Springfield Hospital Reports Radiation Overdose Administered to 76 Cancer Patients

February 26, 2010

The New York Times reported on a recent report filed by CoxHealth medical facility in Springfield, Missouri where they admitted to over-radiating 76 cancer patients during treatment. The majority of the patients were being treated for brain cancer, and received about a 50 overdose of radiation therapy. A hospital employee improperly calibrated the machine used to administer the radiation.

The New York Times — U.S.

Radiation Errors Reported in Missouri

By WALT BOGDANICH and REBECCA R. RUIZ
Published: February 24, 2010

A hospital in Missouri said Wednesday that it had overradiated 76 patients, the vast majority with brain cancer, during a five-year period because powerful new radiation equipment had been set up incorrectly even with a representative of the manufacturer watching as it was done.

The hospital, CoxHealth in Springfield, said half of all patients undergoing a particular type of treatment — stereotactic radiation therapy — were overdosed by about 50 percent after an unidentified medical physicist at the hospital miscalibrated the new equipment and routine checks over the next five years failed to catch the error.

Stereotactic therapy delivers radiation in such high doses that usually only one treatment is required. It is commonly used to treat small tumors in the head, which must be firmly stabilized, allowing radiation to be delivered to a precise location.

The error was discovered in September 2009 only after a second physicist received training on the equipment, made by BrainLAB, and the hospital began questioning whether the machine had been installed correctly in 2004, in a process called commissioning.

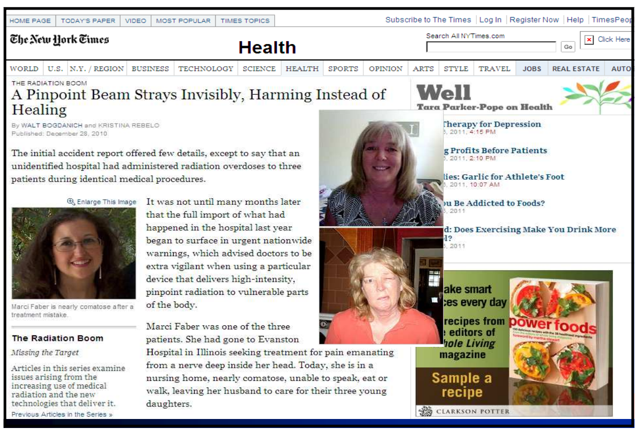
The overdoses at CoxHealth occurred in a state where there is little or no government oversight of radiation therapy, a fact that Robert H. Bezanson, the hospital's president and chief executive, chose to emphasize.

On Wednesday, he released a letter that he wrote to the Food and Drug Administration, saying that its recent decision to toughen oversight of diagnostic radiation did not go far enough.

"The initiative should be broadened to include regulation of medical radiation therapy as well," he wrote. "We have also learned that the incident here at CoxHealth is, unfortunately, not an isolated occurrence. Rather, similar instances of medical overradiation have occurred at other hospitals throughout the country. Without increased regulation and oversight, these instances of medical overradiation will likely continue."

Wrong detector used for BrainLab cone calibration

IJD/Brazil-2012



The New York Times — Health

THE RADIATION BOOM

A Pinpoint Beam Strays Invisibly, Harming Instead of Healing

By WALT BOGDANICH and KRISTINA REBELO
Published: December 28, 2010

The initial accident report offered few details, except to say that an unidentified hospital had administered radiation overdoses to three patients during identical medical procedures.

Marci Faber is nearly comatose after a treatment mistake.

It was not until many months later that the full import of what had happened in the hospital last year began to surface in urgent nationwide warnings, which advised doctors to be extra vigilant when using a particular device that delivers high-intensity, pinpoint radiation to vulnerable parts of the body.

Marci Faber was one of the three patients. She had gone to Evanston Hospital in Illinois seeking treatment for pain emanating from a nerve deep inside her head. Today, she is in a nursing home, nearly comatose, unable to speak, eat or walk, leaving her husband to care for their three young daughters.

The Radiation Boom

Missing the Target

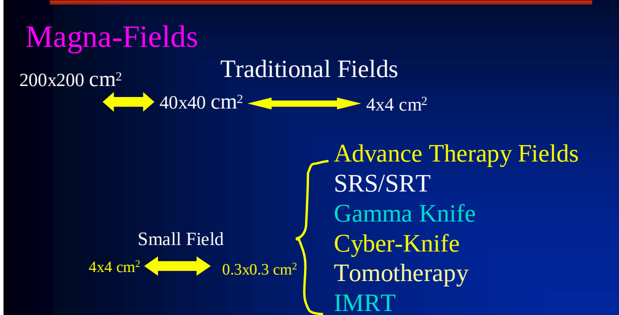
Articles in this series examine issues arising from the increasing use of medical radiation and the new technologies that deliver it.

TG-155 Approved Task

1. Collaborate with the new task group (Non-compliant/IAEA) on absolute dosimetry to ensure that there is no overlap between the two task groups, but rather are complementary to each other.
2. Review and summarize literature on dosimetry of small fields irrespective of the origin and treatment modality.
3. Provide overview of the issue of CPE for the small field dosimetry in homogeneous and inhomogeneous media.
4. Provide meaningful information on the spectrum and shift in beam energy from Monte Carlo.
5. Provide radiation parameters *(men/r, S/r, etc)* for small field dosimetry from published literature from Monte Carlo.
6. Provide suitability of specific detectors with respect to perturbations and signal to noise ratio.
7. Provide available information on the correction and perturbation factors in detectors.
8. Provide guidelines in measurement methods for modeling the treatment planning systems for small fields.
9. Provide suitability of algorithms based on measurement for beam modeling in small fields especially in inhomogeneous medium.
10. Provide error analysis and limit of uncertainty in the measurements.
11. Provide guidelines and recommendations for accurate determination of dosimetric data for small fields.

IJD/Brazil-2012

Treatment Fields



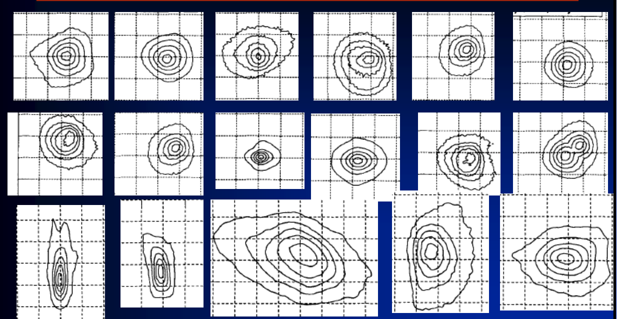
IJD/Brazil-2012

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

IJD/Brazil-2012

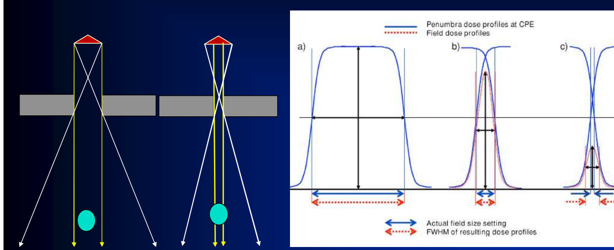
Source Size



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

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

Definition of Small Fields

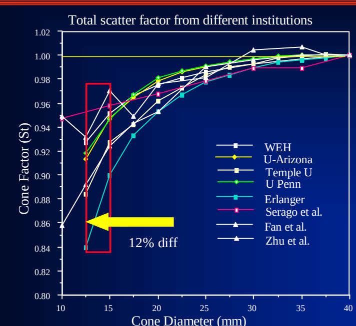


Das et al, Med. Phys. 35, 206-215, 2008

Dosimetry

- Absolute
  - Dose
- Relative
  - Depth Dose
    - [D(r,d)/D(r,dm)]
  - TMR
  - Profiles
  - Output, S_{cp} (total scatter factor)
    - [D(r)/D(ref)]

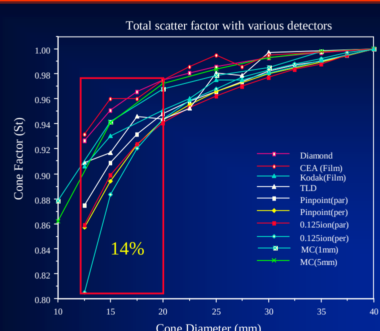
Small Field Dosimetry Problem



Institutional variability in 6 MV Radionics SRS dosimetry

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

Dosimetric Variation with Detectors



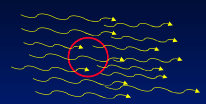
Das et al, J Radiosurgery, 3, 177-186, 2000

Radiation Measurements

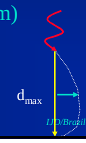
- Charged particle equilibrium or electronic equilibrium
  - Range of secondary electrons
  - Medium (tissue, lung, bone)
- Photon energy and spectrum
  - Change in spectrum
    - Field size
    - Off axis points like beamlets in IMRT
  - Changes m_{en}/r and S/r
- Detector size
  - Volume
  - Signal to noise ratio

CPE & Electron Range

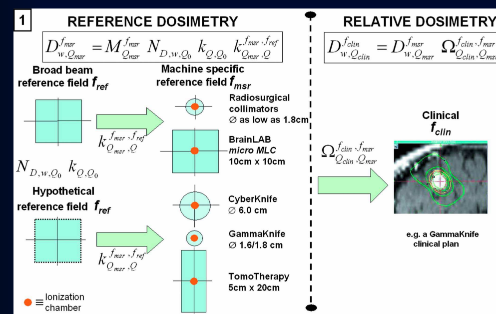
- CPE, Charged Particle Equilibrium



- Electron range= d_{max} in forward direction
- Electron range in lateral direction
  - Nearly energy independent
  - Nearly equal to penumbra (8-10 mm)
- Field size needed for CPE
  - Lateral range
  - 16-20 mm



IAEA/AAPM proposed pathway



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

Relative Dosimetry

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

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

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

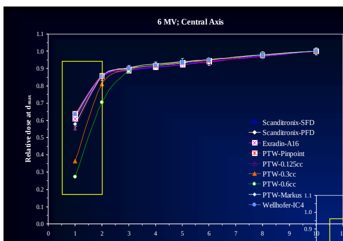
$$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{\left(S_{w,air}\right)_{fclin} \cdot P_{fclin}}{\left(S_{w,air}\right)_{fmsr} \cdot P_{msr}}$$

Why So Much of Fuss?

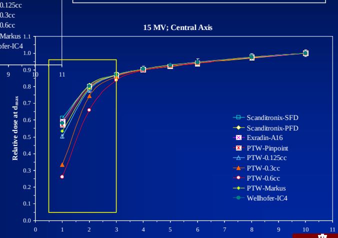
- Reference (ref) conditions cannot be achieved for most SRS devices (cyberknife, gammaknife, tomotherapy etc)
- Machine Specific reference (msr) needs to be linked to ref
- Ratio of reading (PDD, TMR, Output etc) is not the same as ratio of dose

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

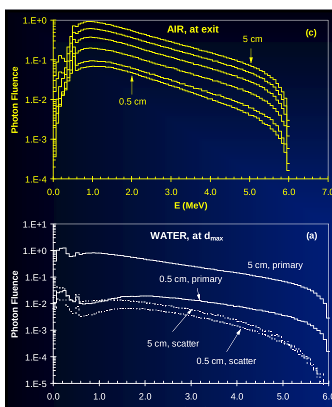
$$\frac{D_1}{D_2} = \frac{M_1}{M_2} \bullet \left[k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}\right]$$



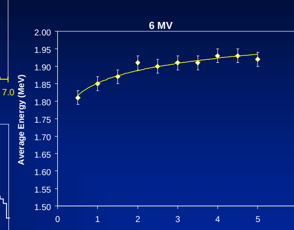
Field Size Limit for Accurate Dose Measurements with Available Detectors



Das et al, TG-106, Med Phys, 35, 4186, 2008



Spectra & Effective Energy from SRS Cones (0.5-5 cm)



Verhaegen, Das, Palmans, PMB, 43, 2755-2768, 1998

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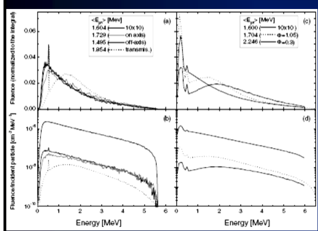
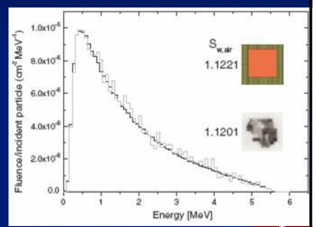
Phys. Med. Biol. 48 (2003) 2081–2099 | PII: S0031-9155(03)61152-8

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]





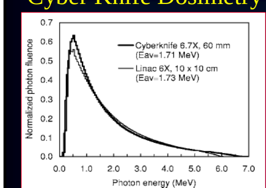
Radiological Parameters

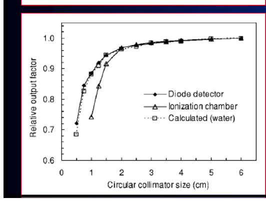
6 MV beams	Beam quality ($TPR_{20,10}$)	$s_{w,air}$ Andreo (1994)[a]	$s_{w,air}$ This work	$s_{w,air}$ Ratio this work/ Andreo	$s_{PMMA,air}$ Andreo (1994)[a]	$s_{PMMA,air}$ This work	$s_{PMMA,air}$ Ratio this work/ Andreo	Configuration
Elekta SL-18 radiosurgery								
10 × 10 cm^2	0.690	1.1187	1.1188	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

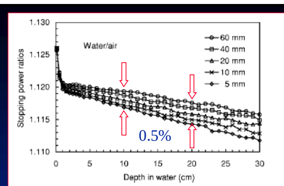
[a] These are the values in the IAEA TRS-398 code of practice (Andreo *et al* 2000).

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).

Francescon et al, Med. Phys. 25(4), 503, 1998

TABLE III. $s_{c,p}$ measured with parallel-plate micro-chamber (filled with air and TMS dielectric liquid, alternatively), radiochromic film, radiographic film, MOSFETs, 1×1×1 mm^3 chips of TLD-800 and calculated by Monte Carlo BEAM code. For $s_{c,p}$ measured with the ion chamber and MOSFETs, the experimental values have been corrected by means of the F factor, as described in Section II G.

Field diameter (mm)	Exradin pp IC (with air) $s_{c,p}$	2σ%	Exradin pp IC (with TMS) $s_{c,p}$	2σ%	Radiochromic film $s_{c,p}$	2σ%	TLD-800 $s_{c,p}$	2σ%	MOSFETs $s_{c,p}$	2σ%	Radiographic film $s_{c,p}$	2σ%	Monte Carlo BEAM code $s_{c,p}$	2σ%
4.4	(0.45[a])	<0.8%	(0.45[a])	<0.8%	0.47	2.4%	0.47	3.7%	(0.48[a])	<1.8%	0.46	3.0%	0.46	<0.5%
MC	0.37	0.5%	0.42	0.5%					0.53	1.7%				
6.7	(0.66[a])	<0.8%	(0.65[a])	<0.8%	0.66	2.7%	0.64	1.9%	(0.65[a])	<3.6%	0.66	2.0%	0.66	<0.5%
MC	0.58	0.5%	0.62	0.5%					0.71	3.5%				
10.5	(0.82[a])	<0.8%	(0.81[a])	<0.8%	0.81	1.8%	0.80	3.5%	(0.80[a])	<1.7%	0.81	2.3%	0.82	<0.5%
MC	0.76	0.5%	0.78	0.5%					0.84	1.6%				
12.7	(0.85[a])	<0.6%	(0.85[a])	<0.6%	0.85	2.5%	0.84	2.8%	(0.84[a])	<1.4%	0.85	2.5%	0.84	<0.5%
MC	0.81	0.4%	0.83	0.4					0.86	1.3%				
16.0	(0.87[a])	<0.6%	(0.87[a])	<0.6%	0.88	2.2%	0.87	3.2%	(0.87[a])	<2.0%	0.88	2.5%	0.87	<0.5%
MC	0.86	0.4%	0.86	0.4%					0.88	1.9%				
19.0	(0.89[a])	<0.6%	(0.89[a])	0.6%	0.89	2.3%	0.89	2.6%	(0.89[a])	<2.0%	0.89	2.5%	0.89	<0.5%
MC	0.89	0.4%	0.89	0.4					0.89	1.9%				

[a]Experimental values divided by the F factor (Section II G).

Correction Factors

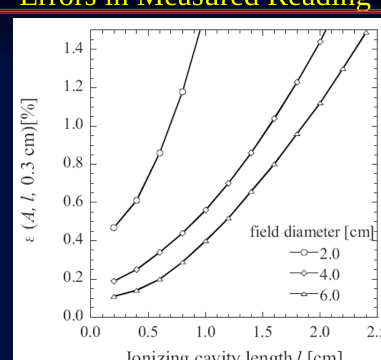
Correction Factor depends on:
- Field size
- Source size (FWHM)
- Detector type

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

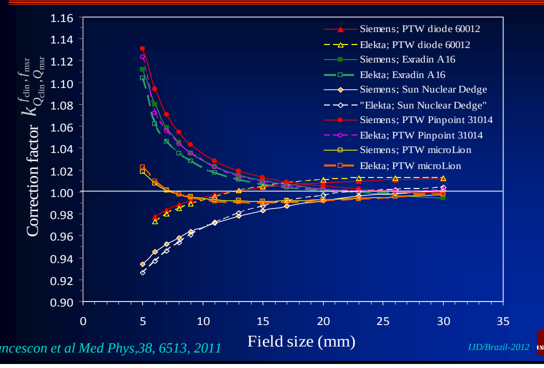
Francescon, et al Med Phys 35, 504, 2008

Errors in Measured Reading



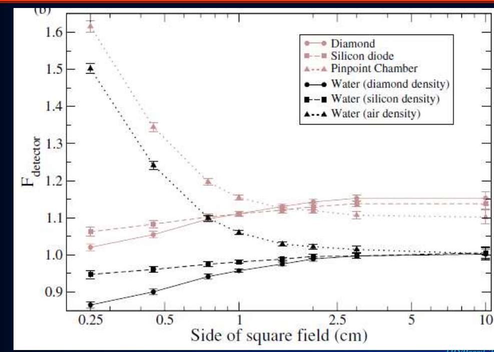
Kawachi et al, Med Phys, 35, 4591-4598, 2008

Published data on $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$



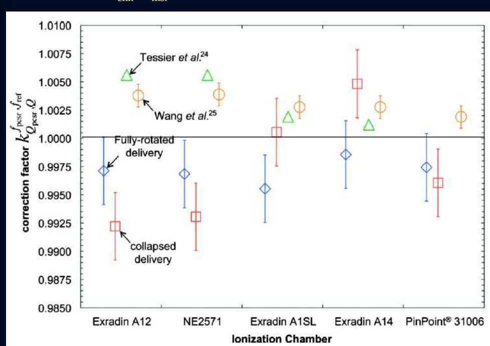
Francescon et al Med Phys,38, 6513, 2011

Detector Density Effect



Scott et al. Phys Med Biol ***57*** *4461–4476, 2012*

$k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ Correction Factor vs Ion Chambers



Chung et al , Med Phys, 37, 2404-2413, 2010

$k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ of Linear Accelerators

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

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Department of Medical Physics, ULSS 6 – 36100 Vicenza, Italy

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

Contents lists available at SciVerse ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

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

$k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ Cyber Knife

Detector	5 mm $M^{f_{clin}}_{Q_{clin}}/M^{f_{msr}}_{Q_{msr}}$	5 mm $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$	7.5 mm $M^{f_{clin}}_{Q_{clin}}/M^{f_{msr}}_{Q_{msr}}$	7.5 mm $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$	10 mm $M^{f_{clin}}_{Q_{clin}}/M^{f_{msr}}_{Q_{msr}}$	10 mm $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$
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

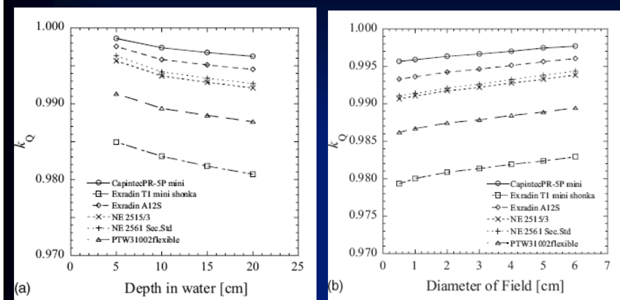
Tomotherapy k_{msr} Reference Dosimetry

Reference: 5x10 cm^2, 85 cm SSD, 10 cm

Chamber type	k_{Q,Q_o} (TRS-398)	$k^{f_{msr},f_{ref}}_{Q_{msr},Q}$	$k^{f_{msr},f_o}_{Q_{msr},Q_o}$ (MC)	$k^{f_{msr},f_o}_{Q_{msr},Q_o}$ (previous studies)
Exradin A1SL	0.996	1.001	0.997	0.997 (Refs. 5 and 10)
Exradin A12 Farmer	0.996	1.004	1.000	
PTW 30006 Farmer	0.993	1.004	0.997	0.995 (Ref. 6)
PTW 31010 Semiflex	0.993	1.002	0.995	0.996 (Ref. 10)
PTW 31014 PinPoint	0.994	0.997	0.993	0.992 (Ref. 10)
PTW 31018 microLion (parallel)	N/A	N/A	0.993	
NE 2571 Farmer	0.994	1.003	0.997	0.995 (Ref. 6)

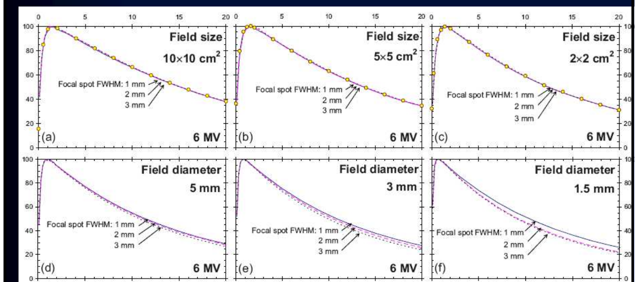
Sterpin et al, Med Phys, 39, 4066, 2012

k_Q is not Constant in Small Field



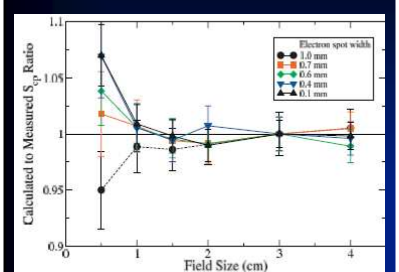
Kawachi et al, Med Phys, 35, 4591-4598, 2008

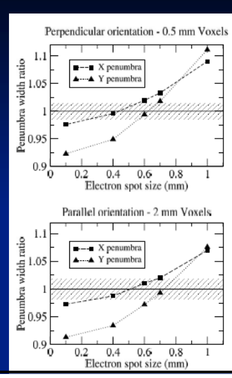
Depth Dose & Source Size



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

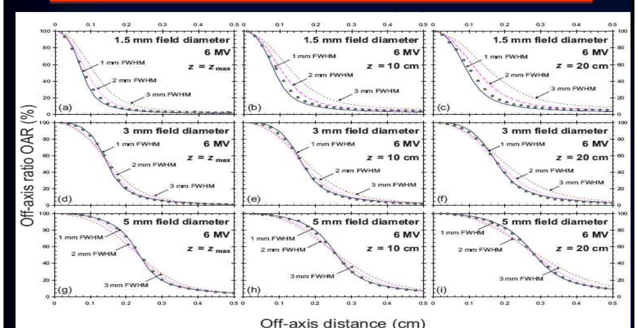
Dose and Penumbra with Spot Size





Scott et al, Med Phys, 36, 3132, 2009

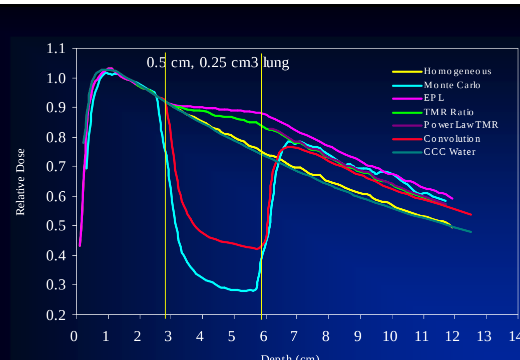
Profile & Source Size



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

Effect of Inhomogeneity

- Range of secondary electrons
  - Simple scaling based on density
    - M. K. Woo, and J. R. Cunningham, "The valididty of density scaling method in primary electron transport for photon and electron beams," Med. Phys. **17**, 187-194 (1990).
- Perturbations of the detector
  - *T. Mauceri, and K. R. Kase, "Effects of ionization chamber construction on dose measurements in heterogeneity," Medical Physics 14, 653-656 (1987).*
  - *R. K. Rice, J. L. Hansen, L. M. Chin, B. J. Mijnheer, and B. E. Bjarngard, "The influence of ionization chamber and phantom design on the measurement of lung dose in photon beam," Medical Physics 15, 884-890 (1988).*



Jones & Das, Med. Phys. 30, 296, 2003

Jones & Das, Med. Phys. 32, 766, 2005

TG-155 Recommendation

- Dosimetric measurements should be carried out with more than one detector system.
- Small volume detector should be used that has minimum energy, dose and dose rate dependence as discussed in TG-120 and Report No103 should be used.
- Stereotactic diodes or electron diodes are recommended for field sizes < 1x1cm2
- Micro chambers are best suited for dosimetric measurements for field sizes > 1x1 cm2 however, signal to noise as well as polarity effect should be evaluated.
- The quality of electrometer and triaxial cable as well as any connector and cables need to be of high quality.
- Stereotactic diode with micron size sensitive volume should be the detector of choice for measurements in beams in radiosurgery.
- The energy spectrum does vary in small fields such as SRS, and IMRT but these changes result in insignificant variations in stopping power ratios when compared to those of the reference field used in dosimetry codes of practice.
- The treatment planning system performance should be carefully validated when used for the treatment planning incorporating small fields. Although pencil beam and convolution/superposition dose engines are expected to perform well in small field treatment geometries and in almost homogeneous media, dose engines based on the Monte Carlo method are the most accurate method for modelling dose from small fields in heterogeneous media. The calculation grid size should be significantly smaller (~1/10) compared to the field size.
- Small field dosimetry should have an independent audit by a different physicist either internal or external like Radiological Physics Center verification.

Summary

- Small volume detector should be used that has minimum energy, dose and dose rate dependence.
- Micro-ion chambers are best suited for small field dosimetry; however, signal to noise should be evaluated.
- Stereotactic diode are ideally suited for radiosurgery beams.
- If field size is small compared to detector measurements should be performed at a greater source to surface distance with proper correction.

-Summary

- Energy spectrum does vary in small fields such as SRS, and IMRT, however, its impact is not significant.
- Stopping power ratio in small fields for most ion chambers is relatively same as the reference field.
- Spot check and verification of smaller fields should be carried out with at least another independent method (TLD, film, MC, etc).
- Stay tuned to newer data and IAEA and AAPM TG guidelines.