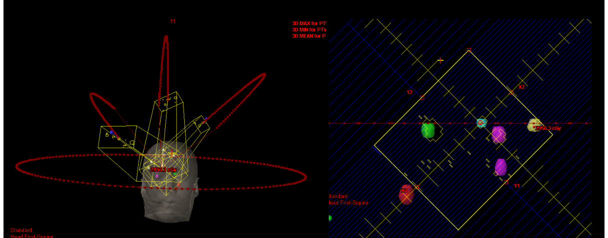
Seng B. Lim MASc DABR
MSKCC Medical Physics
2019 AAPM Spring Clinical Meeting

CONUNDRUM OF SRS BEAM COMMISSIONING

Motivations

- Traditionally one lesion at isocenter
- Time consuming with multiple lesions
- Investigate the feasibility of Eclipse with small fields
  - Energy = 6x
  - Machine = Varian TB
  - MLC = HD120 / M120
  - Model = AAA

Single iso VMAT for multi-mets



Challenge:
- Dosimetry
- Setup accuracy

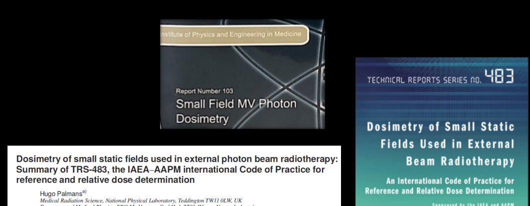
Courtesy of Ase Ballangrud-Popovic

Commissioning Process

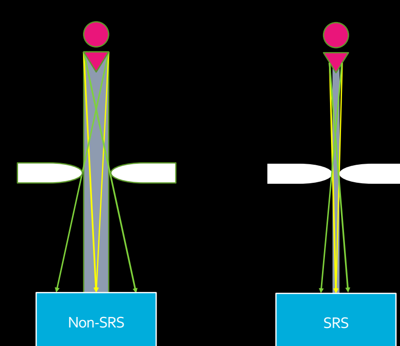
- Basic Beam Acquisition and Validation
  - Output Factor (S_t)
  - Depth Dose (%DD)
  - Profile
  - Absolute Output Calibration
  - MLC
- Clinical field Validation
  - In phantom film dosimetry with clinical fields
- E2E

Challenges

1. Beam Source Size / Shape
2. Lateral Electron Disequilibrium
3. Detector Characteristics



1. Beam Source Size / Shape



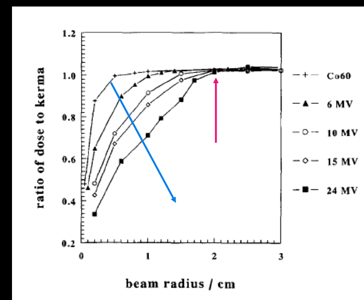
2. Lateral Electron Disequilibrium

- Occurs at high energy photon beams
- Narrow field when beam radius is small compared maximum range of secondary electron
- Small field effect happens at larger field for higher energy!
- FWHM – seems larger than geometric setting*

Dosimetry of small static fields used in external photon beam radiotherapy: Summary of TRS-483, the IAEA–AAPM international Code of Practice for reference and relative dose determination

Hugo Palmans[a)]
Medical Radiation Science, National Physical Laboratory, Teddington TW11 0LW, UK
Department of Medical Physics, EBG MedAustron GmbH, A-2700, Wiener Neustadt, Austria

Lateral Electron Equilibrium



Lateral electron equilibrium and electron contamination in measurements of head-scatter factors using miniphantoms and brass caps

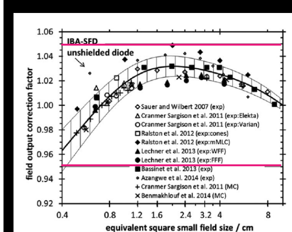
X. Allen Li,[a)] M. Soubra, J. Szanto,[a)] and L. H. Gerig[a)]
Ottawa Regional Cancer Centre, Physics Department, 190 Melrose Avenue, Ottawa, Ontario K1Y 4K7, Canada

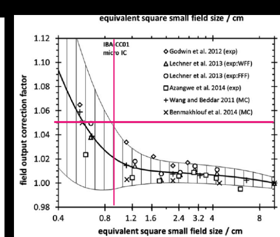
Med. Phys. 22 (7), July 1995

3. Detector

- Spectral response
  - Small fields have harder spectrum
  - Potentially affects silicon-based diode detectors
  - Ion chamber with high-Z electrodes
- Size
  - Volume averaging effect
  - Min FS for Reference Output
    - FWHW > $dim_{max} + 2r_{LCPE}$
    - $r_{LCPE} = 77.97 \times 10^{-3}\ \%dd(10,10)_x - 4.382$

Detector
Field Output Correction Factor





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Detector Recommendations

- Good list on TRS-483
- Daisy Chain
  - Use Larger IC for intermediate to larger field
  - Use small detector for small fields
- Detector Size
  - Small enough with reasonable signal
  - Correction factor should be < 5%
- Directional response
  - <0.5% within ±60° from recommendation orientation

Reference Dosimetry

- Conventional LINAC
  - Use TG-51
    - In water
    - SSD or SAD = 100cm
    - Field size = 10x10 cm^2
- Others
  - TRS-483

Typical MSR

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

Field Size Considerations

		FWHW$_{min}$			
Detector	dim$_{max}$ (mm)	co-60	6x	6FFF	10FFF
PTW 30013	23.6	27.5	39.2	39.8	47.5
A12	21.6	25.5	37.2	37.8	45.5
FC65-G/P	23.0	26.9	38.6	39.2	46.9
PTW 31010	6.5	10.4	22.1	22.7	30.4
PTW 31015	5.7	9.6	21.3	21.9	29.6
PTW 31014	3.6	7.5	19.2	19.8	27.5
PTW 31018	5.7	9.6	21.3	21.9	29.6
A1	6.5	10.4	22.1	22.7	30.4
A14	2.7	6.6	18.3	18.9	26.6
A16	2.5	6.4	18.1	18.7	26.4
cc13	5.8	9.7	21.4	22.0	29.7
cc08	6.0	9.9	21.6	22.2	29.9
cc04	3.6	7.5	19.2	19.8	27.5
cc01	3.6	7.5	19.2	19.8	27.5

Farmer Chamber (PTW 30013, A12, FC65-G/P)

Cylindrical Chamber (remaining detectors)

- Farmer Chamber
  - FS ≥ 60x60 mm² upto 18MV
- Cylindrical chamber
  - FS ≥ 30x30 mm² for 6 to 10FFF
  - FS ≥ 10x10 mm² much smaller for ^{60}Co

k_Q from TG-51 Addendum

Chamber type		Comment	k_Q values for the most common beams (as function of beam-quality specifier $\%dd(10)_x$) 63	67	73	77	81
Capintec	PR-06C/G*	0.6 cc Farmer-type	0.998	0.993	0.985	0.979	0.971
Exradin	A19	Water proof Farmer	0.996	0.991	0.981	0.974	0.966
Exradin	A12	0.6 cc	0.997	0.992	0.983	0.976	0.968
Exradin	A12S	0.2 cc "short Farmer"	0.996	0.992	0.983	0.976	0.968
Exradin	A18	0.125 cc waterproof	0.997	0.992	0.983	0.976	0.969
Exradin	A1	0.06 cc waterproof	0.996	0.991	0.981	0.975	0.967
Exradin	A1SL	0.06 cc waterproof	0.997	0.992	0.983	0.977	0.969
NE	NE2561 *	0.3 cc NPL Sec. Std	0.999	0.994	0.985	0.978	0.971
NE	NE2571 *	0.6 cc Farmer	0.997	0.992	0.983	0.976	0.968
PTW	PTW30010*	0.6 cc Farmer-type	0.997	0.992	0.983	0.976	0.968
PTW	PTW30011*	0.6 cc Farmer-type	0.997	0.992	0.983	0.976	0.969
PTW	PTW30012*	0.6 cc Farmer-type	0.998	0.994	0.985	0.979	0.971
PTW	PTW30013	Waterproof Farmer	0.996	0.991	0.982	0.975	0.967
PTW	PTW31013	0.25 cc waterproof	0.997	0.992	0.982	0.975	0.967
IBA	FC65-G	Waterproof Farmer	0.997	0.992	0.983	0.976	0.968
IBA	FC65-P	Robust Farmer	0.997	0.991	0.982	0.975	0.967
IBA	FC23-C	0.2 cc "short Farmer"	0.996	0.991	0.982	0.975	0.968
IBA	CC25	0.25 cc waterproof	0.997	0.992	0.984	0.977	0.969
IBA	CC13	0.13 cc waterproof	0.996	0.992	0.983	0.976	0.969
IBA	CC08	0.08 cc waterproof	0.995	0.990	0.982	0.975	0.967

Addendum to the AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon beams
Malcolm McEwen
National Research Council, 1200 Montreal Road, Ottawa, Ontario, Canada

TRS-483 (Reference dosimetry)

- TRS-483
  - Generalized form of TG-51
  - *msr* – machine specific reference field
    - TG-51 condition not possible
    - Farmer chambers with msr ≧ 6x6cm²
    - Smaller cylindrical chambers for msr < 6x6cm²
  - $k_{Q_{msr}}$ correction (IAEA: $k_{Q_{msr},Q_o}^{f_{msr},f_{ref}}$):
    - Cyberknife, TomoTherapy, and Gamma Knife
- Three acceptable approaches

1. Chamber calibrated for msr

- Preferred method
- ADCL calibrate the chamber at msr
- Formalism
  - $D_{w,Q_{msr}} = M_{Q_{msr}} \, N_{D,w}^{Q_{msr}}$

Corrected measurements of the chamber at reference depth and msr ($M_{Q_{msr}}$)

From ADCL ($N_{D,w}^{Q_{msr}}$)

2. Chamber with conventional factors with $k_{Q_{msr}}$

- Most of the cases
- Q_o for reference field (ref) of 10x10 cm²
- Formalism
  - $D_{w,Q_{msr}} = M_{Q_{msr}} \, N_{D,w}^{Q_o} \, k_{Q_{msr}}$

When msr = 10x10

  - $D_w^Q = M N_{D,w}^{^{60}Co} \, k_Q$ (TG-51)

Correction factor $k_{Q_{msr}}$

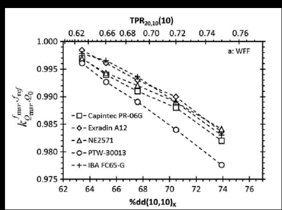

TABLE 14. CORRECTION FACTORS $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ FOR THE GAMMA KNIFE MODELS PERFEXION AND 4C [110, 153]

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

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3. Chamber with conventional factors without $k_{Q_{msr}}$

- Formalism
  - $D_{w,Q_{msr}} = M_{Q_{msr}} \, N_{D,w}^{Q_o} \, k_Q \quad k_{Q_{msr}}$

TG-51 addendum

Cross calibrate factor between 10x10 and msr≈1.0

Done at the same conventional LINAC

Beam Quality Specifier

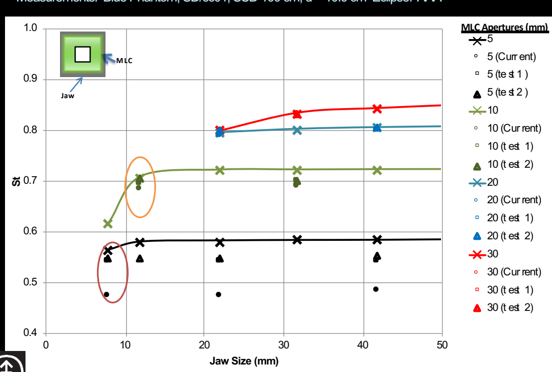
- For MSR < 10x10
  - $TPR_{20,10}(10) = \frac{TPR(S)+c\,(10-S)}{1+c\,(10-S)}$ *s = equivalent square of msr*
  - $\%dd(10,10)^{SSD} = \frac{\%dd(10,S)+80c\,(10-S)}{1+c\,(10-S)}$
  - $c = (16.15 \pm 0.12) \times 10^{-3}$ *(TPR)*
  - $c = (53.4 \pm 1.1) \times 10^{-3}$ *(%dd)*
- For SSD or SAD different from 100cm
  - TPR (80cm ≦ SSD ≦ 150)
    - No correction needed
  - $\%dd(10,10) =$
    $\%dd^{SSD}(10,10)\,\frac{TMR(10,11)}{TMR(10,\frac{SSD+10}{SSD}10)}\,\frac{NPSF(11)}{NPSF(\frac{SSD+10}{SSD}10)}\left(\frac{100+z_{max}}{110}\,\frac{SSD+10}{SSD+z_{max}}\right)^2$

Other Considerations

- Addition FFF correction
  - $D_{w,Q_{msr}} = M_{Q_{msr}} \, N_{D,w}^{Q_o} \, k_Q \quad k_{Q_{msr}}$
  - $D_{w,Q_{msr}} = M_{Q_{msr}} \, N_{D,w}^{Q_o} \, k_Q \quad k_{FFF}^{WFF} \, k_{Q_{msr}}$
- Pb foil for FFF beam quality
  - AAPM TG-51 addendum
- Non-water correction
  - Solid water or PMMA

St with FS (MLC/Jaws) and models

Measurements: Blue Phantom, SD/cc01, SSD 100 cm, d = 10.0 cm Eclipse: AAA



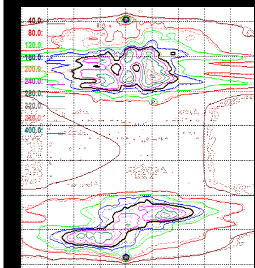
Modeling

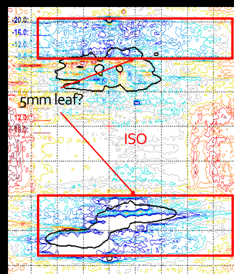
- Modify model current clinical 6x AAA model
  - S_t input
  - Focal spot
    - Clinical spot: (1.75, 0.75)
  - limit FS to (15x15)
  - Secondary scatter
  - Retain current DLG
- Verification
  - S_t output
  - OCR
  - PDD
  - Static clinical fields
- Clinical VMAT Implementation

Apertures ≥ 10mm up to 10 cm expect dose agreement of 0.5%; Apertures < 10mm expect under-dose by at least 3.5% or more; Small lesions (5mm) at 10cm depth can be under-dose by 7% or more.

A Feasibility Study of Using Eclipse AAA for SRS Treatment, Lim, S and LoSasso, T, Medical Physics, 42, 3229-3230 (2015)

VMAT Arc 1 – using SRS Model

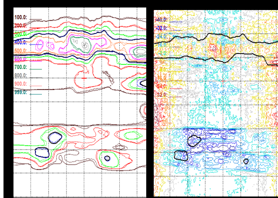


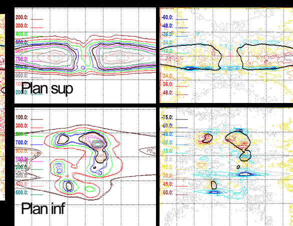


Number of Target: 6
Phantom: 30x30cm² Solid water
Detector: EBT3 Film
Depth: 5cm

Average Dose = 256.9 cGy
Film – TPS = -13.1 cGy (-5.1%)
γ(3%, 2mm) = 70.1 %
Locally, under-dose > 10%
Limitation on single DLG model

1 ISO 2 ISO





<Dose> = 566 cGy
Film – TPS = +1.4%
γ(3%, 2mm) = 95.4%
ROI = 50% of max dose

Plan Sup: <Dose> = 885 cGy (Sup); 1044 (Inf)
Film – TPS = +1.9% (Sup); +1.8% (inf)
γ(3%, 2mm) = 97.3% (Sup); 99.1 (Inf)
ROI = 50% of max dose

Dosimetry Summary

- 7 plans with film and EPID
- 2 single ISO and 4 multi-ISO plans
- Single ISO
  - 5mm leaves region gives under-dose > 10%
  - 2.5mm region gives 2 to 6% over dose
- Multi-ISO
  - Aimed to avoid using 5.0mm leaves
  - Dose difference +1.9 % to -10.1% per arc
  - Arcs with small apertures tend to under-dose
    - -10.1% with small aperture (5-8 mm) as expected from model limitation
  - Composite dose (per plan) = +1.9% to -1.9%

Challenges

- VMAT M120
  - Different dosimetric challenges from HD120
  - Model for VMAT HD120 does not provide satisfactory dosimetry
- Solution
  - Two Different models
    - VMAT M120 (focal spot = 1.75, 0.75)
    - DCA M120 (focal spot = 0.0, 0.0)
  - S_t (1x1) modified (similar to HD120 model)
  - FS (jaw): 1x1 to 15x15 cm²

Pre-Clinical (VMAT)
film (VMAT) & Razor Diode (DCA)

Machine	Plan	Number of Arc	TPS Max Dose (cGy)	Average Dose (cGy) (ROI 80% of Max Dose)	Film - TPS cGy	Film - TPS %	γ (3%, 2mm)
MON_TB2	1	3	1175	1028	53.7	5.2	96.1
	2	3	1763	1590	14.8	0.9	97.9
	3	3	2170	1923	38.0	2.0	97.9
	4	4	2122	1829	75.1	4.1	94.5
444	5	4	1368	1207	20.5	1.7	100.0
	6	3	1175	1028	3.5	0.3	95.9
	7	3	2105	1894	76.7	4.0	98.4

Target Dimension (cc)	Field	Measurement Dose (cGy)	Eclipse (0,0) (DCA) (cGy)	Eclipse (1.75, 0.75) (VMAT) (cGy)	Dose/Eclipse (DCA)	Dose/Eclipse (VMAT)
0.6	9	**868.0**	**863**	**862**	1.005	1.007
	10	**724.0**	**719**	**719**	1.006	1.007
	11	**881.5**	**877**	**877**	1.005	1.005
	12	**904.1**	**900**	**899**	1.004	1.005
0.1	15	**703.3**	**687**	**622**	1.024	1.131
	16	**689.5**	**678**	**615**	1.016	1.121
	17	**717.6**	**718**	**643**	0.999	1.117
	18	**711.5**	**722**	**651**	0.985	1.093

End-to-End Test

- AAA_SRS_11031
- head anthropomorphic phantom
- Dosimetry
  - MU/Avg Dose = 3.3
  - L-R films: -2.3% to -3.4%
  - Sag Film: -2.7%
- Localization

Plane	Error (mm)
A-P	-0.07
S-I	0.10
L-R	-0.09

Question?