Beam commissioning for clinical Monte Carlo dose calculation: AAPM TG-157

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AAPM Task Group Report No. 157: Source modeling and beam commissioning for Monte Carlo dose calculation based radiation therapy treatment planning

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Outline

A. Requirements and paradigms for beam commissioning

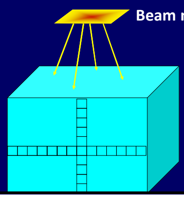
B. Types of commissioning measurements

C. Issues associated with commissioning measurements

Experimental Verification

Perform measurements to test the algorithm performance with emphasis on: (a) incident fluence prediction; (b) radiation transport calculation accuracy

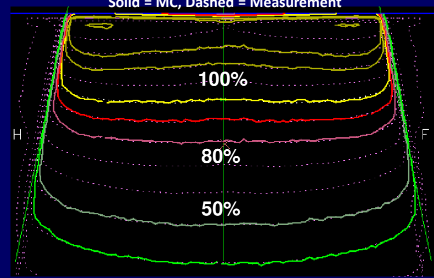
(a) the incident fluence prediction: how accurately does the model characterize interactions in the treatment head?



depth dose, profiles and output ratio measurements in water phantoms for square and shaped fields over a range of field sizes

Photon Beams: large field profiles

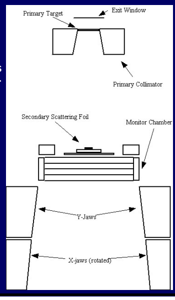
Solid = MC, Dashed = Measurement



40x40 profile MC (RT_DPM) /UMplan) (Univ of Michigan)

Careful treatment head simulation using BEAMnrc/EGSnrc: Faddegon *et al*

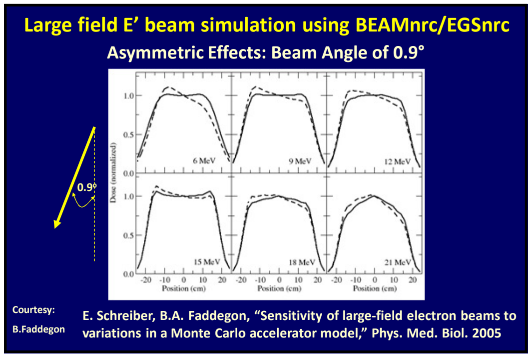
E. Schreiber, B.A. Faddegon, "Sensitivity of large-field electron beams to variations in a Monte Carlo accelerator model," Phys. Med. Biol. 2005

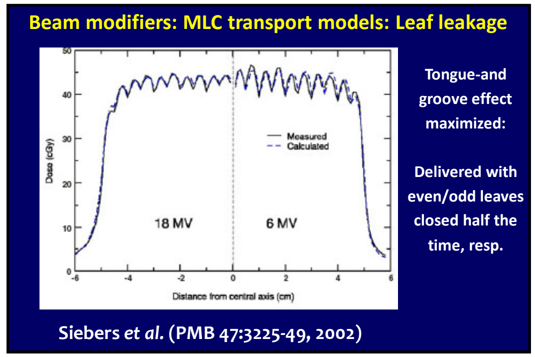


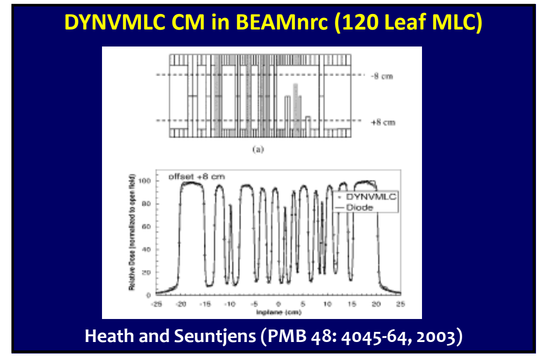
Evaluate large-field approach, 40x40, no applicator for sensitivity analysis and commissioning of electron beam model

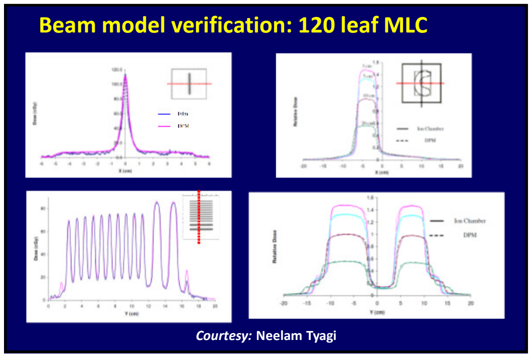
Treatment head simulation accuracy goal: 1%/1mm

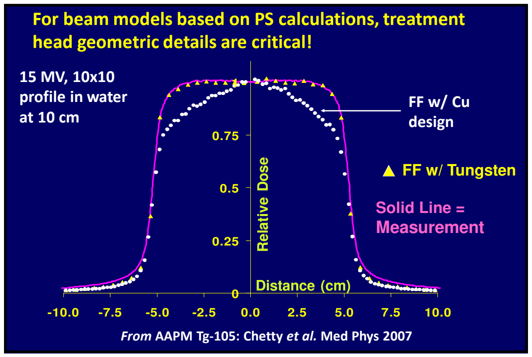
Courtesy: B. Faddegon

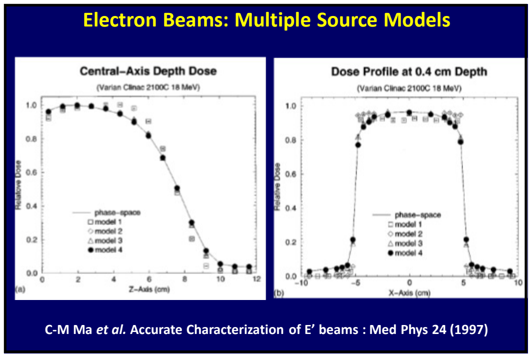

Large field E' beam simulation using BEAMnrc/EGSnrc
Asymmetric Effects: Beam Angle of 0.9°
0.9°
6 MeV
9 MeV
12 MeV
15 MeV
18 MeV
21 MeV
Dose (normalized)
Position (cm)
Courtesy:
B.Faddegon
E. Schreiber, B.A. Faddegon, "Sensitivity of large-field electron beams to variations in a Monte Carlo accelerator model," Phys. Med. Biol. 2005

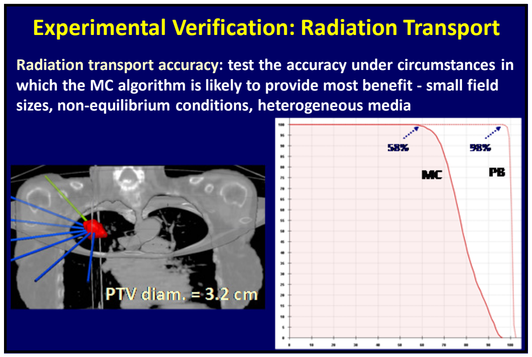

Beam modifiers: MLC transport models: Leaf leakage
Dose (cGy)
Measured
Calculated
18 MV
6 MV
Distance from central axis (cm)
Tongue-and groove effect maximized:
Delivered with even/odd leaves closed half the time, resp.
Siebers et al. (PMB 47:3225-49, 2002)

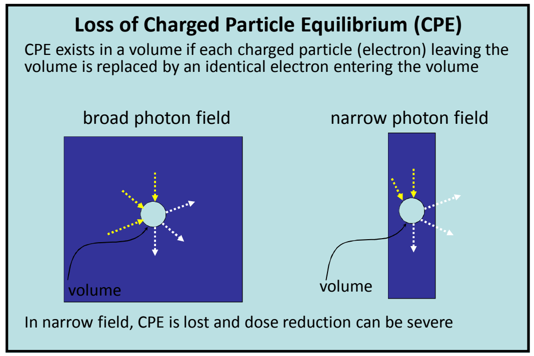

DYNVMLC CM in BEAMnrc (120 Leaf MLC)
-8 cm
+8 cm
(a)
offset +8 cm
DYNVMLC
Diode
Heath and Seuntjens (PMB 48: 4045-64, 2003)

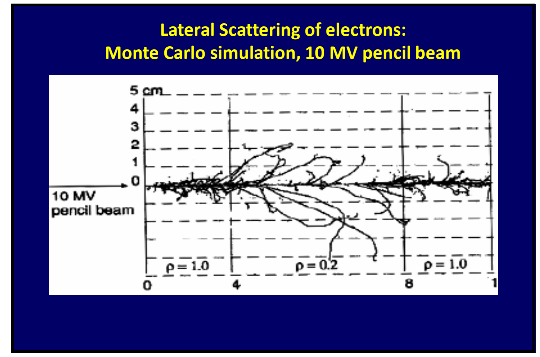

Beam model verification: 120 leaf MLC
Ion Chamber
DPM
Courtesy: Neelam Tyagi

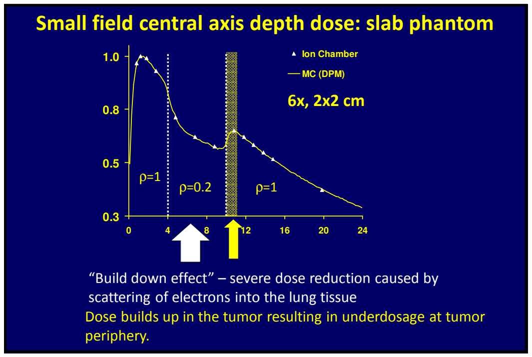

For beam models based on PS calculations, treatment head geometric details are critical!
15 MV, 10x10 profile in water at 10 cm
FF w/ Cu design
▲ FF w/ Tungsten
Solid Line = Measurement
Relative Dose
Distance (cm)
0.75
0.5
0.25
0
-10.0 -7.5 -5.0 -2.5 0.0 2.5 5.0 7.5 10.0
From AAPM Tg-105: Chetty et al. Med Phys 2007

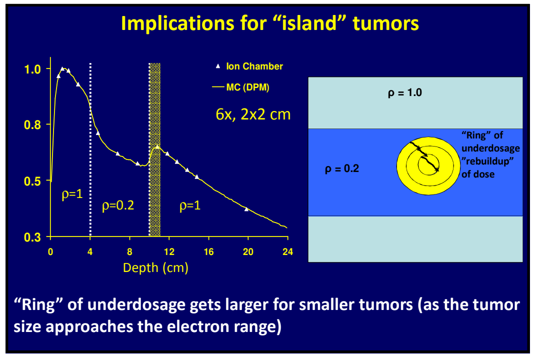

Electron Beams: Multiple Source Models
Central-Axis Depth Dose
(Varian Clinac 2100C 18 MeV)
Dose Profile at 0.4 cm Depth
(Varian Clinac 2100C 18 MeV)
phase-space
model 1
model 2
model 3
model 4
Relative Dose
Z-Axis (cm)
X-Axis (cm)
C-M Ma et al. Accurate Characterization of E' beams : Med Phys 24 (1997)

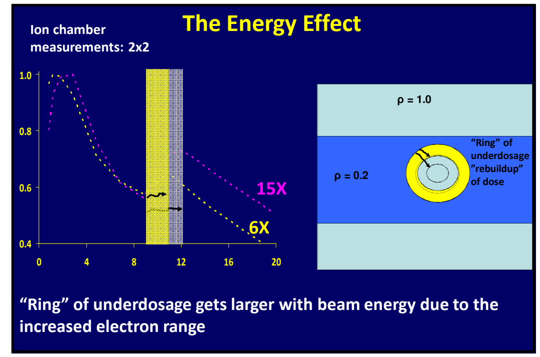

Experimental Verification: Radiation Transport
Radiation transport accuracy: test the accuracy under circumstances in which the MC algorithm is likely to provide most benefit - small field sizes, non-equilibrium conditions, heterogeneous media
58%
98%
MC
PB
PTV diam. = 3.2 cm

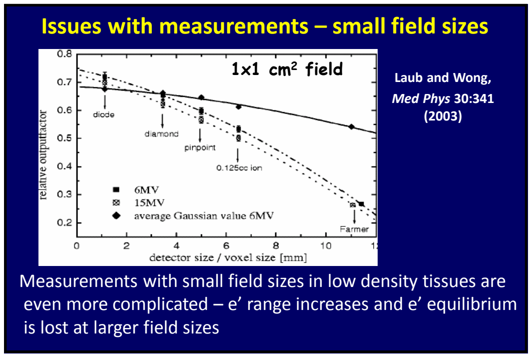

Loss of Charged Particle Equilibrium (CPE)
CPE exists in a volume if each charged particle (electron) leaving the volume is replaced by an identical electron entering the volume
broad photon field
narrow photon field
volume
volume
In narrow field, CPE is lost and dose reduction can be severe

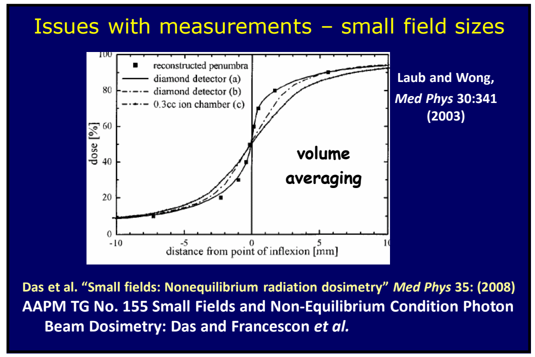

Lateral Scattering of electrons:
Monte Carlo simulation, 10 MV pencil beam
5 cm
4
3
2
1
0
10 MV
pencil beam
ρ = 1.0
ρ = 0.2
ρ = 1.0
0
4
8

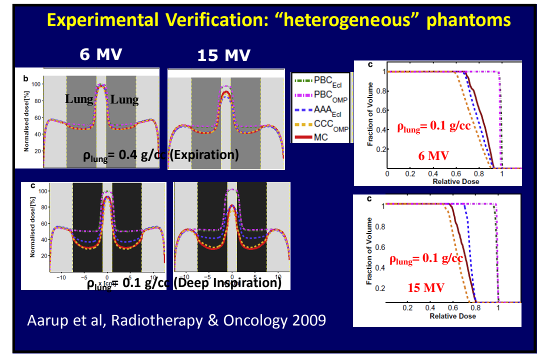

Small field central axis depth dose: slab phantom
Ion Chamber
MC (DPM)
6x, 2x2 cm
1.0
0.8
0.5
0.3
ρ=1
ρ=0.2
ρ=1
0
4
8
12
16
20
24
"Build down effect" – severe dose reduction caused by scattering of electrons into the lung tissue
Dose builds up in the tumor resulting in underdosage at tumor periphery.

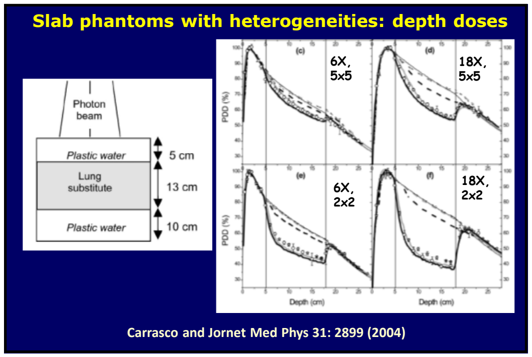

Implications for "island" tumors
Ion Chamber
MC (DPM)
6x, 2x2 cm
1.0
0.8
0.5
0.3
ρ=1
ρ=0.2
ρ=1
0
4
8
12
16
20
24
Depth (cm)
ρ = 1.0
ρ = 0.2
"Ring" of underdosage "rebuildup" of dose
"Ring" of underdosage gets larger for smaller tumors (as the tumor size approaches the electron range)

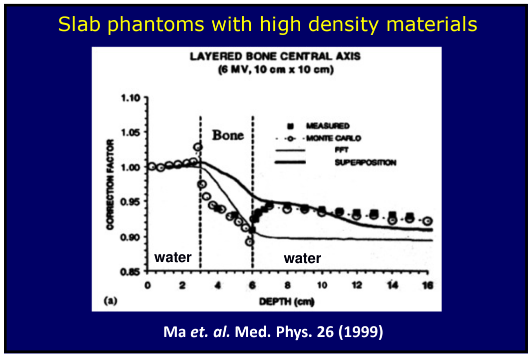

The Energy Effect
Ion chamber measurements: 2x2
1.0
0.8
0.6
0.4
0
4
8
12
16
20
15X
6X
ρ = 1.0
ρ = 0.2
"Ring" of underdosage "rebuildup" of dose
"Ring" of underdosage gets larger with beam energy due to the increased electron range

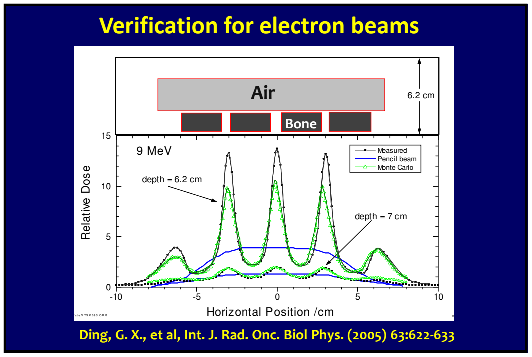

Issues with measurements – small field sizes
1x1 cm² field
relative outputfactor
detector size / voxel size [mm]
diode
diamond
pinpoint
0.125cc ion
Farmer
6MV
15MV
average Gaussian value 6MV
Laub and Wong, Med Phys 30:341 (2003)
Measurements with small field sizes in low density tissues are even more complicated – e' range increases and e' equilibrium is lost at larger field sizes

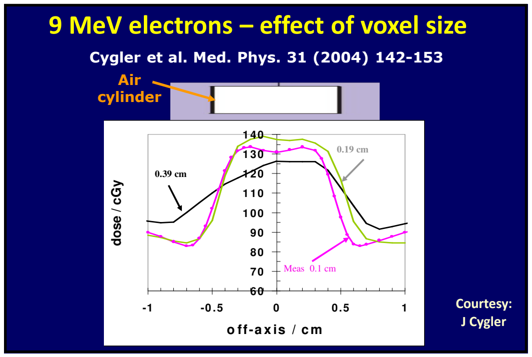

Issues with measurements – small field sizes
reconstructed penumbra
diamond detector (a)
diamond detector (b)
0.3cc ion chamber (c)
dose [%]
distance from point of inflexion [mm]
volume averaging
Laub and Wong, Med Phys 30:341 (2003)
Das et al. "Small fields: Nonequilibrium radiation dosimetry" Med Phys 35: (2008)
AAPM TG No. 155 Small Fields and Non-Equilibrium Condition Photon Beam Dosimetry: Das and Francescon et al.

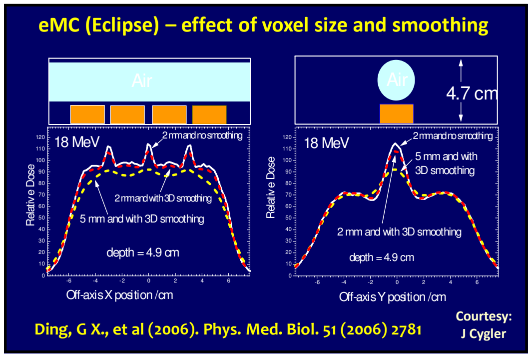

Experimental Verification: "heterogeneous" phantoms
6 MV
15 MV
Lung
Lung
ρlung= 0.4 g/cc (Expiration)
ρlung= 0.1 g/cc (Deep Inspiration)
PBC
AAA
CCC
MC
ρlung= 0.1 g/cc
6 MV
15 MV
Fraction of Volume
Relative Dose
Aarup et al, Radiotherapy & Oncology 2009

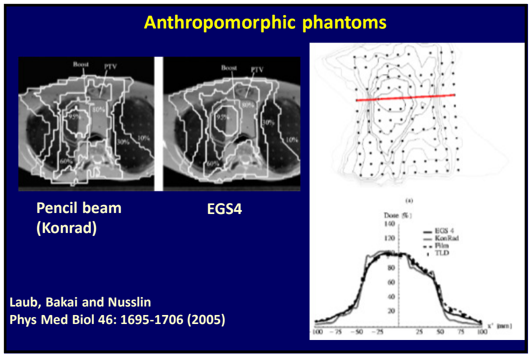

Slab phantoms with heterogeneities: depth doses
Photon beam
Plastic water
Lung substitute
Plastic water
5 cm
13 cm
10 cm
6X, 5x5
18X, 5x5
6X, 2x2
18X, 2x2
PDD (%)
Depth (cm)
Carrasco and Jornet Med Phys 31: 2899 (2004)


Slab phantoms with high density materials
LAYERED BONE CENTRAL AXIS
(6 MV, 10 cm x 10 cm)
CORRECTION FACTOR
Bone
water
water
MEASURED
MONTE CARLO
FFT
SUPERPOSITION
DEPTH (cm)
(a)
Ma et. al. Med. Phys. 26 (1999)

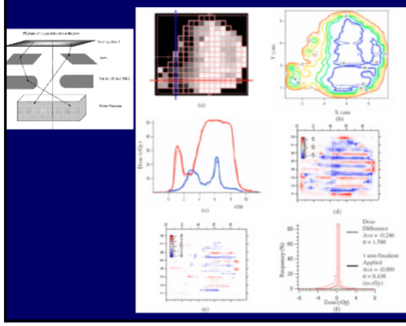

Verification for electron beams
Air
Bone
6.2 cm
9 MeV
depth = 6.2 cm
depth = 7 cm
Measured
Pencil beam
Monte Carlo
Relative Dose
Horizontal Position /cm
Ding, G. X., et al, Int. J. Rad. Onc. Biol Phys. (2005) 63:622-633


9 MeV electrons – effect of voxel size
Cygler et al. Med. Phys. 31 (2004) 142-153
Air cylinder
dose / cGy
off-axis / cm
0.39 cm
0.19 cm
Meas 0.1 cm
Courtesy: J Cygler


eMC (Eclipse) – effect of voxel size and smoothing
Air
4.7 cm
18 MeV
Relative Dose
2 mm and no smoothing
2 mm and with 3D smoothing
5 mm and with 3D smoothing
depth = 4.9 cm
Off-axis X position /cm
Off-axis Y position /cm
Ding, G X., et al (2006). Phys. Med. Biol. 51 (2006) 2781
Courtesy: J Cygler


Anthropomorphic phantoms
Pencil beam (Konrad)
EGS4
Laub, Bakai and Nusslin
Phys Med Biol 46: 1695-1706 (2005)

IMRT verification



Tyagi *et al.*

"Experimental verification of a Monte Carlo-based MLC simulation model for IMRT dose calculation" *Med Phys 34*: 652 (2007)

Summary

Commissioning of beam models must include measurements to verify the accuracy of the head model, as well as the radiation transport model in the patient

Measurements in complex geometries, small fields and non-equilibrium conditions, will be helpful to verify the expected improved accuracy of the MC algorithm under such circumstances

Measurements in complex geometries is difficult and must be done with care, to minimize systematic errors

When performing direct treatment head simulation, accurate geometric details of the components are critical!

Acknowledgements

Henry Ford Health System
Salim Siddiqui, MD, PhD
Sanath Kumar, MD
Ning (Winston) Wen, PhD
Corey Fraser, CMD
Haisen Li, PhD
Hualiang Zhong, PhD
Dezhi Liu, PhD
Mubin Shaikh, MS
Margarida (Maggy) Fragoso, PhD
Benjamin Movsas, MD
Munther Ajlouni, MD

University of Michigan
Benedick Fraass, PhD
Randy Ten Haken, PhD
Spring Kong, MD, PhD

Ottawa Hospital
Joanna Cygler, PhD

NIH/NCI Grant Support: R01 CA106770

Thank You!