Small Field Dosimetry: Overview of AAPM TG-155 and the IAEA-AAPM Code of Practice (Therapy)

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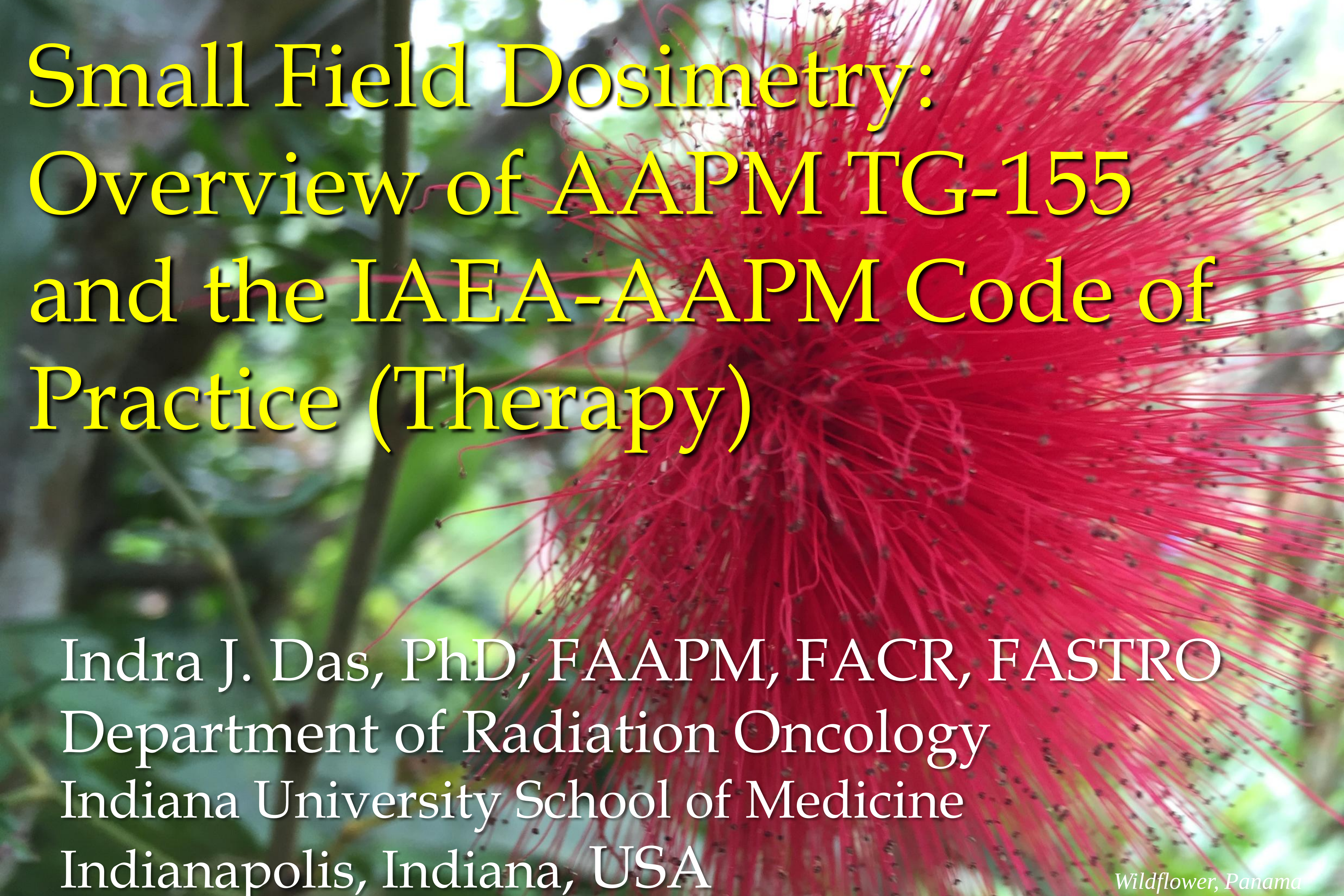
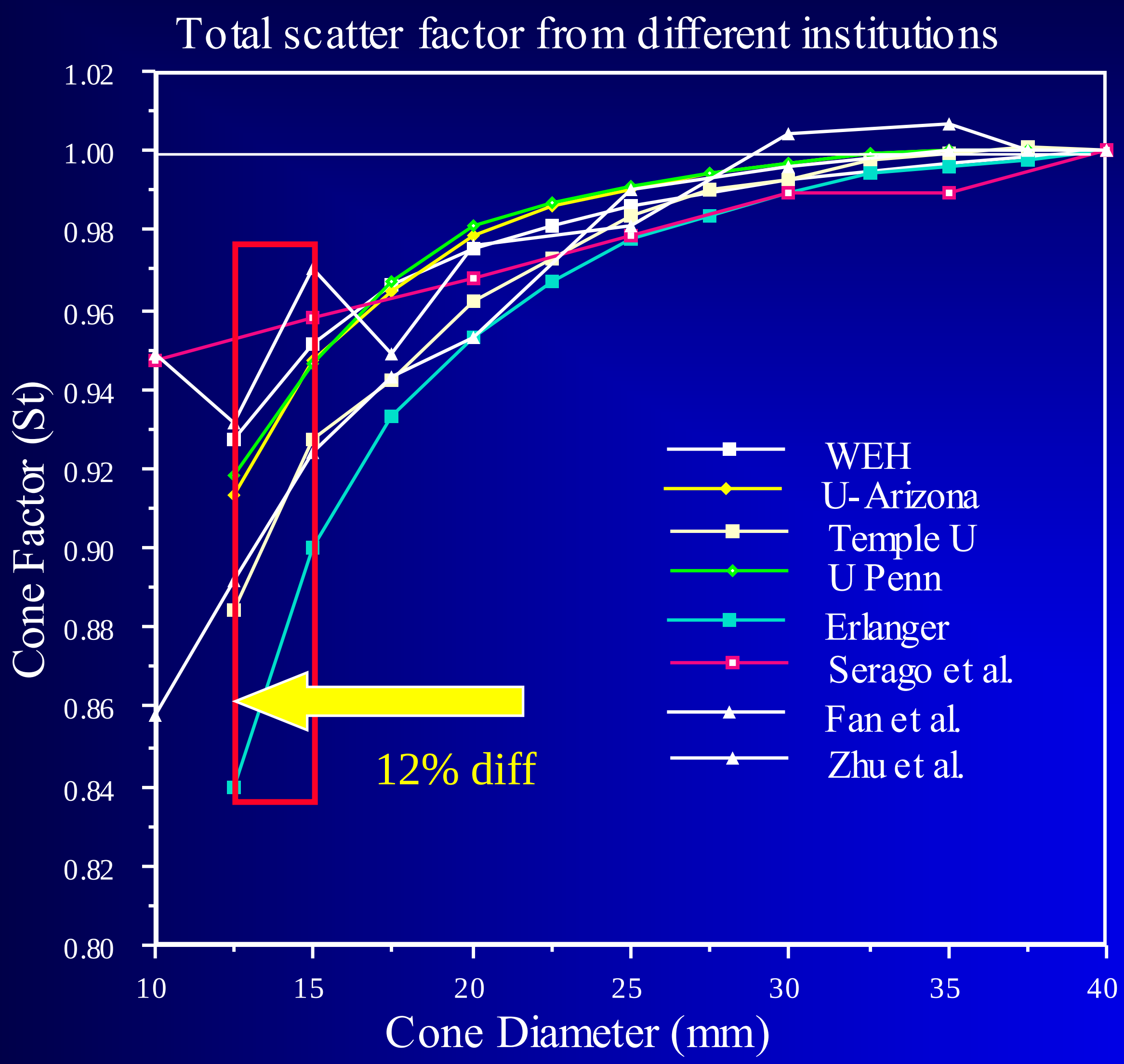


Wildflower, Panama

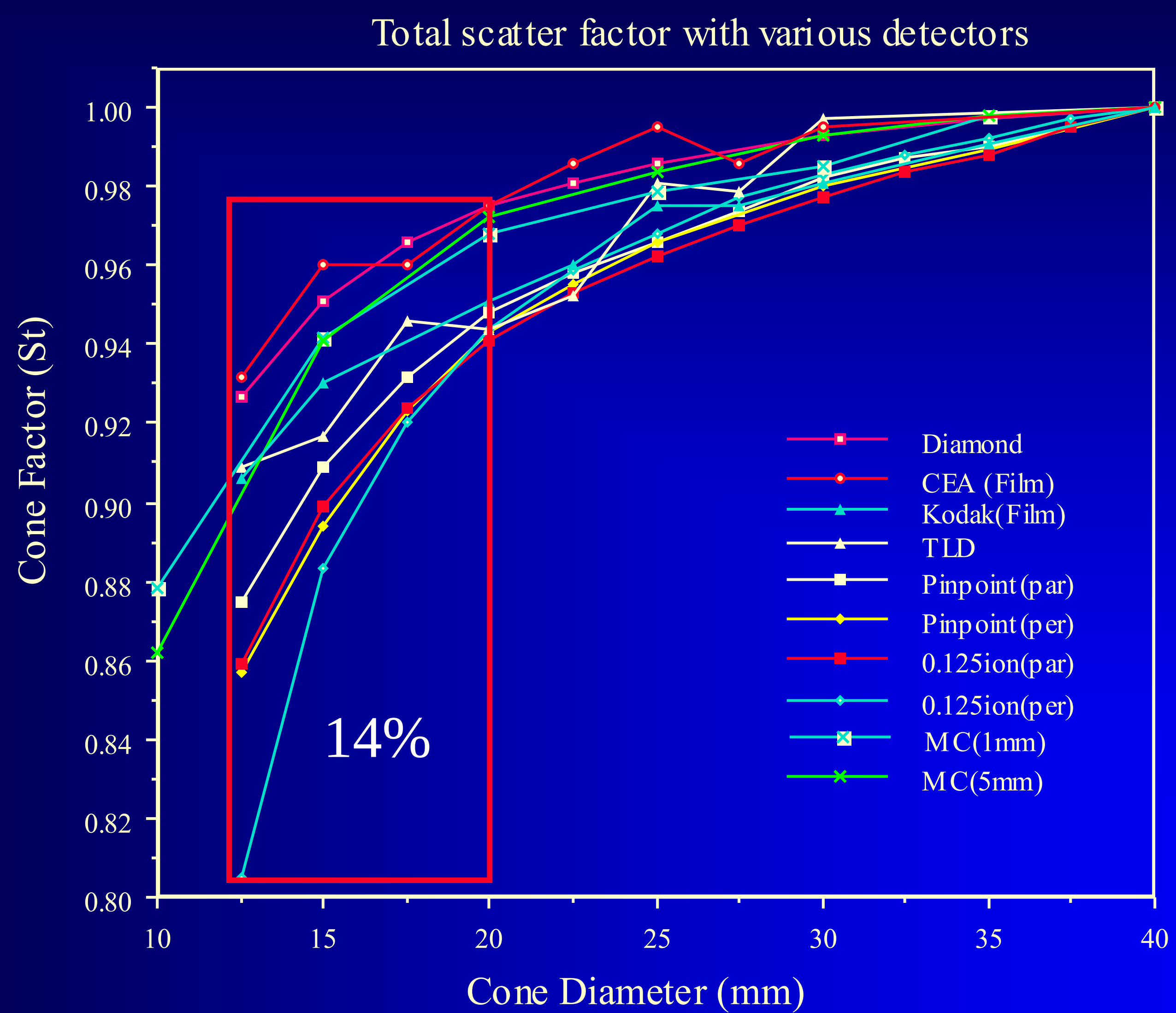
Small Field Dosimetry Problem



Institutional variability in 6 MV Radionics SRS dosimetry

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

Dosimetric Variation with Detectors

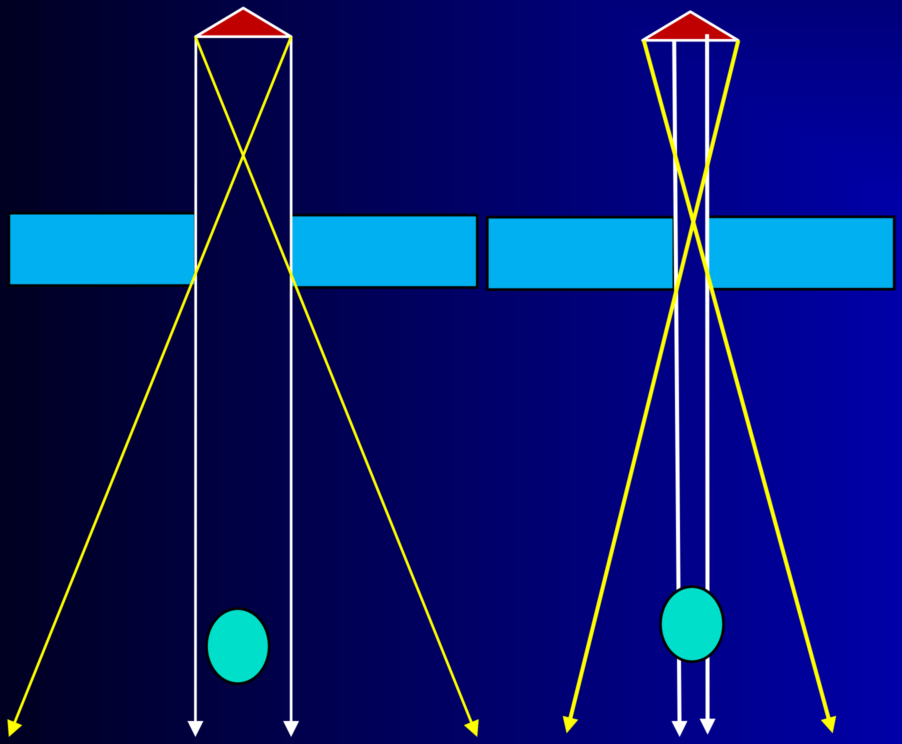


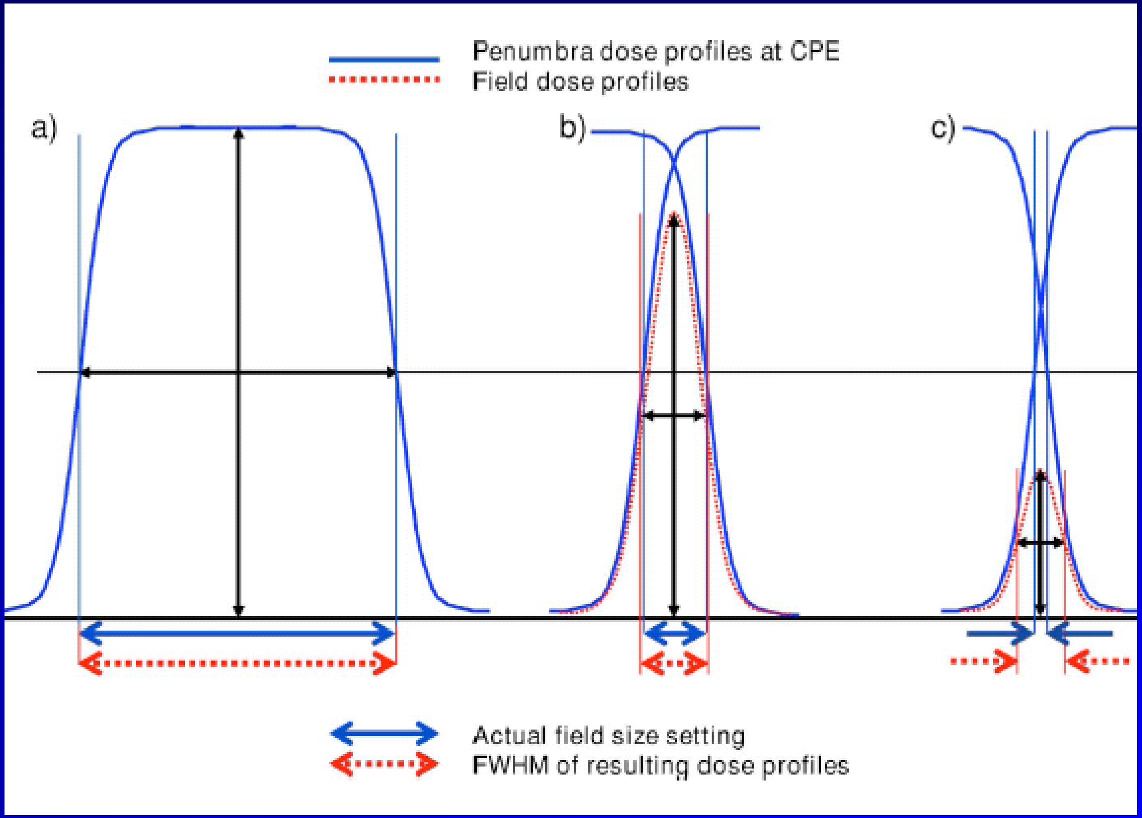
Das et al, J Radiosurgery, 3, 177-186, 2000

What is a Small Field?

- Lack of charged particle
  - Dependent on the range of secondary electrons
  - Photon energy
- Collimator setting that obstructs the source size
- Detector is comparable to the field size

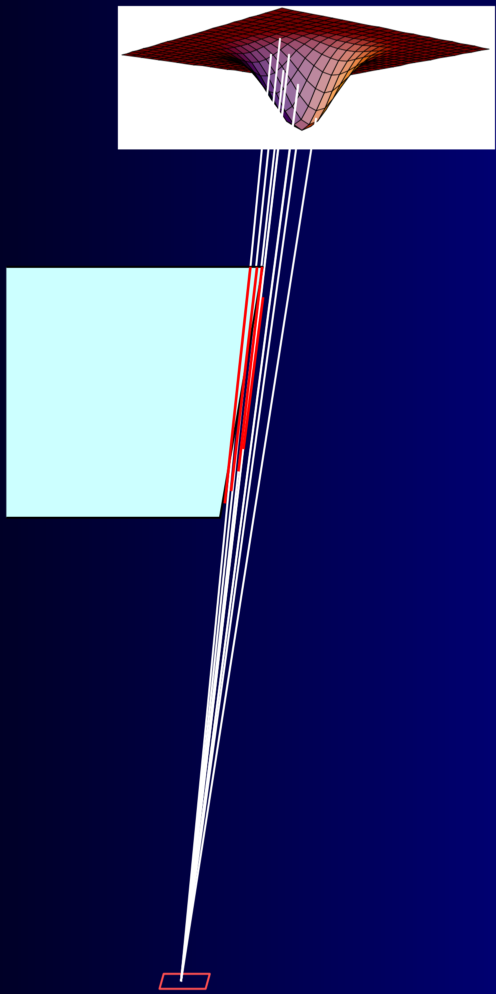
Definition of Small Fields

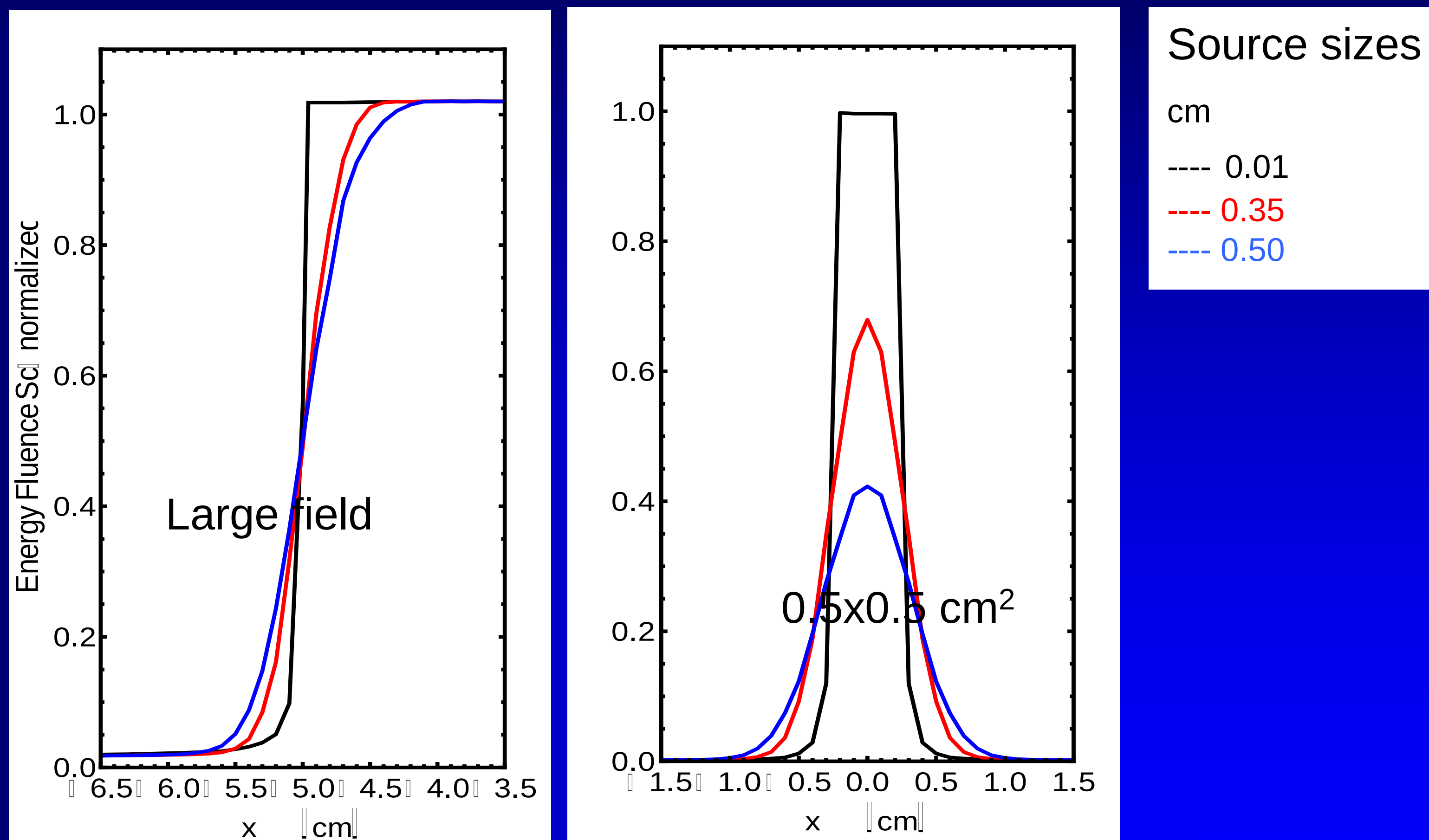




Das et al, Med. Phys. 35, 206-215, 2008

Energy Fluence Penumbra/Output





Nyholm *et al* Radiother Oncol 78, 347, 2006 and Phys Med Biol 51,6245, 2006

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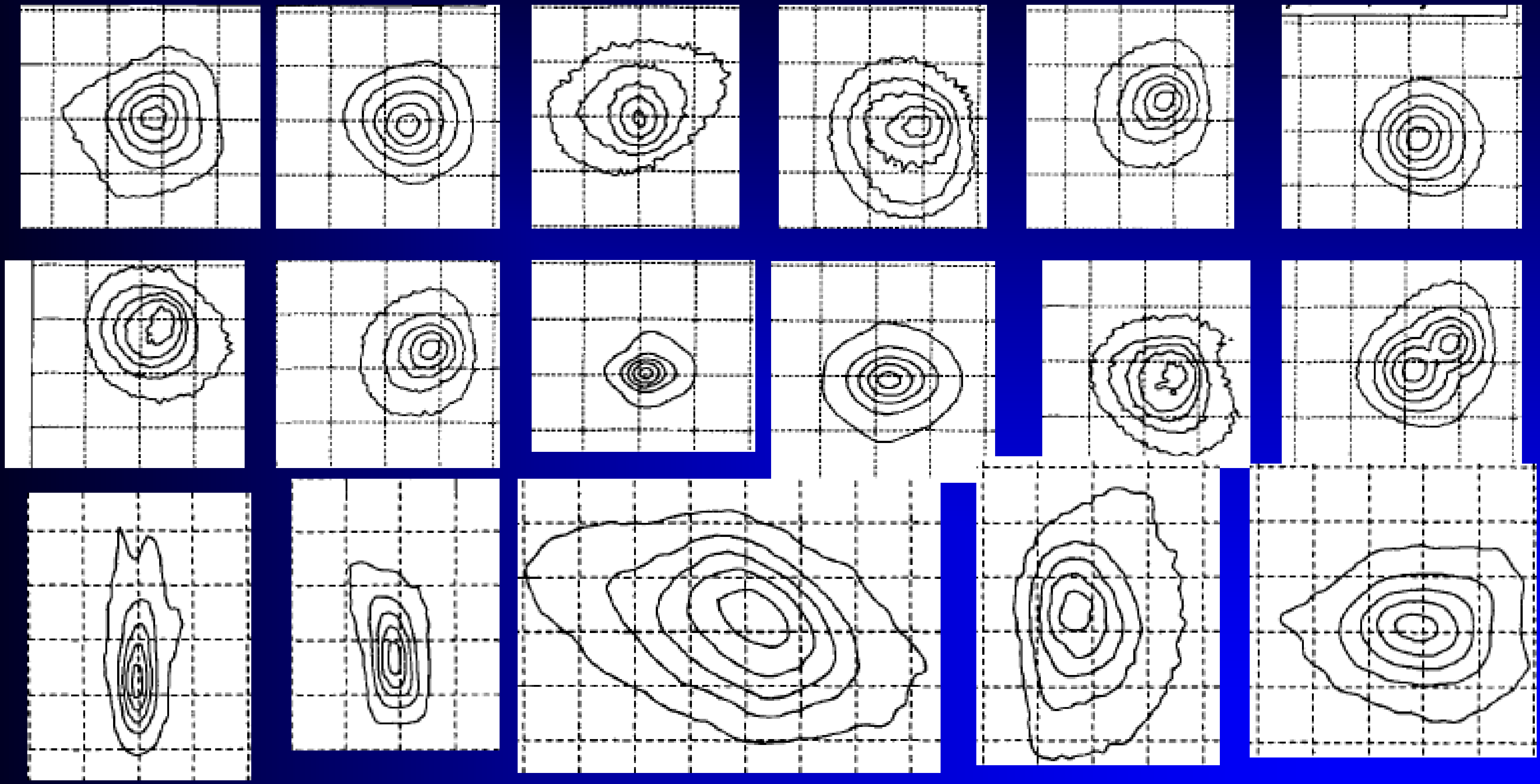
Source Size



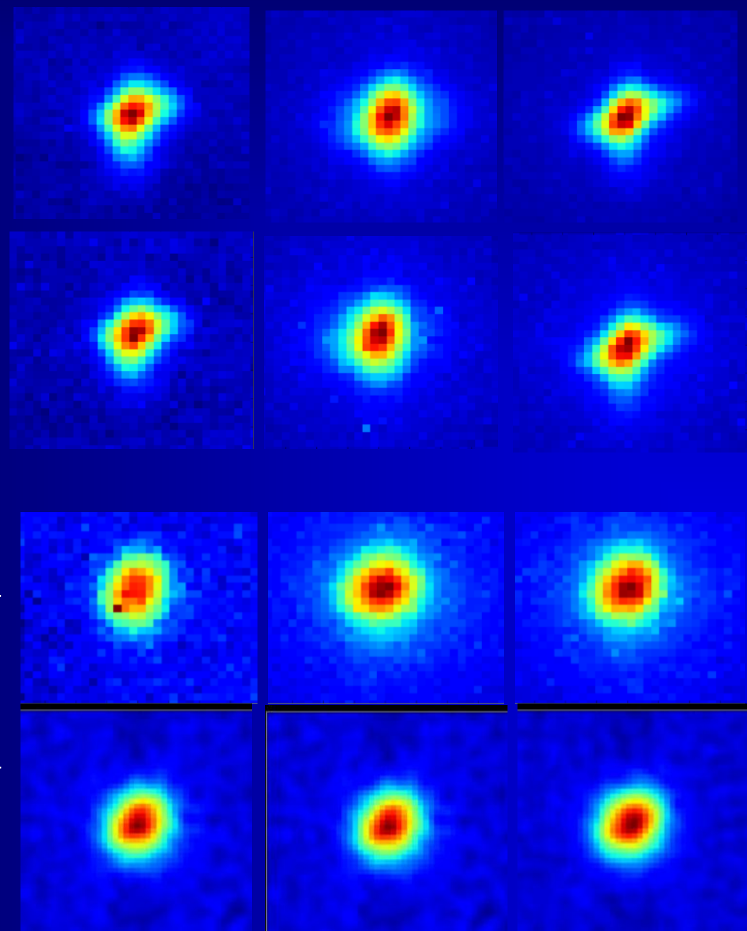
90%, 70%, 50%, 30%, 10% iso-intensity line

Jaffray et al, Med Phys 20, 1417-1427 (1993)

Source Size, Modern Machines

Varian TrueBeam

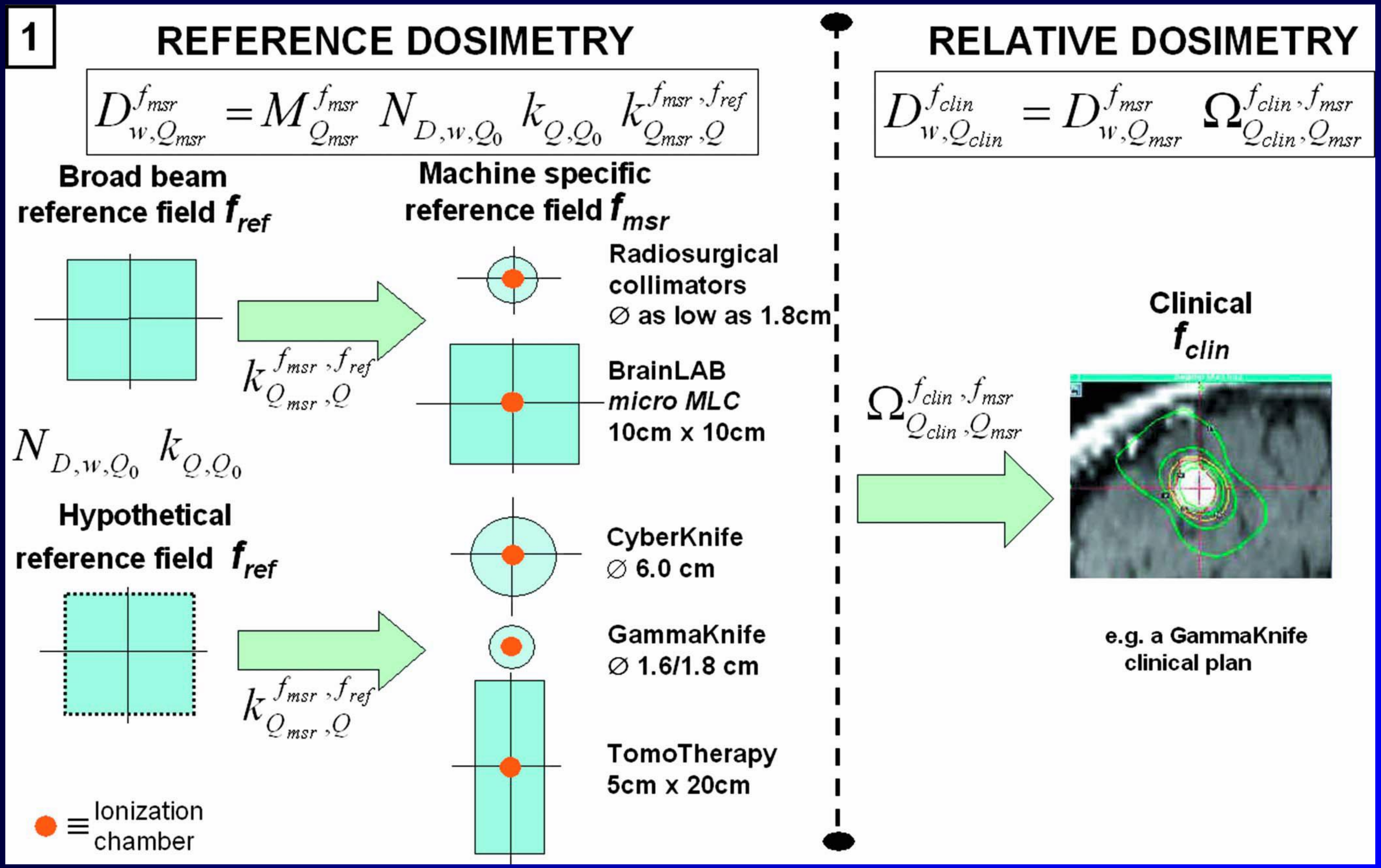
T1 T2 T3



	Dimensions x, y (mm)
6 MV	0.9, 0.7
6 MV FFF	0.8, 0.7
10 MV	0.9, 0.9
10 MV FFF	0.9, 0.8

Sawkey et al, Med Phys, 40, 332, 2013

IAEA/AAPM Proposed Pathway



Alfonso, et al. Med Phys ***35****, 5179-5186 (2008)*

Why So Much of Fuss?

- Reference (ref) conditions cannot be achieved for most SRS devices (cyberknife, gammaknife, tomotherapy etc)
- Machine Specific reference (msr) needs to be linked to ref
- Ratio of reading (PDD, TMR, Output etc) is not the same as ratio of dose

$$\frac{D_1}{D_2} \neq \frac{M_1}{M_2}$$

$$\frac{D_1}{D_2} = \frac{M_1}{M_2} \bullet \left[k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} \right]$$

Relative Dosimetry

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

$$\Omega_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} \left[\frac{\left(D_{w,Q_{clin}}^{f_{clin}}\right)/\left(M_{Q_{clin}}^{f_{clin}}\right)}{\left(D_{w,Q_{msr}}^{f_{msr}}\right)/\left(M_{Q_{msr}}^{f_{msr}}\right)} \right] = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$$

$$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{\left(D_{w,Q_{clin}}^{f_{msr}}\right)/\left(M_{w,Q_{clin}}^{f_{clin}}\right)}{\left(D_{w,Q_{msr}}^{f_{clin}}\right)/\left(M_{w,Q_{msr}}^{f_{clin}}\right)} = \frac{(Output)_{rel}}{(Re\,ading)_{rel}}$$

$$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{(S_{w,air})_{fclin} \cdot P_{fclin}}{(S_{w,air})_{fmsr} \cdot P_{msr}}$$

Meaning of k in Micro-Chambers

$$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{\left[\left(\frac{\overline{L}}{\rho}\right)_{air}^{w} \cdot P_{fl} \cdot P_{grad} \cdot P_{stem} \cdot P_{cell} \cdot P_{wall}\right]_{f_{clin}}}{\left[\left(\frac{\overline{L}}{\rho}\right)_{air}^{w} \cdot P_{fl} \cdot P_{grad} \cdot P_{stem} \cdot P_{cell} \cdot P_{wall}\right]_{f_{msr}}}$$

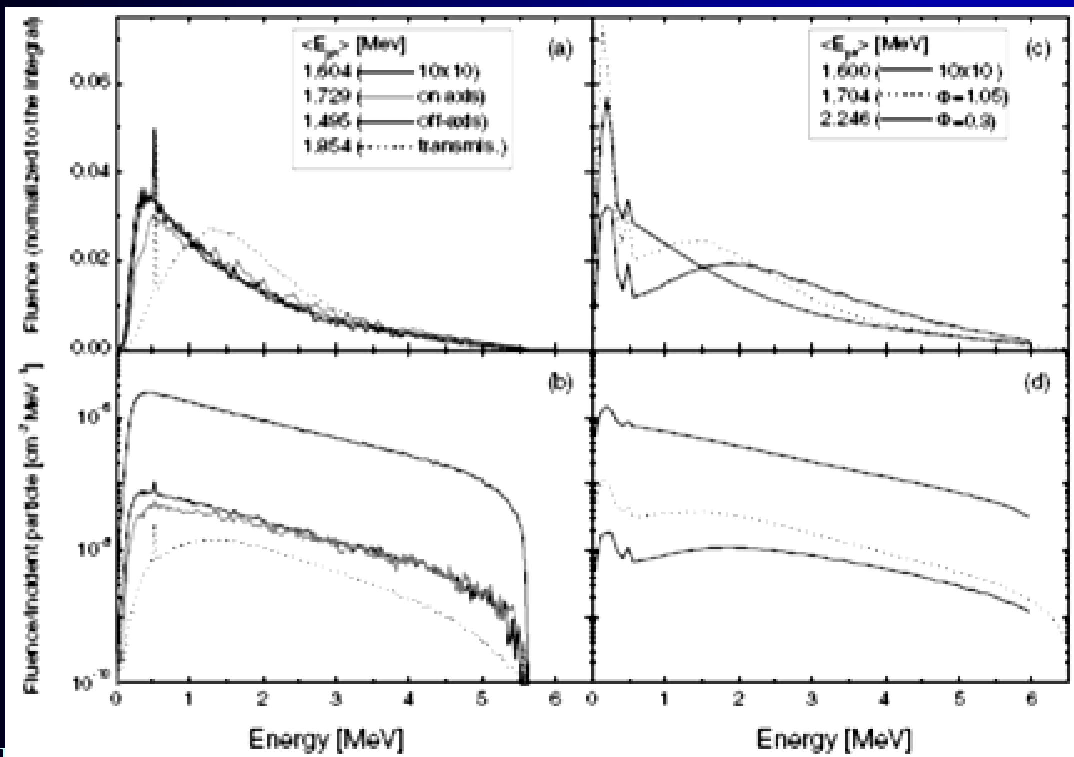
Stopping Power Ratio

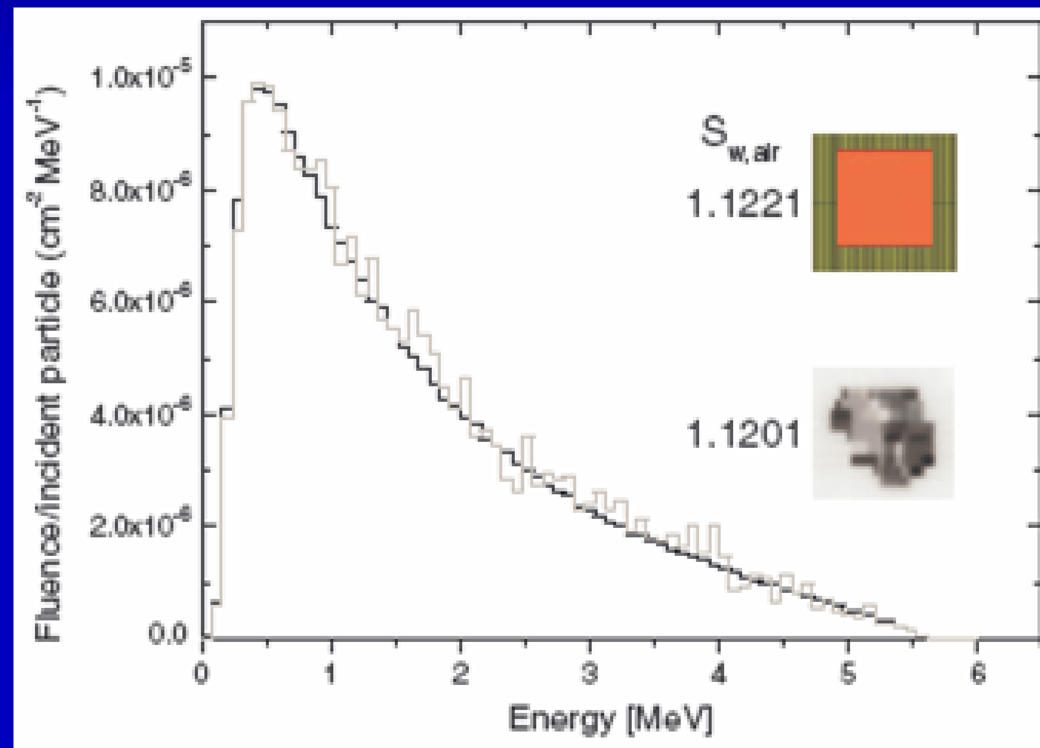
INSTITUTE OF PHYSICS PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. 48 (2003) 2081–2099 PII: S0031-9155(03)61152-8

Ionization chamber dosimetry of small photon fields: a Monte Carlo study on stopping-power ratios for radiosurgery and IMRT beams

F Sánchez-Doblado[1,2], P Andreo[3], R Capote[1,2], A Leal[1,2], M Perucha[2], R Arráns[1], L Núñez[4], E Mainegra[5], J I Lagares[1,2] and E Carrasco[1,2]





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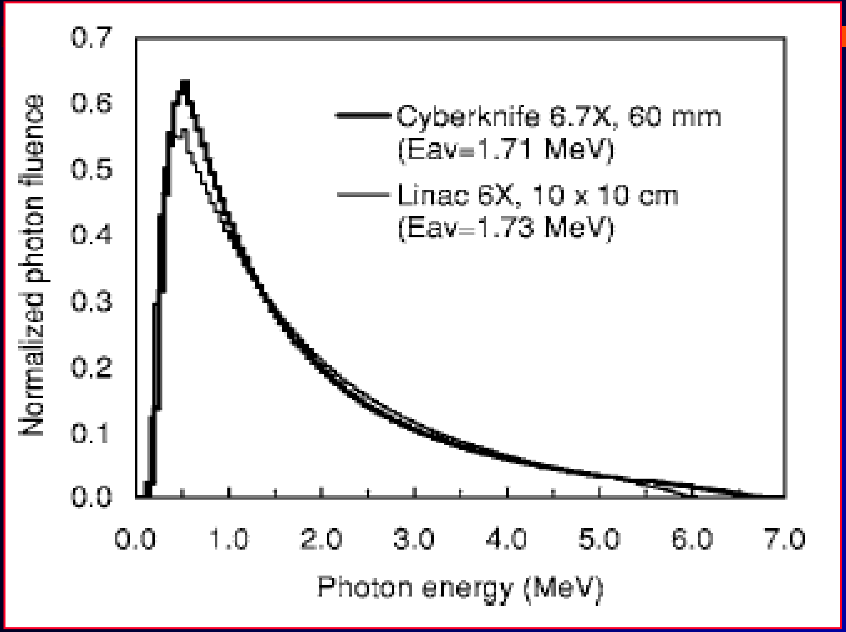
Radiological Parameters

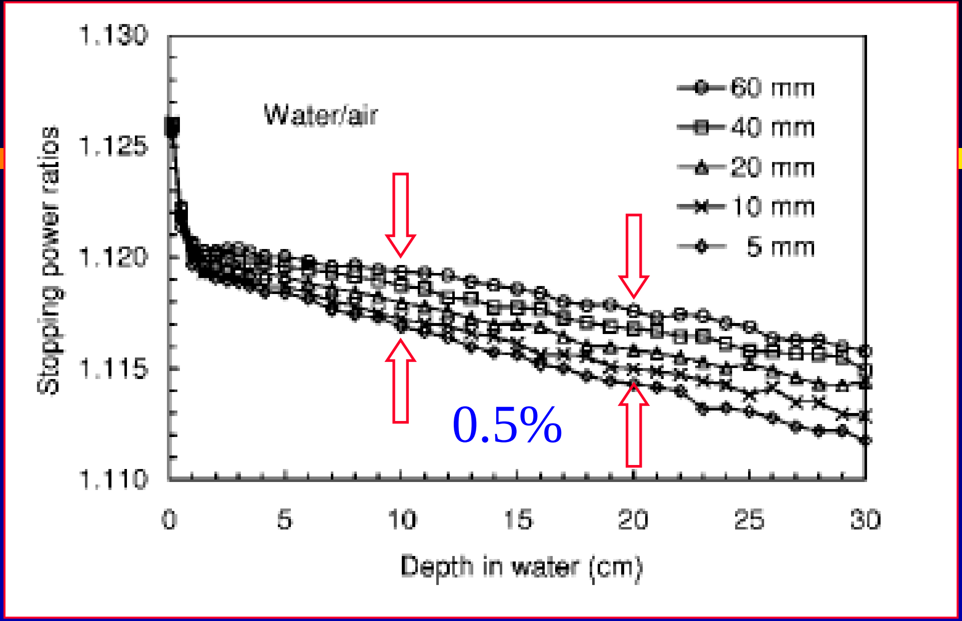
6 MV beams	Beam quality ($TPR_{20,10}$)	$s_{w,air}$ Andreo (1994)[a]	$s_{w,air}$ This work	$s_{w,air}$ Ratio this work/ Andreo	$s_{PMMA,air}$ Andreo (1994)[a]	$s_{PMMA,air}$ This work	$s_{PMMA,air}$ Ratio this work/ Andreo	Configuration
Elekta SL-18 radiosurgery								
10 × 10 cm^2	0.690	1.1187	1.1188	1.000	1.0853	1.0856	1.000	figure 1(a)
1.0 cm diameter			1.1155	0.997		1.0819	0.997	figure 1(b)
0.3 cm diameter			1.1153	0.997		1.0817	0.997	figure 1(c)
Siemens Primus MLC								
10 × 10 cm^2	0.677	1.1213	1.1221	1.001	1.0880	1.0892	1.001	figure 1(d)
2 × 2 cm^2 irregular on-axis			1.1203	0.999		1.0870	0.999	figure 1(e)
2 × 2 cm^2 irregular 8 cm off-axis			1.1250	1.003		1.0922	1.004	figure 1(f)
MLC transmission			1.1300	1.008				figure 1(i)
IMRT beam (10 × 10 cm^2 approx)			1.1201	0.999				figure 12

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

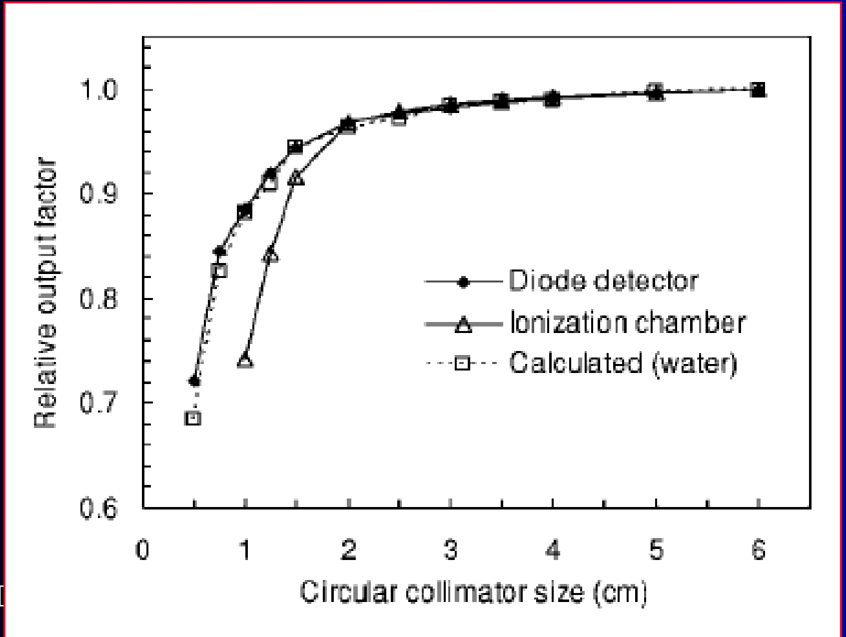
Sanchez-Deblado et al, Phy. Med. Biol., 48, 2081, 2003

Cyber Knife Dosimetry





Machine type	$\%dd(10)_x$	$(\bar{\mu}_{en}/\rho)^{w}_{wall}$
		Wall=C-552
Linac	66.3	1.1091
Cyberknife	60.8	1.1088
		Wall=Carbon
Linac	66.3	1.1144
Cyberknife	60.8	1.1144
		Wall=PMMA



Machine type	$\%dd(10)_x$	$(\bar{L}/\rho)^{m}_{air}$			
		Water	PMMA	Carbon	C-552
Linac	66.3[a]	1.1208	1.0878	0.9876	0.9836
Cyberknife	60.8[b]	1.1194	1.0859	0.9854	0.9817

[a]For a 10×10 cm[2] field at 100 cm SSD from a Varian 6 MV-linear accelerator.
[b]For a 60 mm circular collimator at 80 cm SSD from a Cyberknife system.

F. Araki, Med. Phys. 33, 2955-2963 (2006).

Correction Factors

Correction Factor depends on:

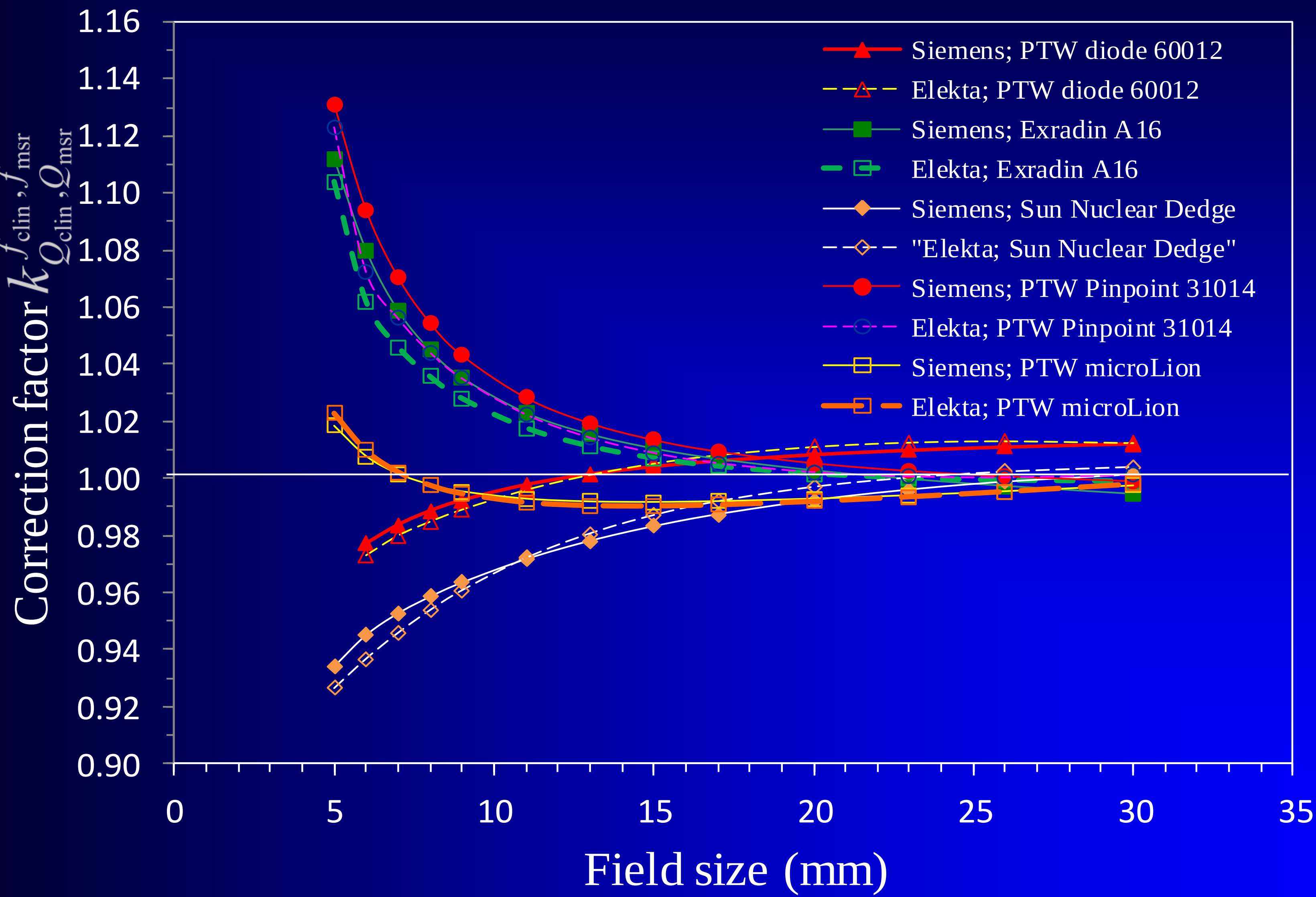
- Field size
- Source size (FWHM)
- Detector type

TABLE VII. F_{corr} of the four detectors for the 5, 7.5, and 10 mm collimators, as a function of the FWHM.

A16	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.067	1.021	1.008
1.8	1.087	1.017	1.007
2.2	1.102	1.020	1.012
2.6	1.112	1.027	1.010
Pin Point	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.082	1.025	1.017
1.8	1.099	1.024	1.013
2.2	1.110	1.025	1.013
2.6	1.124	1.037	1.016
Diode	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	0.953	0.966	0.978
1.8	0.955	0.966	0.978
2.2	0.957	0.967	0.978
2.6	0.940	0.967	0.978
Diamond	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.066	1.001	1.001
1.8	1.093	1.007	1.000
2.2	1.107	1.010	0.999
2.6	1.123	1.012	1.001

Francescon, et al Med Phys 35, 504, 2008

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



Francescon et al Med Phys,38, 6513, 2011

$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ of Linear Accelerators (Varian)

Implementing a newly proposed Monte Carlo based small field dosimetry formalism for a comprehensive set of diode detectors

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Med. Phys. 38 (12), 6992, 2011

$k_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}}$ of Linear Accelerators

Calculation of $k_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}}$ for several small detectors and for two linear accelerators using Monte Carlo simulations

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Med. Phys. 38 (12), 6513-6527, 2011

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Experimental small field 6 MV output ratio analysis for various diode detector and accelerator combinations

Gavin Cranmer-Sargison[a,b,*], Steve Weston[b,c], Narinder P. Sidhu[a,d], David I. Thwaites[b,e]

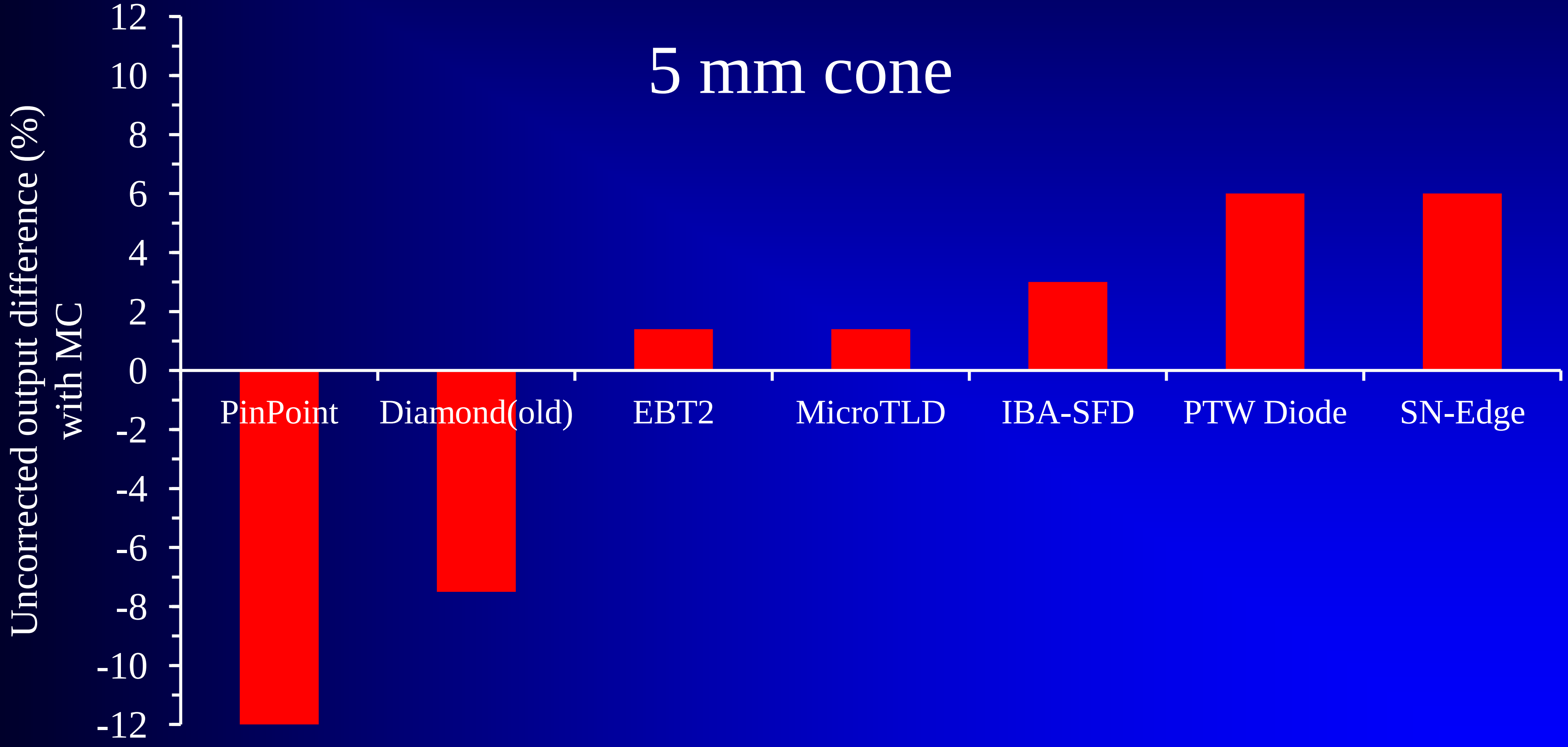
Radiotherapy and Oncology 100 (2011) 429–435

$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ Cyber Knife

Detector	5 mm		7.5 mm		10 mm	
	$M_{Q_{clin}}^{f_{clin}} / M_{Q_{msr}}^{f_{msr}}$	$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$	$M_{Q_{clin}}^{f_{clin}} / M_{Q_{msr}}^{f_{msr}}$	$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$	$M_{Q_{clin}}^{f_{clin}} / M_{Q_{msr}}^{f_{msr}}$	$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$
A16	0.626 (15)	1.089 (3)	0.811 (10)	1.018 (3)	0.866 (6)	1.010 (3)
PinPoint	0.620 (17)	1.101 (3)	0.801 (7)	1.024 (3)	0.862 (5)	1.015 (3)
Diode 60008	0.726 (1)	0.943 (3)	0.873 (1)	0.949 (3)	0.912 (1)	0.964 (3)
Diode 60012	0.705 (1)	0.956 (3)	0.847 (2)	0.966 (3)	0.891 (1)	0.978 (3)
EDGE	0.726 (1)	0.948 (3)	0.864 (1)	0.955 (3)	0.906 (1)	0.966 (3)
Alanine	0.544 (8)	1.249 (8)	0.785 (12)	1.059 (4)	0.855 (13)	1.019 (3)
TLD	0.668 (4)	···	0.809 (6)	···	0.880 (8)	···
EBT films	0.659 (17)	···	0.811 (16)	···	0.853 (18)	···
Polymer gels[a]	0.702 (21)	···	0.872 (27)	···	0.929 (29)	···

Pantelis et al, Med Phy. 37, 2369-2379, 2010

CyberKnife data

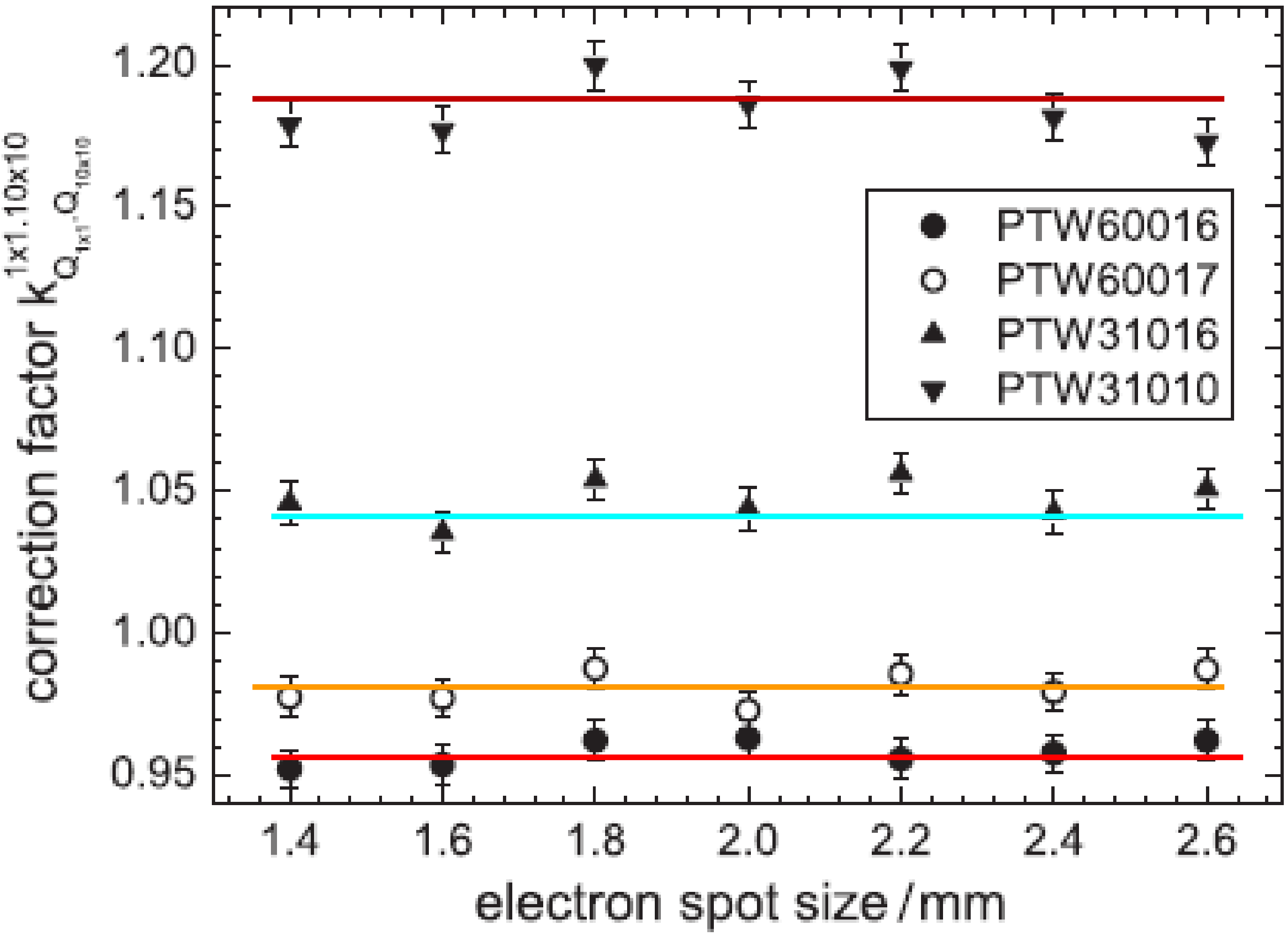


Moignier et al, Med Phys 41(7), 071702, 2014

IOP PUBLISHING METROLOGIA
Metrologia 49 (2012) S215–S218 doi:10.1088/0026-1394/49/5/S215

The influence of linac spot size on scatter factors

D Czarnecki[1], J Wulff[1] and K Zink[1,2]



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Output correction factors for nine small field detectors in 6 MV radiation therapy photon beams: A PENELOPE Monte Carlo study

Med Phys, 41(4), 041711, 2014

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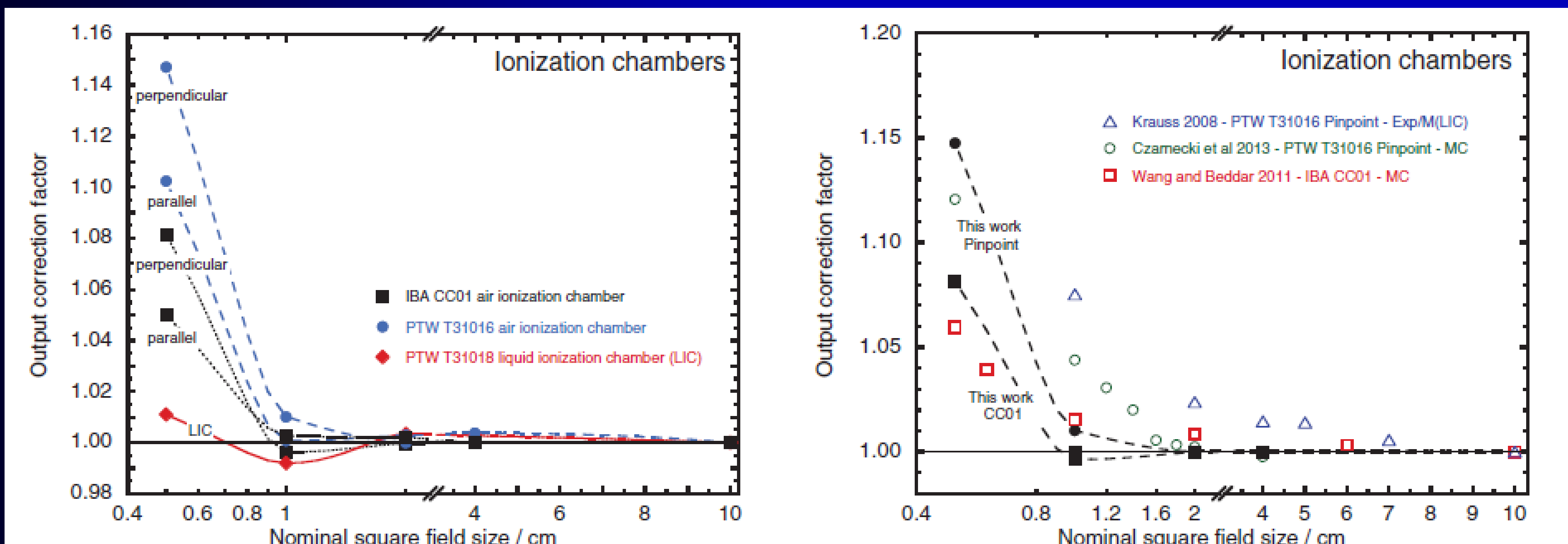
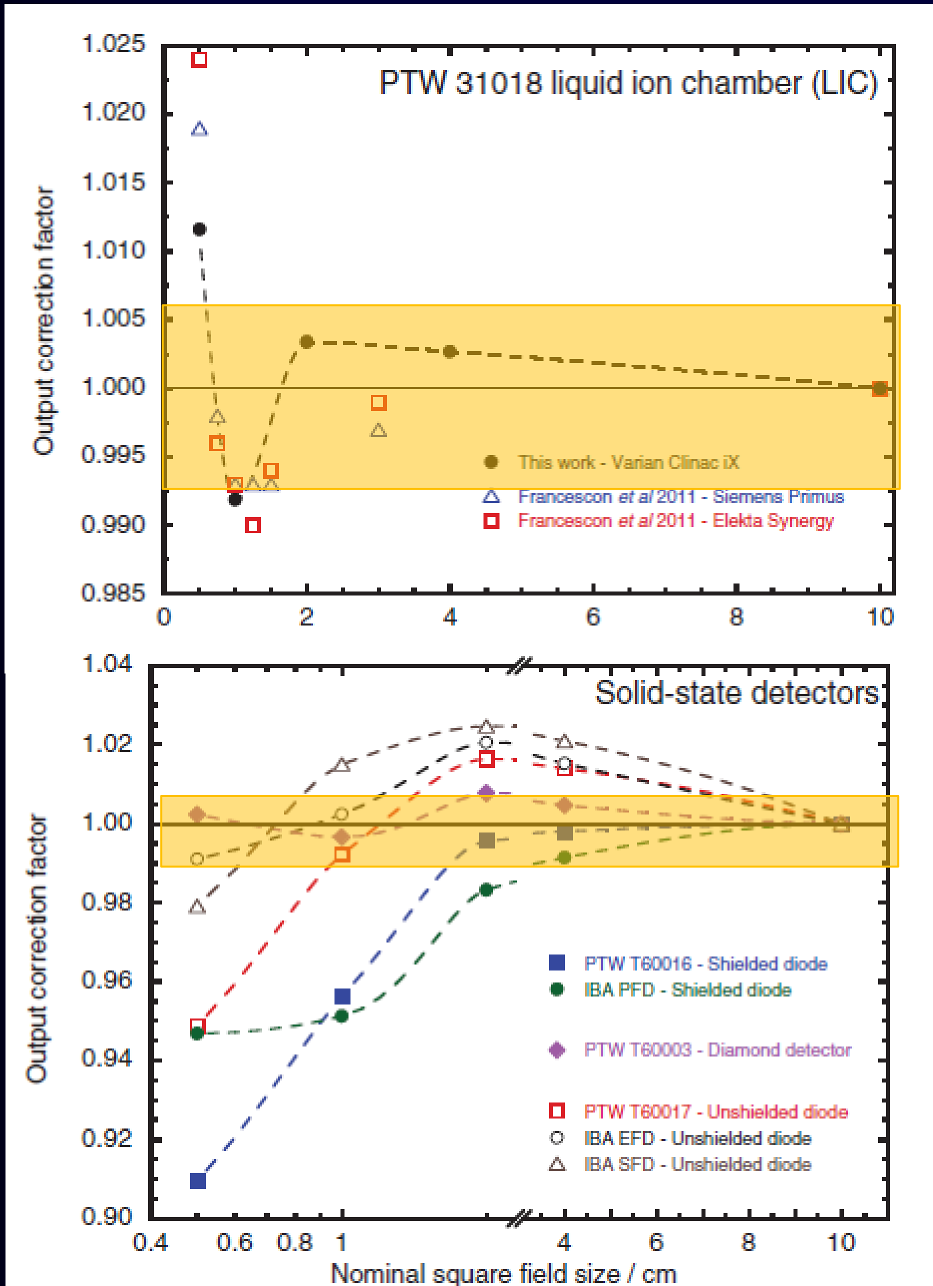
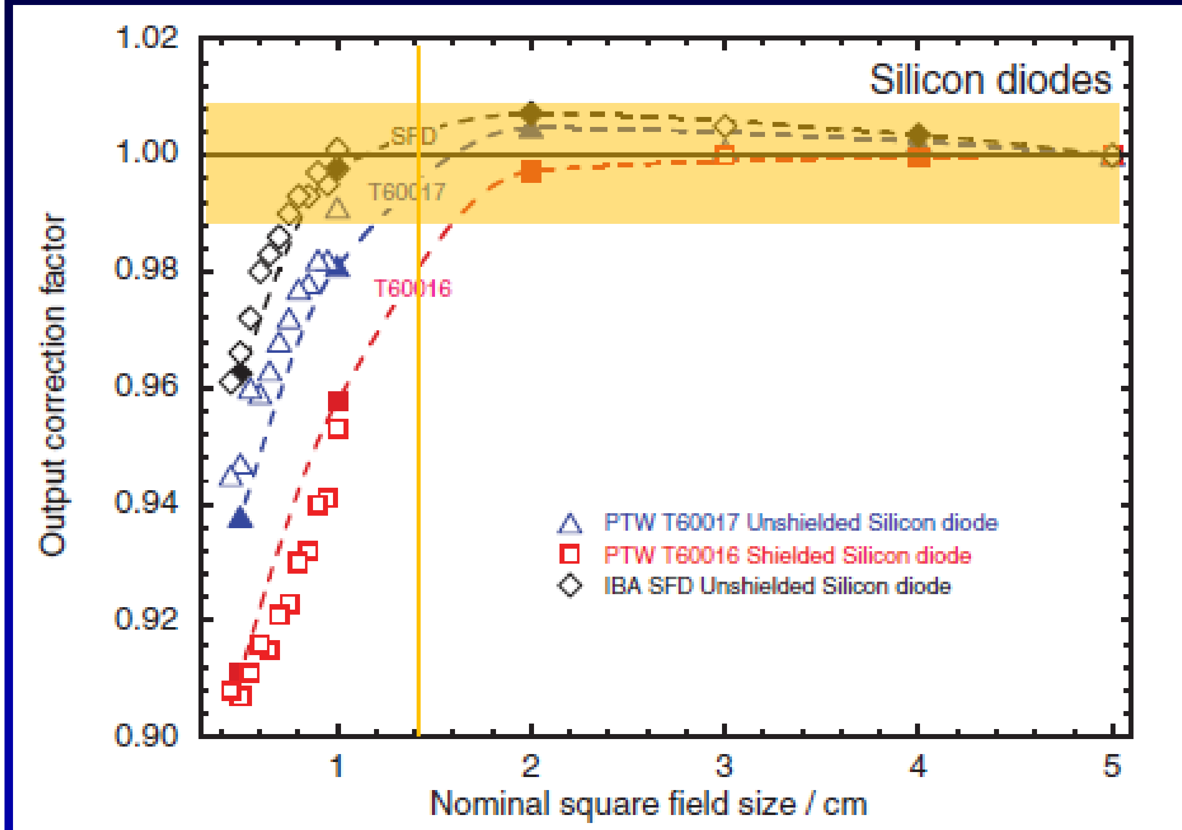


Newer Data on $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$





Benmakhlouf et al, Med Phys, 41(4), 041711, 2014

New Published data From IAEA

Detector to detector corrections: A comprehensive experimental study of detector specific correction factors for beam output measurements for small radiotherapy beams

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072103-1 Med. Phys. 41 (7), July 2014

Correction Factors

TABLE V. Detector correction factors $(p_{fl})^{Q_{clin}}_{Q_{int}}(p_{spec})^{Q_{clin}}_{Q_{int}}$. Factors shown are ratios of detector ratios relative to the dose ratios determined from alanine measurement for each field size $\left(\frac{D^{f_{clin}}_{w,Q_{clin}}}{D^{f_{int}}_{w,Q_{int}}}\right)/\left(\frac{M^{f_{clin}}_{Q_{clin}}}{M^{f_{int}}_{Q_{int}}} \times (p_{vol})^{Q_{clin}}_{Q_{int}}\right)$.

FS [cm]	0.6	0.9	1.2	1.8	2.4	3.0	4.2	10.0
TLD chips	1.000	...	1.003	1.008	1.004	1.000	1.005	1.010
TLD micro-cubes	0.998	...	1.000	1.001	1.009	1.000	1.001	1.007
IBA SFD diode	0.995	...	0.998	1.002	1.006	1.000	0.990	0.969
IBA PFD diode	0.936	...	0.962	0.985	0.999	1.000	1.000	1.001
IBA EFD diode	0.961	...	0.983	0.992	1.002	1.000	0.997	0.989
PTW 60003Diamond (Sensitive area ~ 15 mm^2)	0.995	...	0.983	0.992	1.002	1.000	0.996	0.995
PTW 60019 microDiamond	0.961	...	0.980	0.990	1.001	1.000	0.999	1.000
RPLD (GDM-302M)	...	...	...	0.993	0.998	1.000	0.994	0.997
Al_2O_3:C	0.980	0.982	0.985	0.991	0.999	1.000	...	0.995
Scintillator 1	1.022	1.009	1.000	0.996	1.001	1.000	...	0.992
Scintillator 2	1.028	1.015	1.006	1.000	1.004	1.000	...	0.988
PTW 31018microLion	0.970	...	0.980	0.990	1.000	1.000	0.999	1.005
IBA CC01	1.000	...	0.993	0.993	1.000	1.000	0.997	0.990
IBA CC04	1.096	...	1.007	0.998	1.003	1.000	0.997	0.998
IBA CC13[b]	...	...	1.033	1.008	1.005	1.000	0.996	0.996
Wellhöfer IC10[b]	...	...	1.030	1.005	1.005	1.000	0.996	0.996
PTW 31014 PinPoint	1.034	...	1.007	1.002	1.000	1.000	0.998	1.002
PTW 31016 PinPoint 3D	1.078	...	1.013	1.000	1.001	1.000	0.998	0.999
PTW 31010 Semiflex[b]	...	...	1.027	1.002	1.004	1.000	0.996	0.997
PTW 31013 Semiflex[a,b]	...	...	...	...	1.013	1.000	0.992	0.993

[a]This chamber was included in the table for completeness but it is not recommended to use for small field dosimetry in fields smaller than 2.0 × 2.0 cm^2 because the volume averaging effect is unacceptably high.

[b]For these ionization chambers, corrections for the smallest field were unacceptably high (>20%) for field sizes smaller than 1 × 1 cm^2 and therefore were excluded from Table V.

Variation of $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ for the small-field dosimetric parameters percentage depth dose, tissue-maximum ratio, and off-axis ratio

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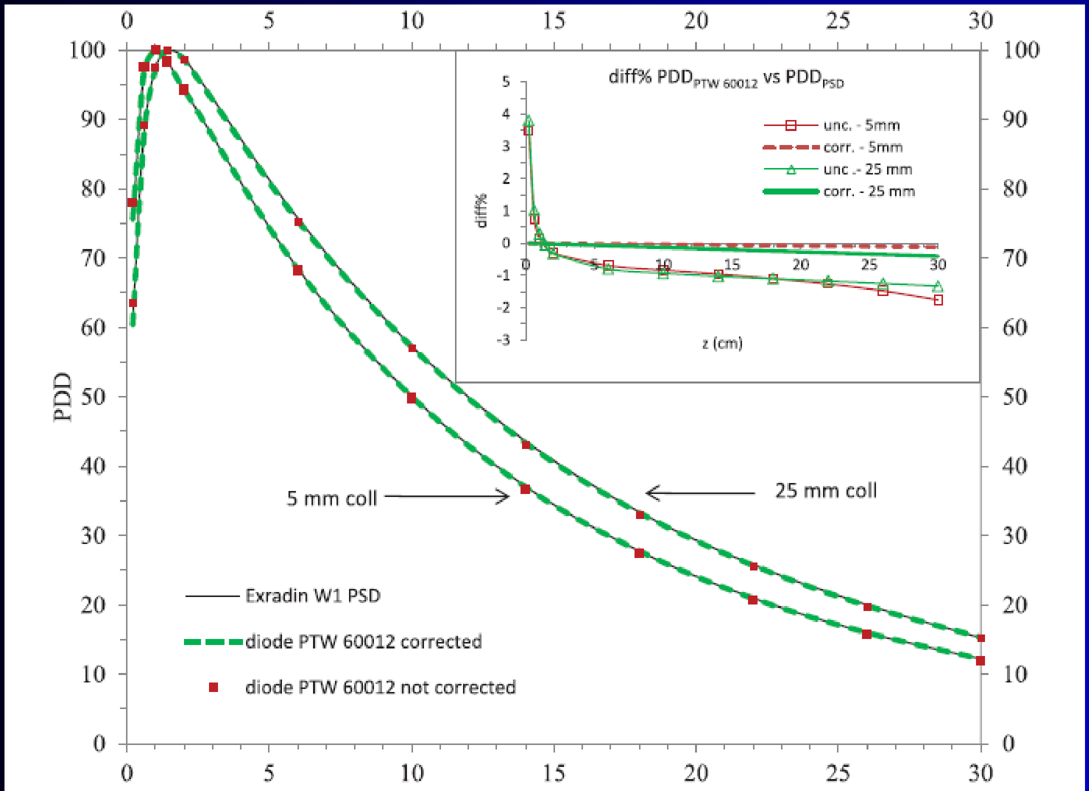
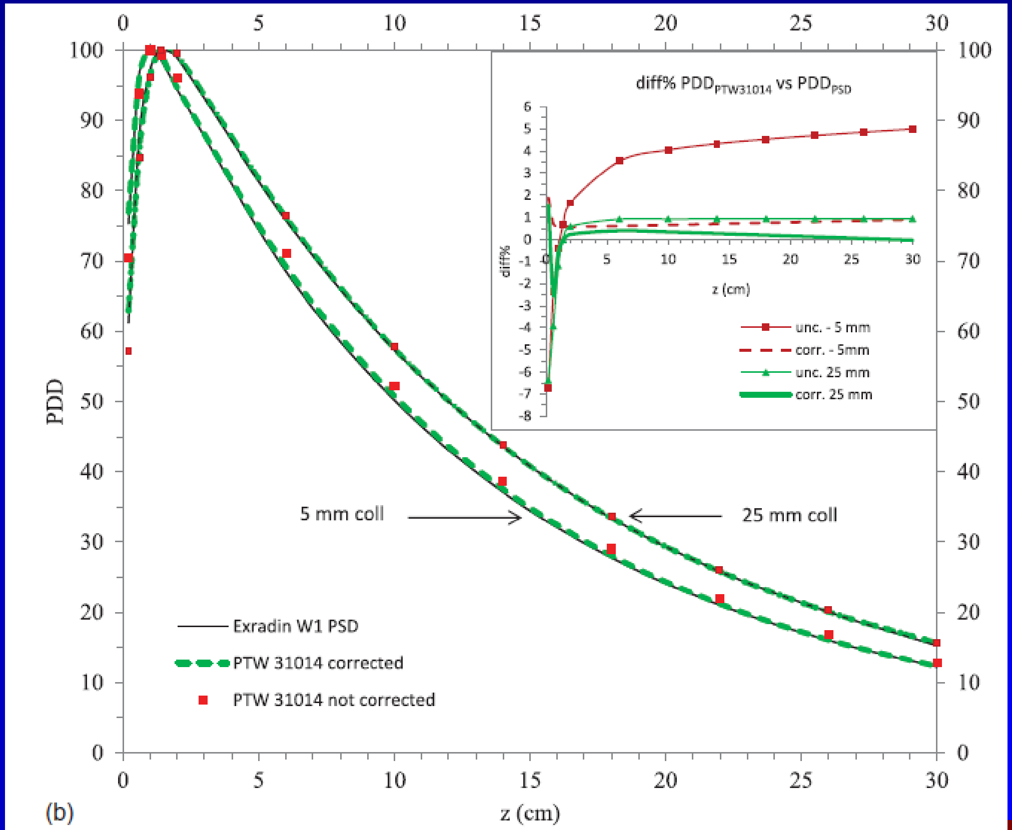


(a)



(b)

Med. Phys. 41 (10), October 2014 0094-2405/2014/41(10)/101708/

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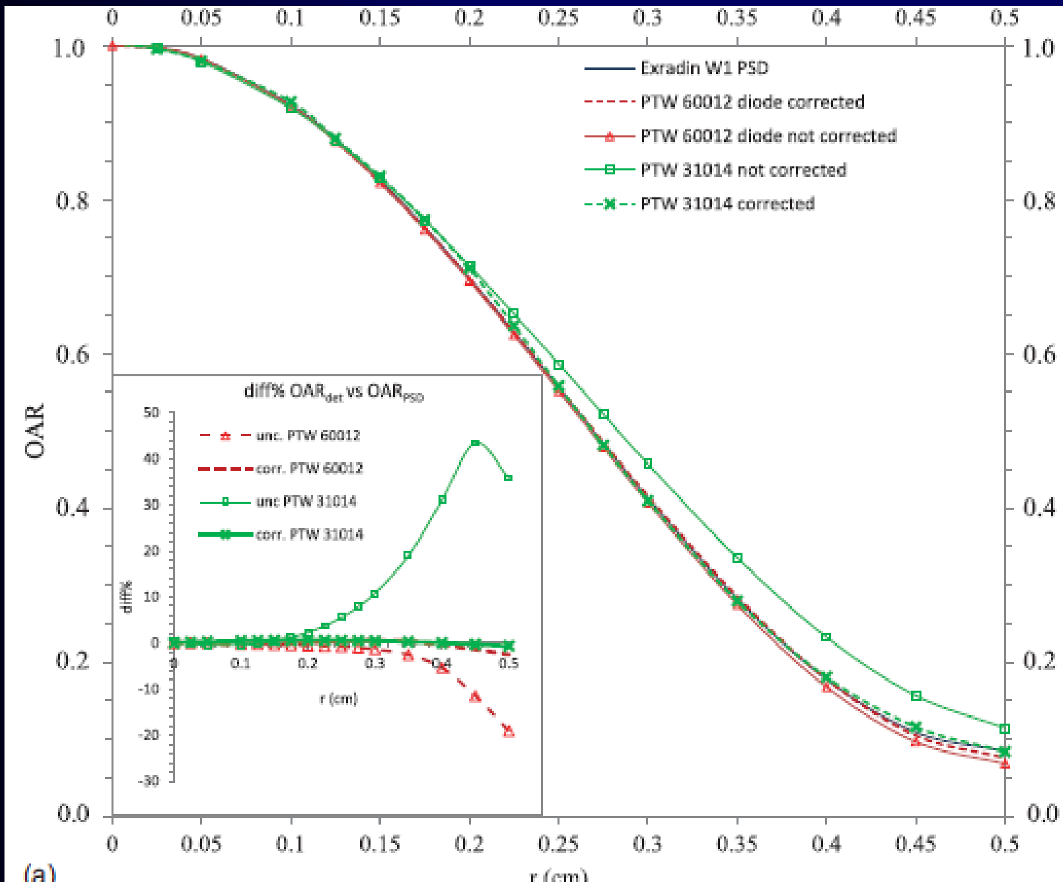
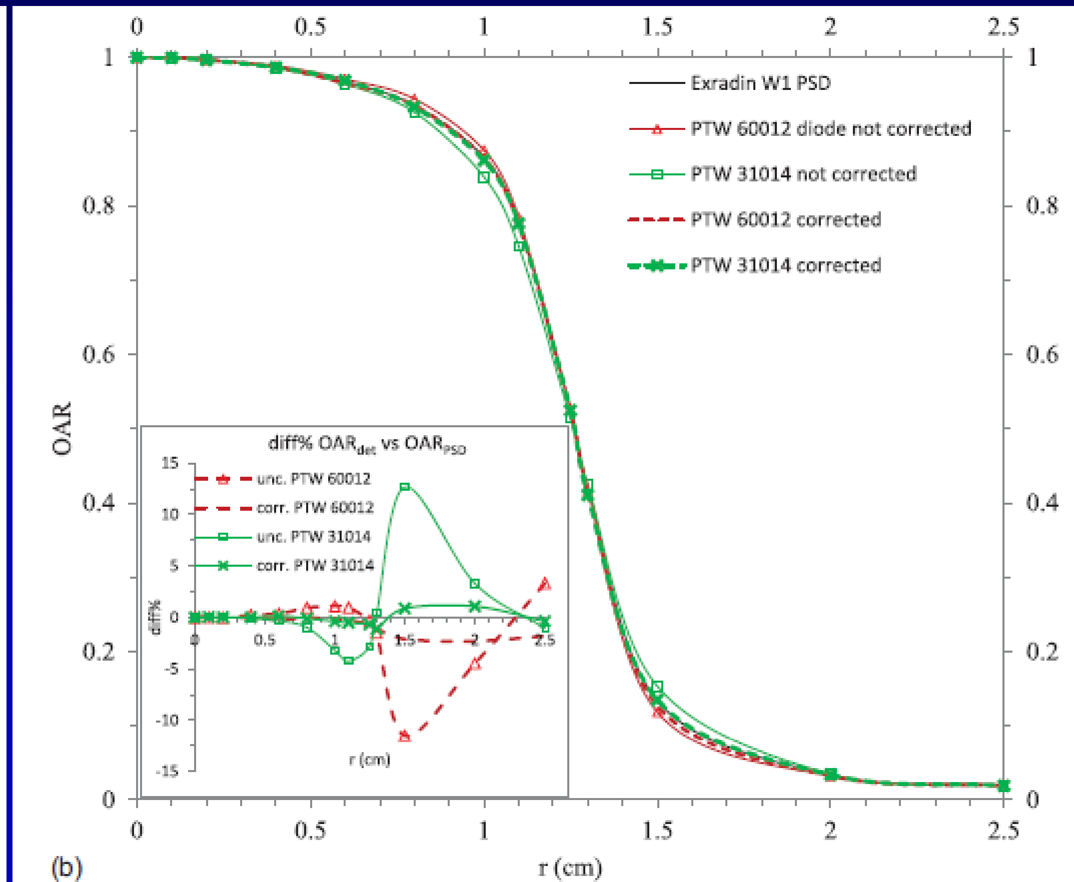
Correction in Profile (OAR)

5 mm cone



25 mm cone



Francescon et al, Med Phys, 41(10), 101708, 2014

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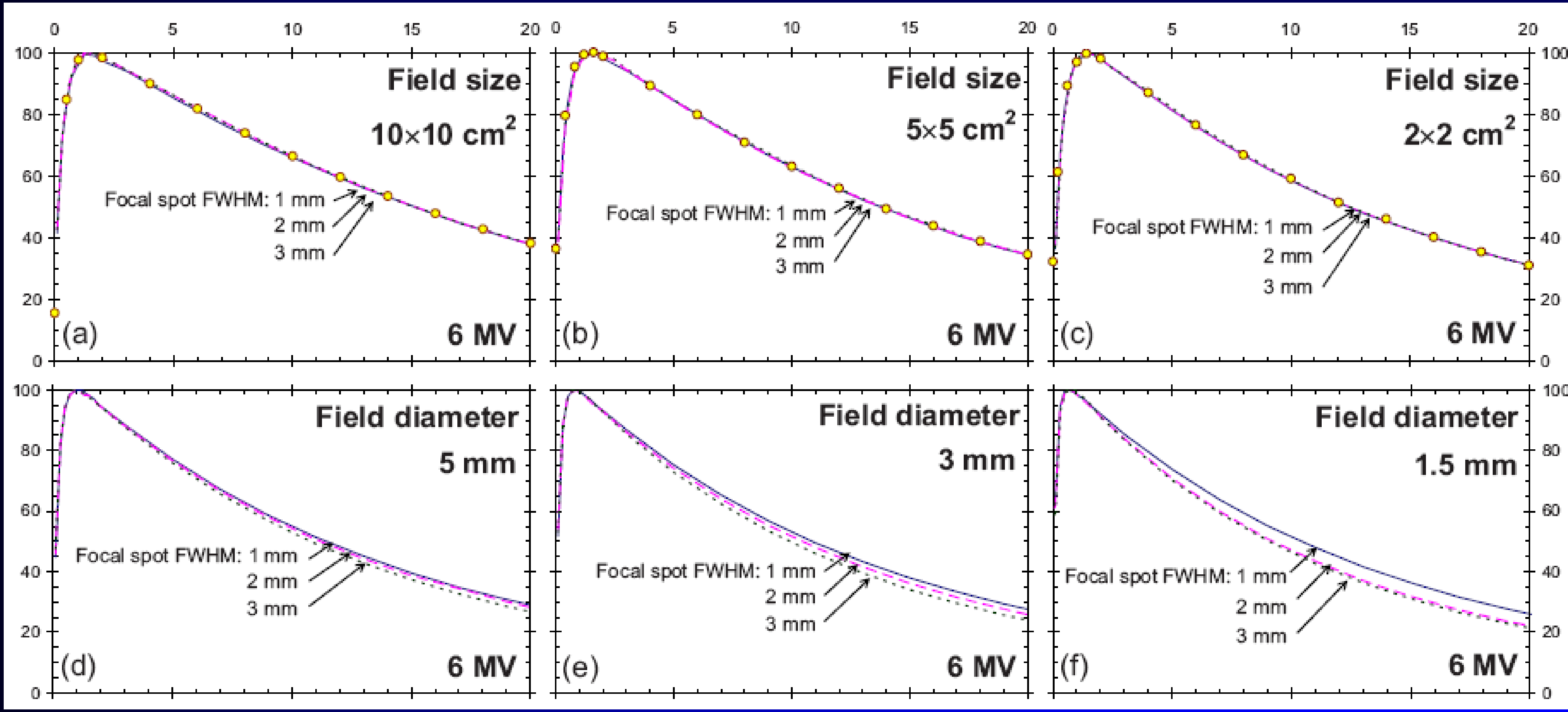
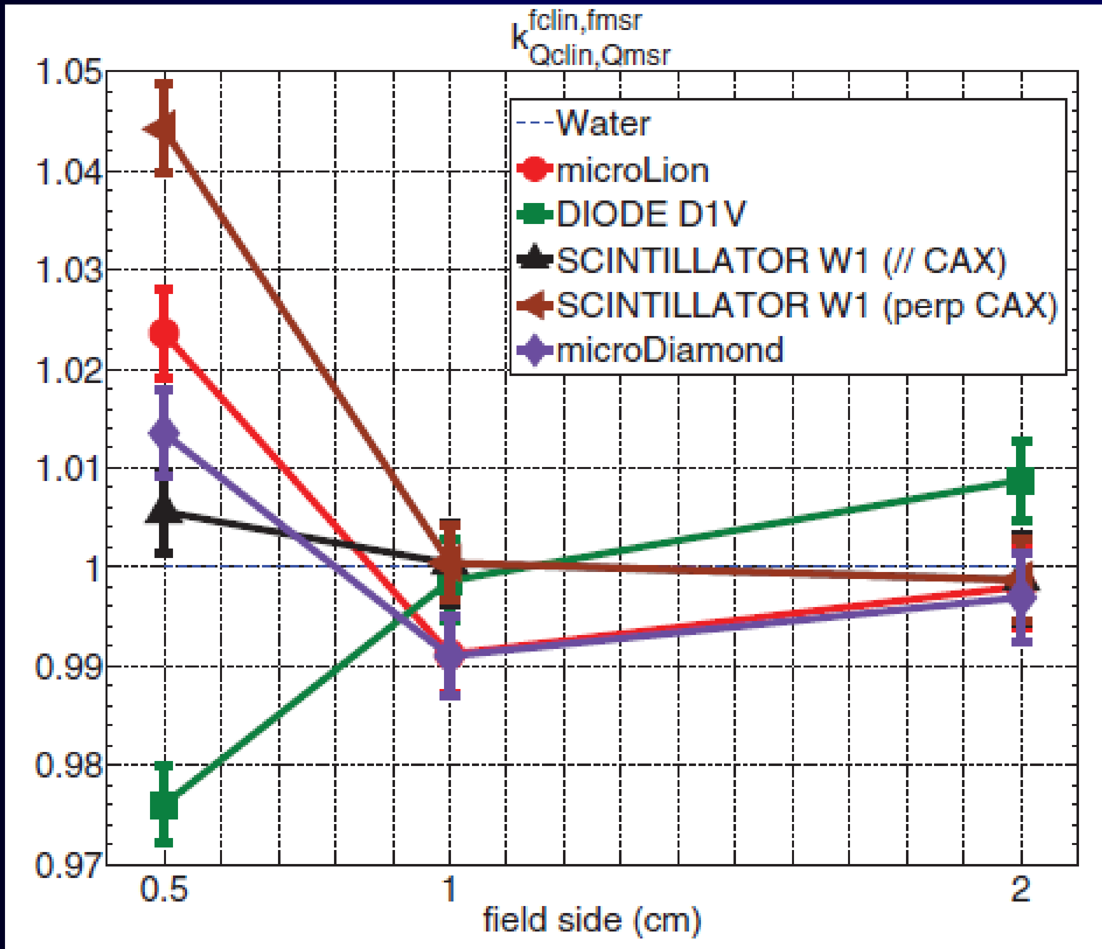
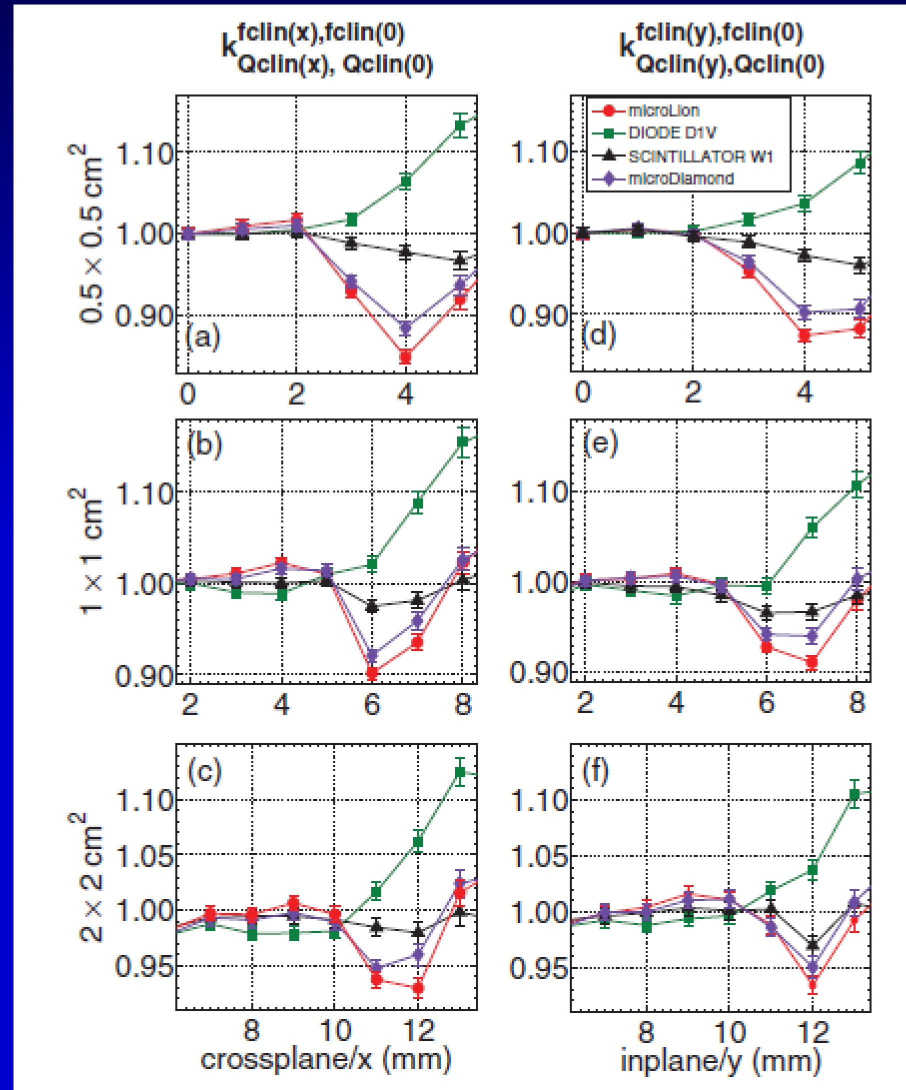
Depth Dose & Source Size



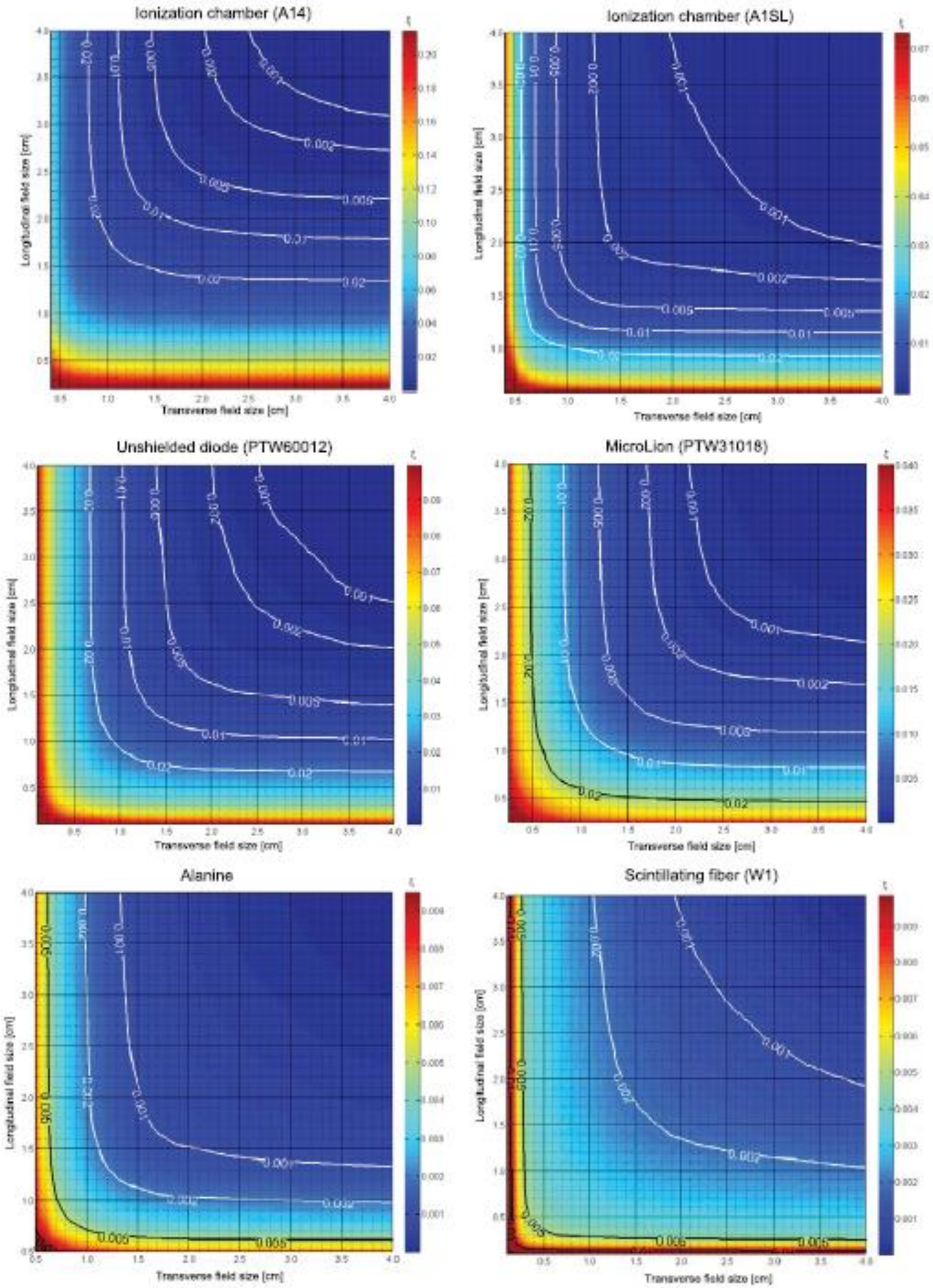
Sham et al, Med Phys, 35, 3317-3330, 2008

Good News with Modern Microdetectors





Papaconstadopoulos, et al, Phys. Med. Biol. 59 (2014) 5937–5952,



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Phys. Med. Biol. 59 (2014) 4973–5002   doi:10.1088/0031-9155/59/17/4973

Correction-less dosimetry of nonstandard photon fields: a new criterion to determine the usability of radiation detectors

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[3] Acoustics and Ionising Radiation Team, National Physical Laboratory, Hampton Road, Teddington TW11 0LW, UK

6 MV

Detectors	Square field size (cm)								
	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.50	3.00
MicroLion	3.1	2.0	1.3	0.8	0.5	0.3	0.2	0.1	0.1
N. Diamond	3.8	2.4	1.5	1.0	0.6	0.4	0.3	0.2	0.1
U. diode	4.9	3.0	1.9	1.2	0.8	0.5	0.4	0.2	0.1
Alanine	1.4	0.6	0.3	0.2	0.1	0.1	0.1	0.0	0.0
S. Fiber	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1

[a] Values are rounded to the nearest 0.1%.

25 MV

Detectors	Square field size (cm)								
	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.50	3.00
MicroLion	2.4	1.8	1.4	1.0	0.8	0.6	0.5	0.3	0.2
N. Diamond	3.3	2.1	1.5	1.0	0.8	0.6	0.5	0.3	0.1
U. diode	4.0	2.8	2.1	1.6	1.3	1.0	0.9	0.5	0.3
Alanine	1.5	0.8	0.6	0.4	0.3	0.2	0.2	0.1	0.1
S. Fiber	0.7	0.5	0.4	0.3	0.3	0.2	0.2	0.1	0.1

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Machine, Cone & Depth?

Can small field diode correction factors be applied universally?

Paul Z.Y. Liu [a,b,*], Natalka Suchowerska [a,b], David R. McKenzie [a]

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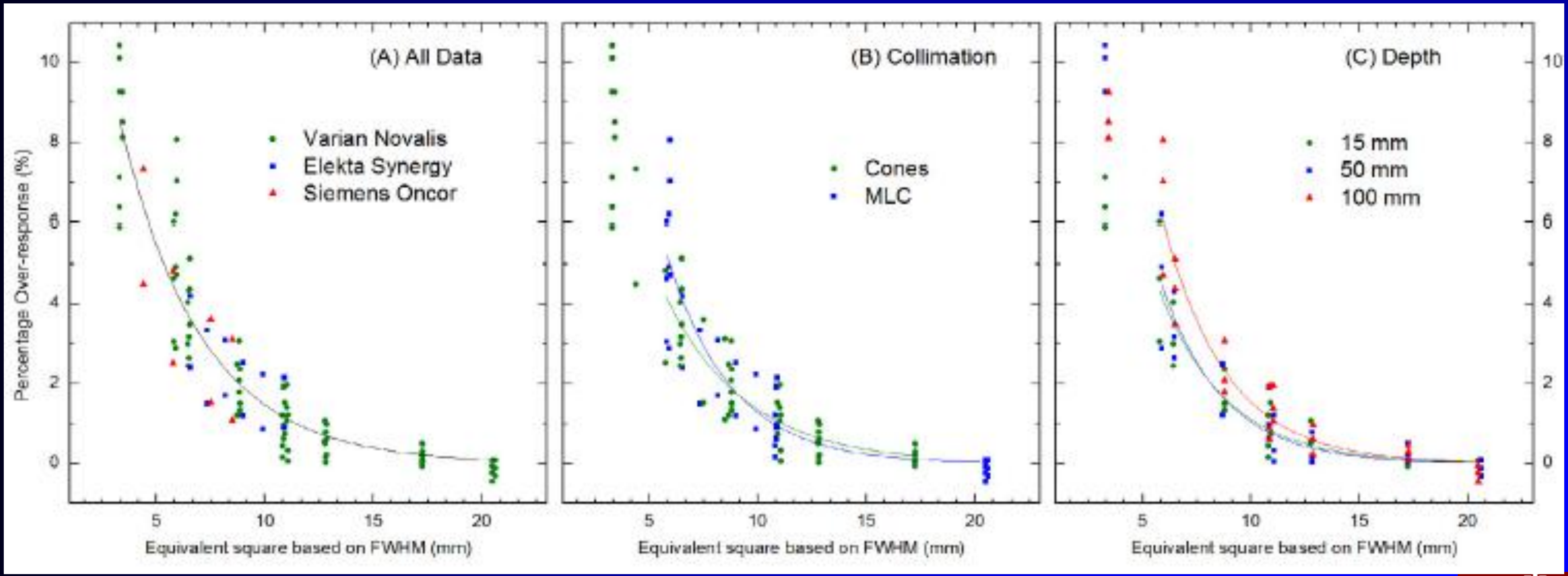
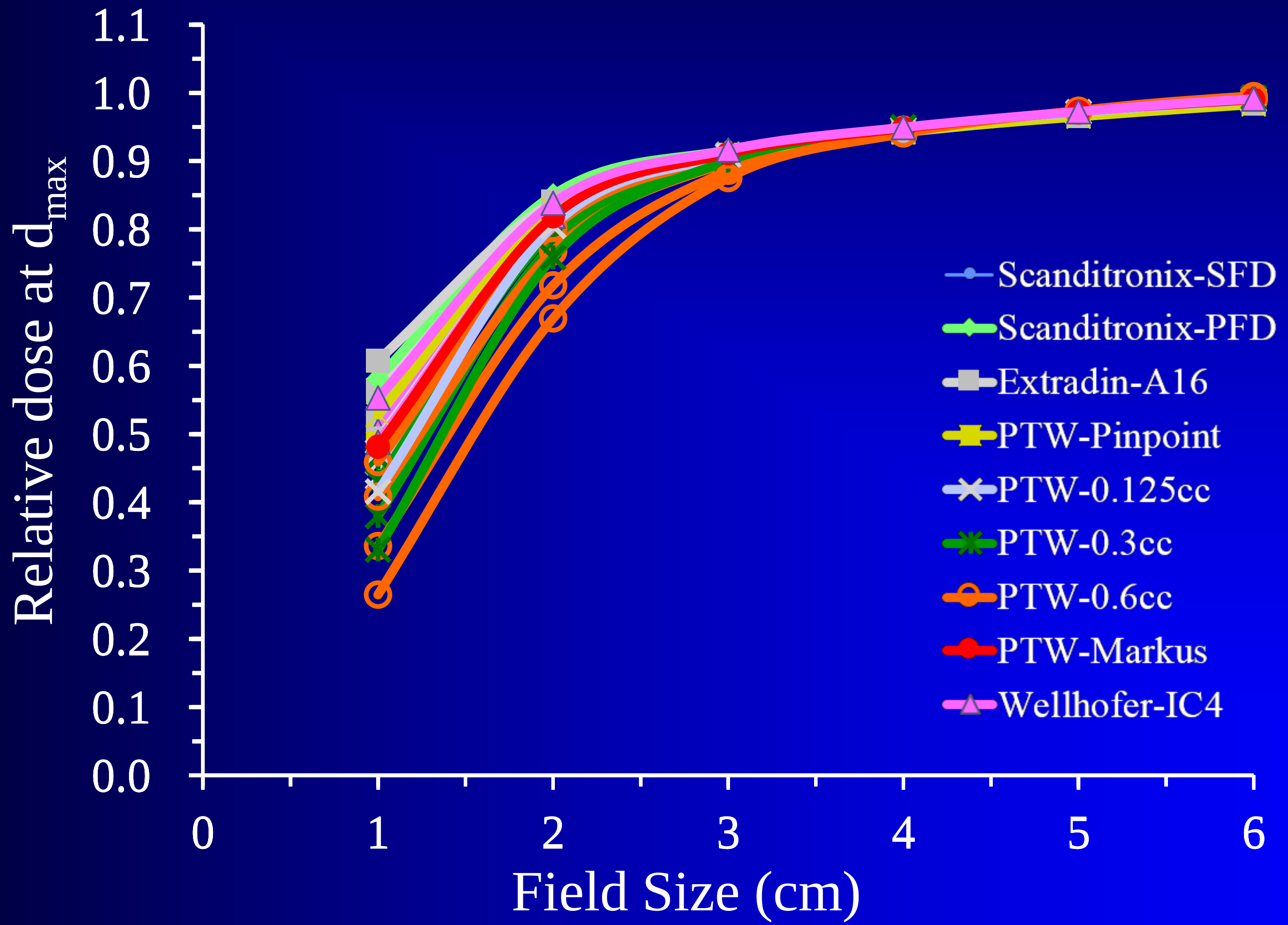
Radiotherapy Oncology, 112, 442-446, 2014



Validity of Proposed Method



Summary

- Understand the limit of small field
- Focal spot issues
- Detectors that are water equivalent like, MicroLion, MicroDiamond and Plastic Scintillators are best suited
- Use proper correction factors to correct detector response to correct for the dose
- Watch for IAEA and TG-155 guidelines when they are published

Sam Question # 1

What is a "small field" in photon beam dosimetry?

- 6% A. Less than 3x3 cm2
- 25% B. Less than 2x2 cm^2
- 2% C. Depends on type of machine (CyberKnife, Gamma Knife, etc)
- 4% D. Depends on detector (pinpoint, microdiamond, micro-diode etc)
- 63% E. Depends on beam energy and source size

Sam- Answer

Answer: E - Depends on Beam Energy and Source Size

Ref: “Das et al, Small fields: Non-equilibrium radiation dosimetry," Med Phys **35**, 206-215 (2008)

Sam Question # 2

The source size of a linear accelerator is typically?

0% A. 20 mm

4% B. 10 mm

3% C. 5 mm

15% D. 2 mm

78% E. 1-10 mm, depending on the machine

Sam- Answer 2

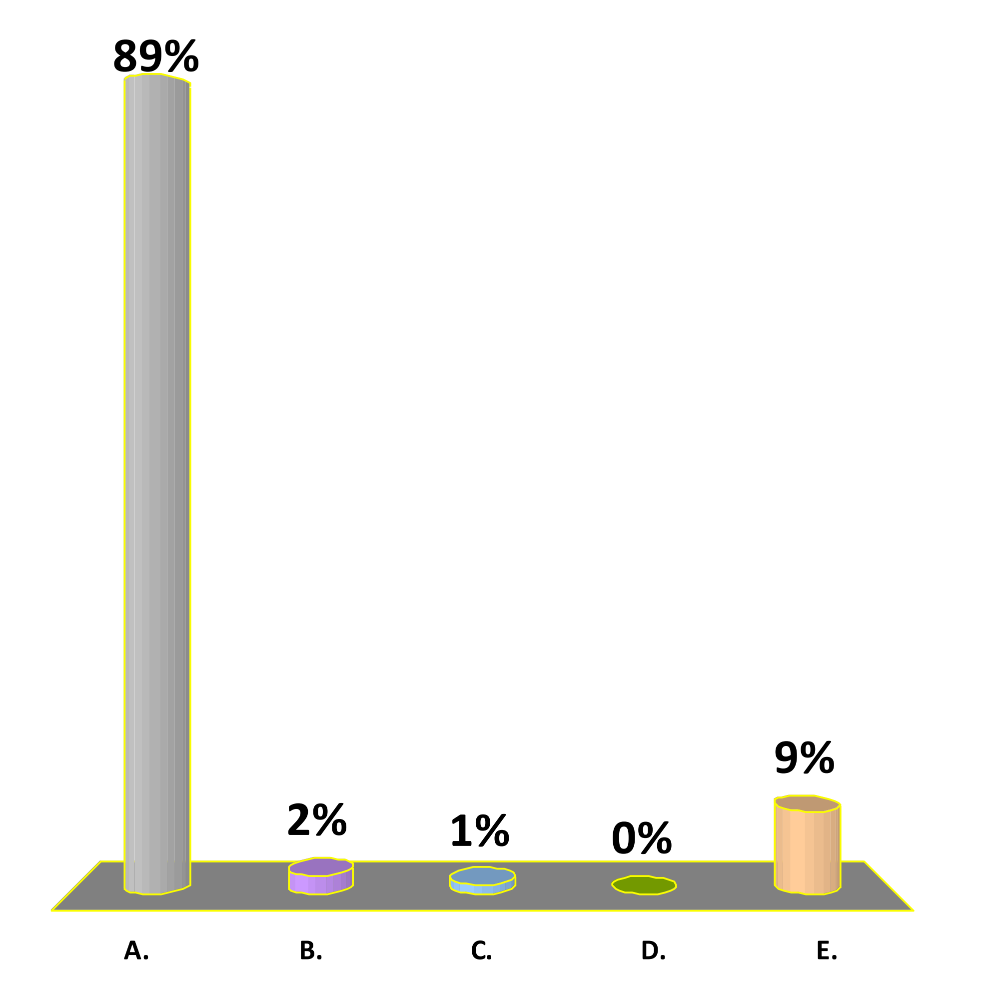
Answer: E – Depending on machine

Ref: Jaffray et al, Med Phys 20, 1417-1427 (1993)

Sam Question # 3

Dosimetry of small field should be performed with;

A. Small water-equivalent detectors (MicroLion, MicroDiamond, Plastic Scintillators)
B. Edge detector
C. Pinpoint
D. MicroMosfet
E. Any micro-detector



Sam- Answer #3

Answer: **A** – The detectors that are water equivalent

Ref: Azangwe et al, Med Phys 41, 072103 (2014)

Benmakhlouf et al, Med Phys 41, 041711 (2014)


Thanks