Small-Field Dosimetry

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TG-155: Small Fields and Non-Equilibrium Condition Photon Beam Dosimetry

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Treatment Fields

Magna-Fields

200x200 cm^2

Traditional Fields

40x40 cm^2 ⟷ 4x4 cm^2

Small Field

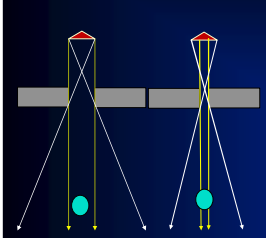
4x4 cm^2 ⟷ 0.3x0.3 cm^2

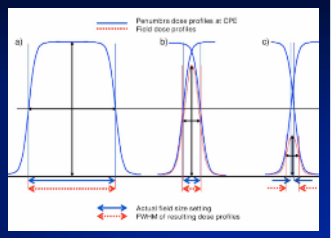
Advance Therapy Fields
- SRS/SRT
- Gamma Knife
- Cyber-Knife
- Tomotherapy
- IMRT

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



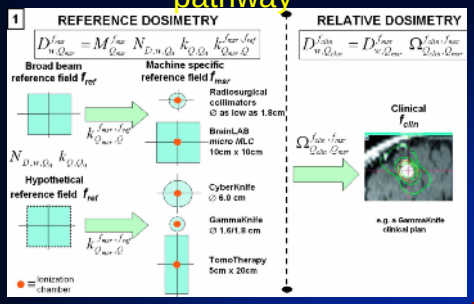


Das et al, Med. Phys. 35, 206-215, 2008

Dosimetry

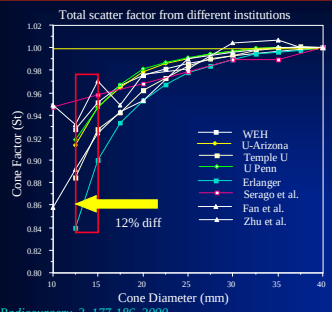
- Absolute
  - Dose
- Relative
  - Depth Dose [D(r,d)/D(r,dm)]
  - TMR
  - Profiles
  - Output, S_{cp} (total scatter factor), [D(r)/D(ref)]

IAEA/AAPM proposed pathway



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

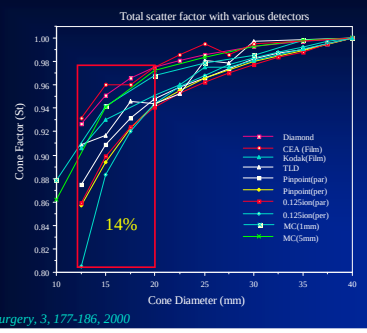
Small Field Dosimetry Problem



Institutional variability in 6 MV Radionics SRS dosimetry

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

Dosimetric Variation with Detectors



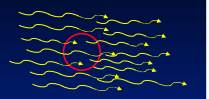
Das et al, J Radiosurgery, 3, 177-186, 2000

Radiation Measurements

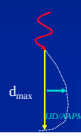
- Charged particle equilibrium or electronic equilibrium
  - Range of secondary electrons
  - Medium (tissue, lung, bone)
- Photon energy and spectrum
  - Change in spectrum
    - Field size
    - Off axis points like beamlets in IMRT
  - Changes μ_{en}/ρ and S/ρ
- Detector size
  - Volume
  - Signal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



Dosimeters & Associated Problems

- Ion Chambers
  - Diameter, volume, and window thickness
  - W/e, S/ρ, $\mu en/\rho$
  - Perturbation
- Films
  - Silver bromide films
    - high Z, sensitivity, thickness
  - GAFchromic polymer films
    - Sensitivity, thickness, polymerization at low energy
- TLD/OSL (sensitivity at low energy, F center)
  - Size 10-15 µm, difficulty of handling
- Fricke Dosimeter (G value)
  - (Size and dose)
- MOSFET (thickness, dose rate, burnout, life, cost)
- Monte Carlo (benchmarking, expertise, reliability)

Ratio of Readings?

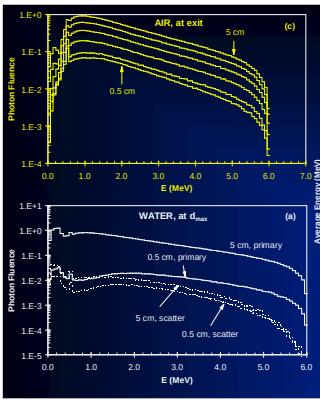
$$D = \int_0^{h\nu_{max}} \frac{d\phi(h\nu)}{d(h\nu)} \left(\frac{\mu(h\nu)}{\rho} \right) E_{ab}(h\nu) d(h\nu)$$

$$D_m = \left(\frac{Q}{m} \right) \left(\frac{\overline{W}}{e} \right) \left(\frac{S}{\rho} \right)_a^m$$

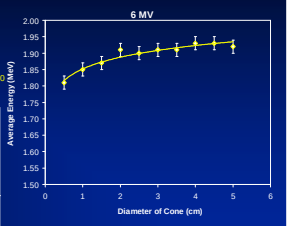
$$\frac{D(r)}{D_{ref}} = \left(\frac{Q(r)}{Q_{ref}} \right) \left(\frac{\overline{W}}{e} \right)_{ref}^r \left(\left(\frac{S}{\rho} \right)_a^m \right)_{ref}^r$$

$$Q(E,r) = Q_r P_{ion} P_{repl} P_{wall} P_{cec} P_{pcf}$$

$$\frac{D(r)}{D_{ref}} = \left(\frac{Q(r)}{Q_{ref}} \right) \left(\frac{\overline{W}}{e} \right)_{ref}^r \left(\left(\frac{S}{\rho} \right)_a^m \right)_{ref}^r = \left(\frac{Q(r)}{Q_{ref}} \right) \bullet CF_1 \bullet CF_2$$



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

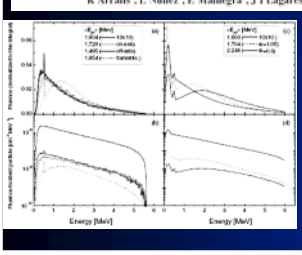


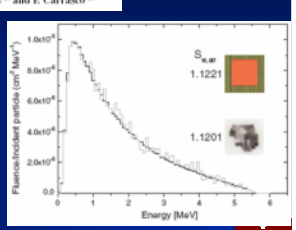
Verhaegen, Das, Palmans, PMB, 43, 2755-2768, 1998

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[2], 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]





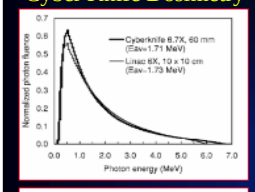
Radiological Parameters

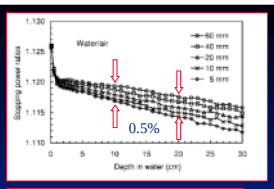
6 MV beams	Beam quality ($TPR_{20,10}$)	$s_{w,air}$ Andreo (1994)*	$s_{w,air}$ This work	$s_{w,air}$ Ratio this work/ Andreo	$s_{PMMA,air}$ Andreo (1994)*	$s_{PMMA,air}$ This work	$s_{PMMA,air}$ Ratio this work/ Andreo	Configuration
Elekta SL-18 radiosurgery								
10 × 10 cm²	0.690	1.1187	1.1188	1.000	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 cm²	0.677	1.1213	1.1221	1.001	1.0880	1.0892	1.001	figure 1(d)
2 × 2 cm² irregular on-axis			1.1203	0.999		1.0870	0.999	figure 1(e)
2 × 2 cm² 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 cm² approx)			1.1201	0.999				figure 12

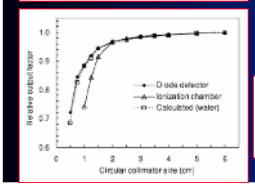
* These are the values in the IAEA TRS-398 code of practice (Andreo *et al* 2000).

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

Cyber Knife Dosimetry







Machine type	%dd(10)$_x$	$(\bar{L}/\rho)^{w}_{air}$
		Wall=C-552
Linac	66.3	1.1094
Cyberknife	60.8	1.1088
		Wall=Carbon
Linac	66.3	1.1144
Cyberknife	60.8	1.1144
		Wall=PMMA

Machine type	%dd(10)$_x$	$(\bar{L}/\rho)^{w}_{air}$			
		Water	PMMA	Carbon	C-552
Linac	66.3[a]	1.1206	1.1176	0.9878	0.9836
Cyberknife	60.8[b]	1.1194	1.1159	0.9854	0.9817

[a]For a 10 × 10 cm² 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. $x_{w,p}$ measured with parallel-plate micro-chamber (filled with air and TMS dielectric liquid, alternatively), radiochromic film, radiographic film, MOSFETs, 1×1×1 mm³ chips of TLD-800 and calculated by Monte Carlo BEAM code. For $x_{w,p}$ 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)		Exradin pp IC (with TMS)		Radiochromic film		TLD-800		MOSFETs		Radiographic film		Monte Carlo BEAM code	
		$x_{w,p}$	2σ%	$x_{w,p}$	2σ%	$x_{w,p}$	2σ%	$x_{w,p}$	2σ%	$x_{w,p}$	2σ%	$x_{w,p}$	2σ%	$x_{w,p}$	2σ%
4.4		(0.45*)	<0.8%	(0.45*)	<0.8%	0.47	2.4%	0.47	3.7%	(0.48*)	<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*)	<0.8%	(0.65*)	<0.8%	0.66	2.7%	0.64	1.9%	(0.65*)	<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*)	<0.8%	(0.81*)	<0.8%	0.81	1.8%	0.80	3.5%	(0.80*)	<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*)	<0.6%	(0.85*)	<0.6%	0.85	2.5%	0.84	2.8%	(0.84*)	<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*)	<0.6%	(0.87*)	<0.6%	0.88	2.2%	0.87	3.2%	(0.87*)	<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*)	<0.6%	(0.89*)	0.6%	0.89	2.3%	0.89	2.6%	(0.89*)	<2.0%	0.89	2.5%	0.89	<0.5%
	MC	0.89	0.4%	0.89	0.4					0.89	1.9%				

*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_{rel} of the four detectors for the 5, 7.5, and 10 mm collimators, as a function of the FWHM.

AIS	F_{rel}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.007	1.011	1.008
1.8	1.007	1.013	1.007
2.2	1.012	1.018	1.012
2.6	1.012	1.017	1.010
Pin Point	F_{rel}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.002	1.015	1.017
1.8	1.009	1.024	1.013
2.2	1.010	1.022	1.013
2.6	1.024	1.037	1.016
Diode	F_{rel}		
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	0.960	0.967	0.978
Diamond	F_{rel}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.046	1.001	1.001
1.8	1.040	1.007	1.000
2.2	1.037	1.010	0.999
2.6	1.025	1.012	1.001

Francescon, et al Med Phys 35, 504, 2008

Issues with IMRT Dose Delivery

- About 50% of the total MU contributes to ~95% of the dose and 30% of the total MU contributes <0.5% to isocenter due to small beamlets
- With insufficient lateral equilibrium in at least one direction, the absorbed dose never reaches the equilibrium value, and can be significantly lower for very small field sizes
- The large difference between 0.6cm³ and the 0.015 cm³ ion chamber data is due to the under sampling of the 0.6 cm³ data because of the detector size.

Cheng, Das, Huq, Med. Phys. 30(11), 2959-2968, 2003

Dependence on Chamber Volume

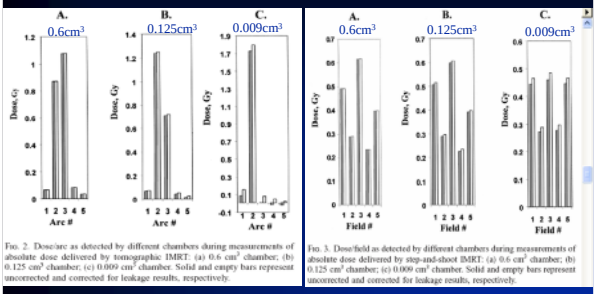
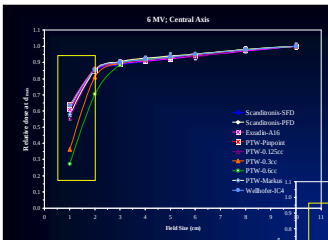


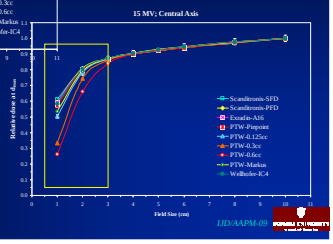
FIG. 2. Dose/arc as detected by different chambers during measurements of absolute dose delivered by tomographic IMRT: (a) 0.6 cm³ chamber; (b) 0.125 cm³ chamber; (c) 0.009 cm³ chamber. Solid and empty bars represent uncorrected and corrected for leakage results, respectively.

FIG. 3. Dose/field as detected by different chambers during measurements of absolute dose delivered by step-and-shoot IMRT: (a) 0.6 cm³ chamber; (b) 0.125 cm³ chamber; (c) 0.009 cm³ chamber. Solid and empty bars represent uncorrected and corrected for leakage results, respectively.

Leybovich et al Med Phys. 30, 119-123, 2003

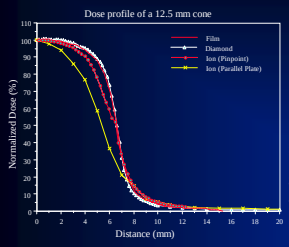


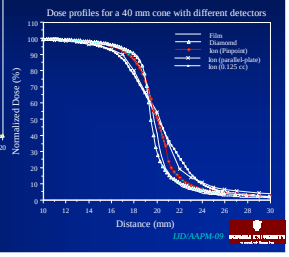
Field Size Limit for Accurate Dose Measurements with Available Detectors



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

Profiles with different detectors



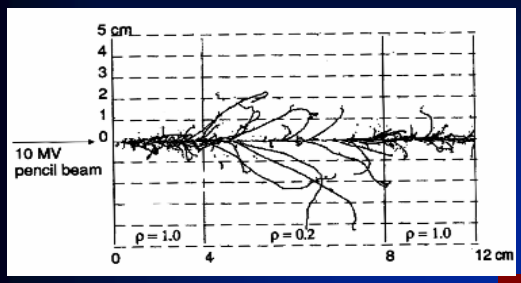


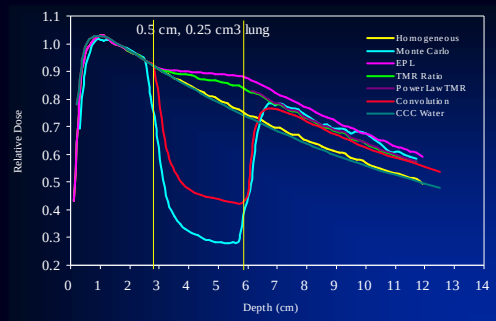
Hedrian, Hoban & Beddoe, PMB, 41, 93-110, 1996
Das et al, J Radiosurgery, 3, 177-186, 2000

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).*

Electron range & inhomogeneity





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

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

Conclusions

- 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 with micron size detector could be suitable for radiosurgery beam.
- If field size is small compared to detector and electronic equilibrium could be compromised, measurements should be performed at greater source to surface distance with proper correction.

-Conclusions

- 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).

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.