	0.9881	0.9916	0.9889
Exradin A 12 Farmer	0.9915	0.9914	0.9895	0.9881	0.9984	0.9957

±0.3%

TABLE I. Physical characteristics of cylindrical ion chambers.

		Cavity dimensions		Wall			
Chamber type	Cavity volume (cm^3)	Length (mm)	Radius (mm)	Material	Thickness (g/cm^2)	Central electrode material	Waterproof
PTW 31002 flexible	0.13	6.5	2.8	PMMA	0.078	Aluminum	Y
PTW 30001 Farmer	0.6	23.0	3.1	PMMA	0.045	Aluminum	N
PTW 30002 Farmer	0.6	23.0	3.1	Carbon	0.079	Carbon	N
PTW 30004 Farmer	0.6	23.0	3.1	Carbon	0.079	Aluminum	N
PTW 30013 Farmer	0.6	23.0	3.1	PMMA	0.057	Aluminum	Y
Exradin A 12 Farmer	0.65	24.2	3.1	C-552	0.088	C-552	Y

Araki (2006), Med Phys 33(8)

<u>Challenge:</u> size of detector

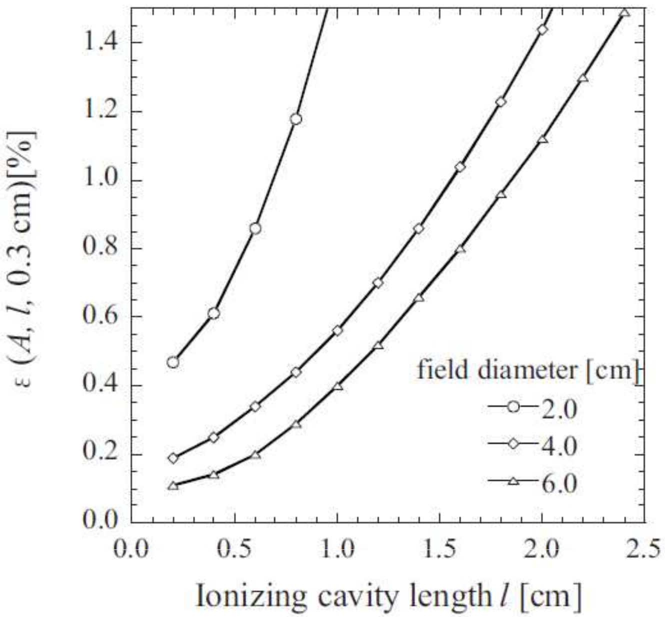


FIG. 2. The error of dosimeter reading $\varepsilon(A,l,0.3\text{ cm})$ (%) as a function of cavity length l of ionization chamber and field A. The cavity radius r is calculated in 0.3 cm, and these values are for a SCD of 80 cm at a depth of 10 cm in water.

Kawachi *el al* (2008), Med Phys 35 (10)

$$\varepsilon(A,l,r) = \frac{100\int_{-l/2}^{l/2}\int_{-r}^{r}|\mathrm{OAR}(A,x,y)-1|\mathrm{d}x\mathrm{d}y}{\int_{-l/2}^{l/2}\int_{-r}^{r}\mathrm{d}r\mathrm{d}y}$$

OAR(x,y) is the off axis distribution of field A in orthogonal directions x and y

A chamber of cavity length of 24mm underestimates dose by 1.5% in the 6cm field on Cyberknife

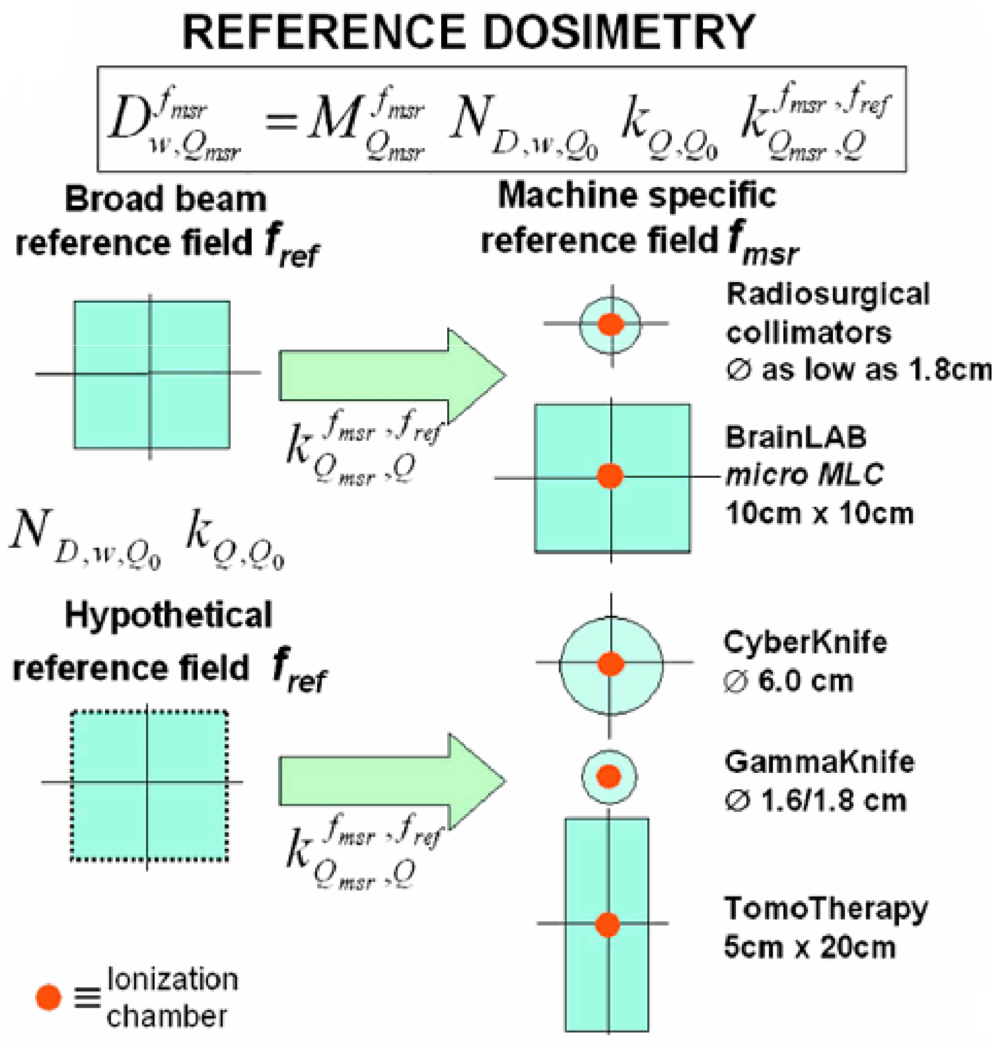
Reference dose measurements in a 6cm diameter radiation field need to be carried out with an ionisation chamber of length not greater than 10mm at a source-to-chamber distance of 80cm (CyberKnife).

Current status with reference dosimetry in small fields

1. Use of mini- or micro- air-filled ionisation chambers (BUT signal to noise ratio?)
2. The lack of perturbation factors increases uncertainty in the measurement.
3. Need to consider:
   - Chamber fully covered by the radiation field
   - Leakage
   - Cable effects
   - Polarity effects
4. Liquid-filled ion-chambers, diamonds and diodes not yet sufficiently characterised and commissioned for use in reference dosimetry.
5. Specialised systems:
   - alternative reference conditions or adopt the proposed IAEA/AAPM formalism (*Alfonso el al (2008), Med Phys 35 (11))*
   - alternative procedures to determine beam quality (Sauer, (2009). Med Phys 36(9): 4168-72).

The IAEA/AAPM formalism for reference dosimetry in small static MV photon fields

Alfonso el al (2008), Med Phys 35 (11), ***Update: AAPM2010 Poster SU-EE-A2-02***



f_{msr} machine specific reference field

Q_{msr} beam quality of machine specific reference field

The IAEA/AAPM formalism for reference dosimetry in small static MV photon fields

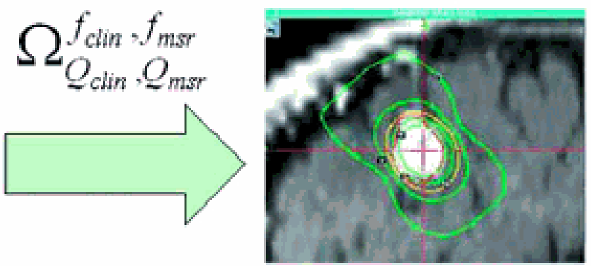
Alfonso el al (2008), Med Phys 35 (11), ***Update: AAPM2010 Poster SU-EE-A2-02***

RELATIVE DOSIMETRY

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

f_{clin} field size used in patient specific treatment plan

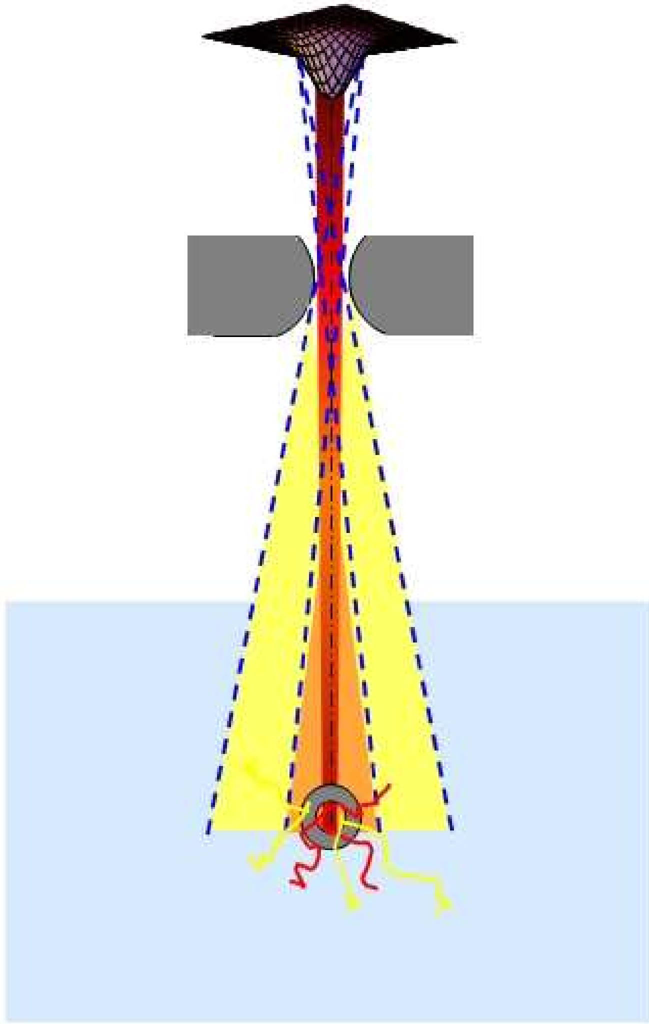
Clinical f_{clin}



e.g. a GammaKnife clinical plan

Q_{clin} beam quality for the field used clinically for the patient specific treatment plan

Any recommendations on the determination of dosimetric parameters in small MV photon fields?



IPEM report 523: Small field MV photon dosimetry

*Aspradakis, M. M., Byrne, J. P., Palmans, H., Conway, J., Rosser, K., Warrington, A. P. and Duane, S. (2010)**. IPEM, in press**.*

Chapters:

1. Introduction
2. Physics and challenges in small field dosimetry
3. Detectors
4. Machine acceptance and quality assurance
5. General considerations with measurements
6. Reference dose measurement
7. Relative dose measurement – depth functions
8. Relative dose measurement – output factors
9. Relative dose measurement – specialized systems
10. Monte Carlo
11. Verification
12. Summary and conclusions

Available from:

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