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COLLEGE ON MEDICAL PHYSICS
AND
WORKSHOP ON
NUCLEAR DATA FOR SCIENCE AND TECHNOLOGY:
MEDICAL APPLICATIONS
(20 SEPTEMBER - 15 OCTOBER 1999)

"Monte Carlo Application in Medical Accelerator Simulation and Radiation Dosimetry"

C.-M. Charlie MA
Stanford University
School of Medicine
Radiation Oncology Department
Stanford, CA 94305-5304
U.S.A.

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C.-M. Charlie Ma

Radiation Oncology Department
Stanford University School of Medicine
Stanford, CA 94305-5304

cma@reyes.stanford.edu
Tel: (650) 723-5591
Fax: (650) 498-4015

OUTLINE

- A brief review
- Medical accelerator simulation
- Source modelling
- Beam commissioning
- CT number conversion
- Monte Carlo dose calculation
- Application in clinical radiation therapy

What is Monte Carlo?

- Monte Carlo is a game of probability
- Monte Carlo radiation transport is a process of random sampling
    - a good supply of random numbers
    - probability distributions governing the physics processes
- Information obtained by simulating large number of histories

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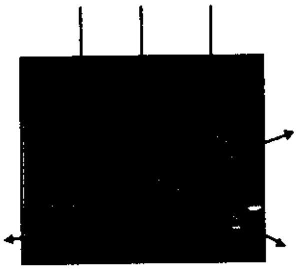
Photons



Why Use Monte Carlo for Radiotherapy Treatment Planning

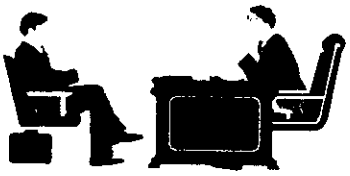
An accuracy of about 5% in dose delivery is required to effectively treat certain types of cancers and to reduce complications.

ICRU Reports 24 (1976) and 42 (1988)

Overall uncertainty in dose at a point

step	(2-σ) uncertainty (%)
dosimeter calibration	1.6
daily calibration	2.0
methods and parameters	3.0
effective depth	2.0
SSD	2.0
wedges	2.0
block trays	2.0
cumulative	5.6

Monte Carlo is the most accurate method for radiotherapy dose calculations BUT…



CPU time required

1 Gy => 1 billion electrons

1% uncertainty for 0.3 cm cubes requires a few million electrons (hours on a PC)

1 Gy => 1000 billion photons

1% uncertainty for 0.3 cm cubes requires up to a few billion photons (days on a PC)

Applications of M-C in radiotherapy

- Fluence and spectrum calculations
- Dosimetric parameters (stopping powers, etc.)
- Correction factors (BSF, HS, PS, P/S ratio...)
- Dosimeter response simulations
- Treatment head simulations
- Treatment planning dose calculations

Monte Carlo programs available for dose calculations

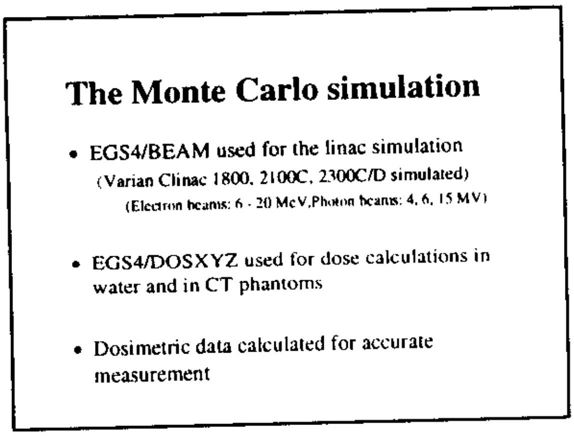
- The OMEGA BEAM/DOSXYZ system
- The Peregrine program
- Voxel Monte Carlo
- Macro Monte Carlo
- Superposition Monte Carlo
- Other programs (ITS, MCNP, PENELOPE)

Monte Carlo treatment planning

at Stanford

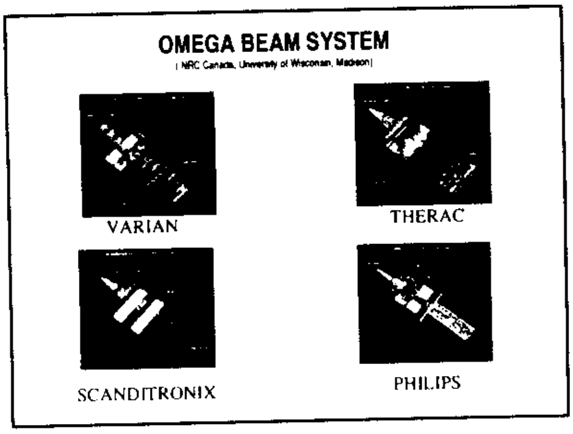
Implementation procedures

- Commissioning the simulated beam data
- Characterization of the simulated beams
- CT data and beam setup conversion
- Dose calculations
- Display of M-C calculated 3D dose data



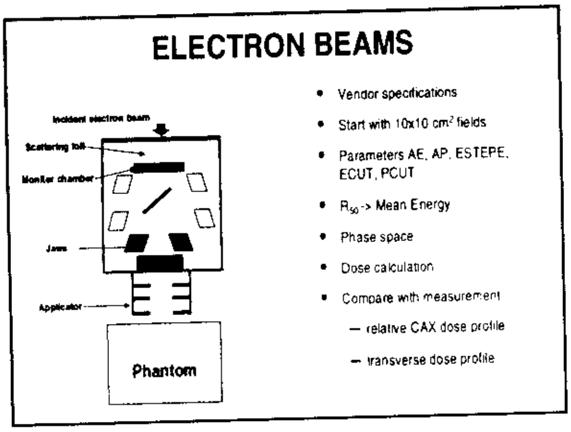
The Monte Carlo simulation

- EGS4/BEAM used for the linac simulation
  (Varian Clinac 1800, 2100C, 2300C/D simulated)
  (Electron beams: 6 - 20 MeV,Photon beams: 4, 6, 15 MV)
- EGS4/DOSXYZ used for dose calculations in water and in CT phantoms
- Dosimetric data calculated for accurate measurement



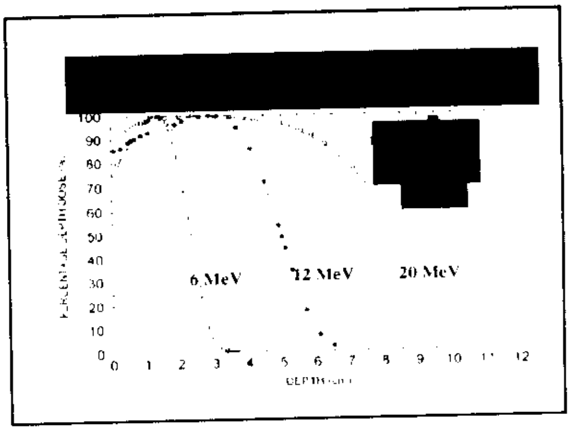
OMEGA BEAM SYSTEM

(NRC Canada, University of Wisconsin, Madison)



ELECTRON BEAMS

- Vendor specifications
- Start with 10x10 cm² fields
- Parameters AE, AP, ESTEPE, ECUT, PCUT
- R_{50} -> Mean Energy
- Phase space
- Dose calculation
- Compare with measurement
  - relative CAX dose profile
  - transverse dose profile



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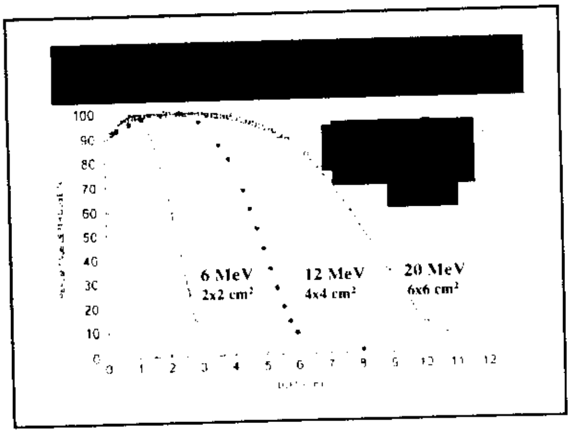

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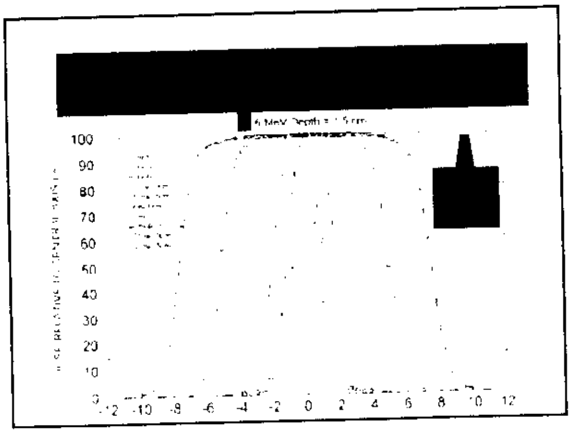

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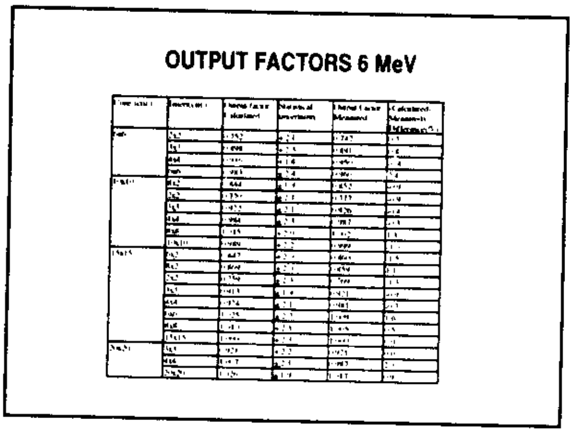
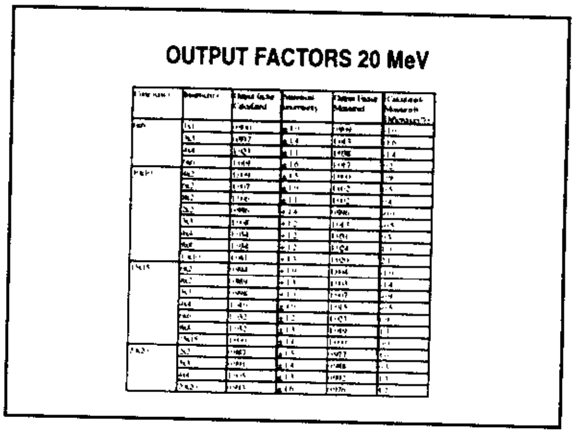
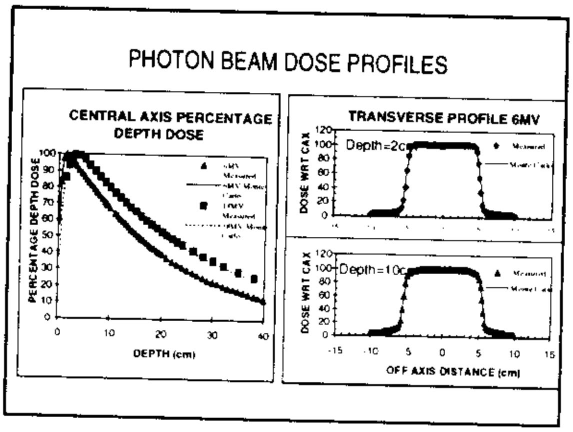


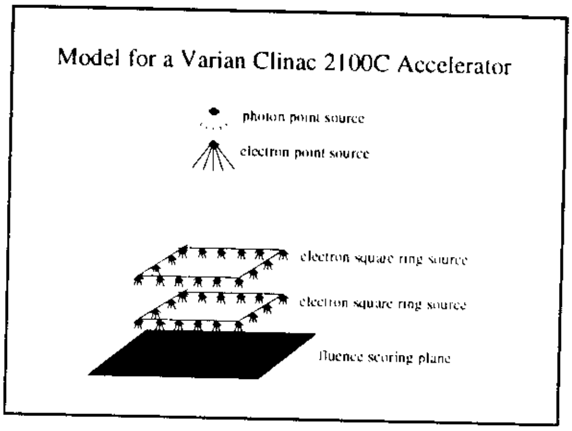
OUTPUT FACTORS 6 MeV



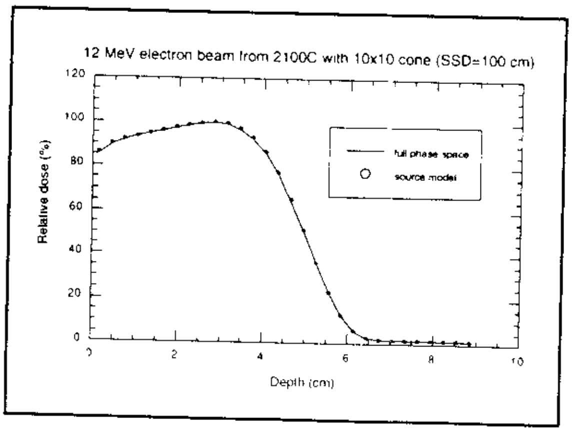
OUTPUT FACTORS 20 MeV



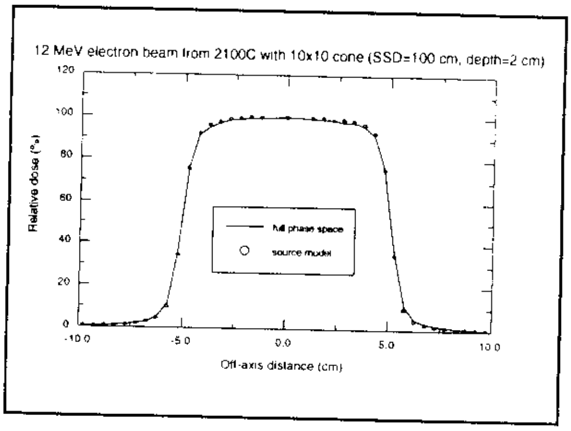
PHOTON BEAM DOSE PROFILES



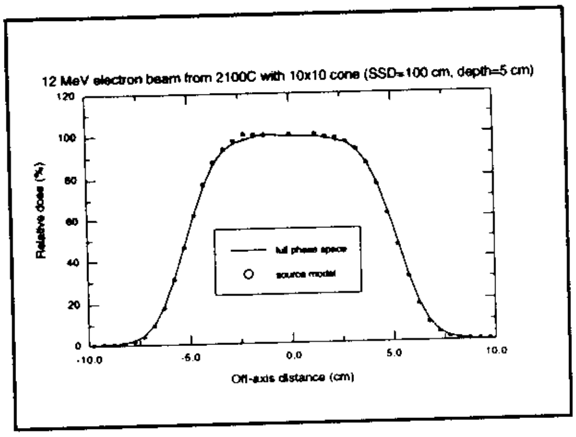
Model for a Varian Clinac 2100C Accelerator

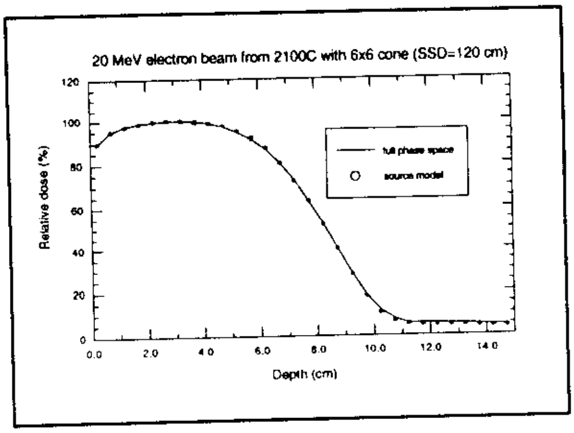


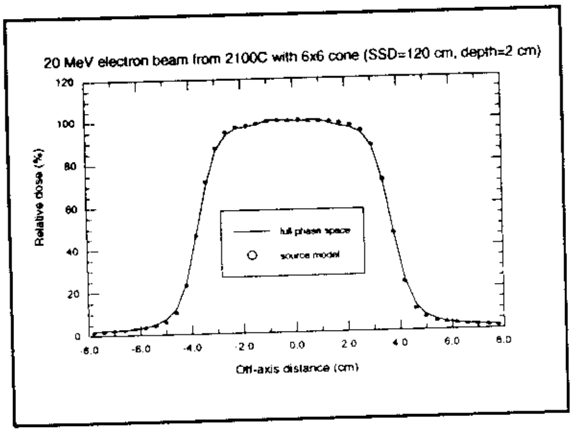
12 MeV electron beam from 2100C with 10x10 cone (SSD=100 cm)

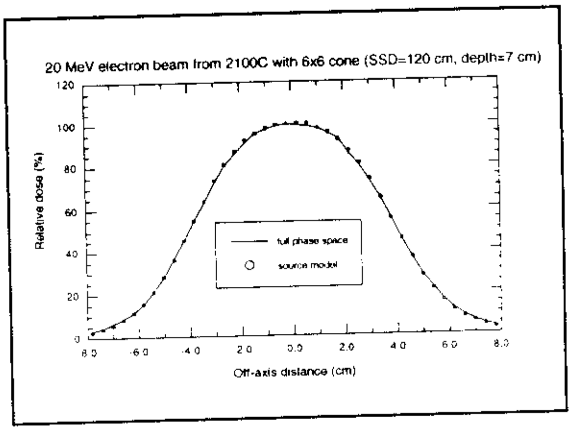


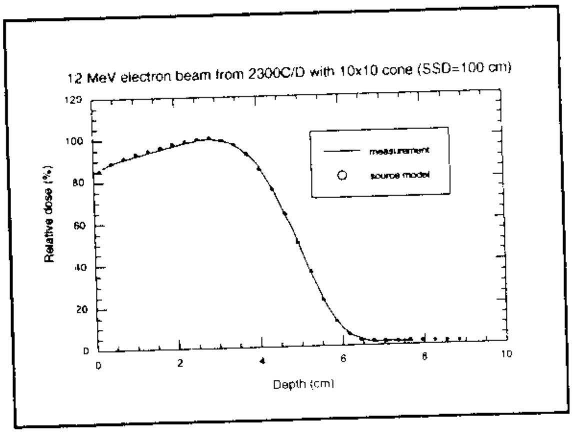
12 MeV electron beam from 2100C with 10x10 cone (SSD=100 cm, depth=2 cm)

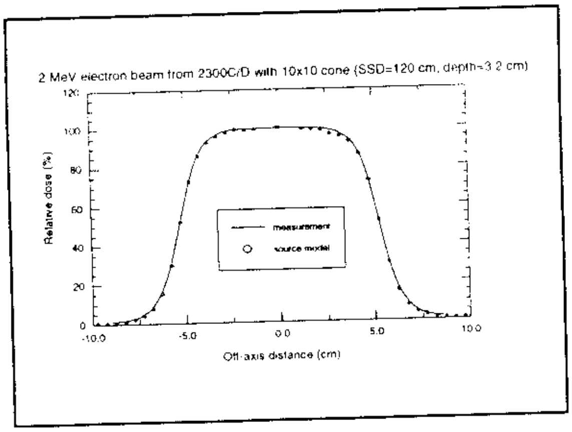

12 MeV electron beam from 2100C with 10x10 cone (SSD=100 cm, depth=5 cm)

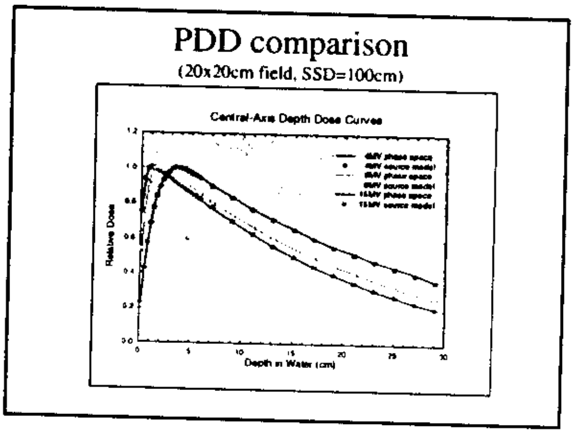

20 MeV electron beam from 2100C with 6x6 cone (SSD=120 cm)


20 MeV electron beam from 2100C with 6x6 cone (SSD=120 cm, depth=2 cm)


20 MeV electron beam from 2100C with 6x6 cone (SSD=120 cm, depth=7 cm)

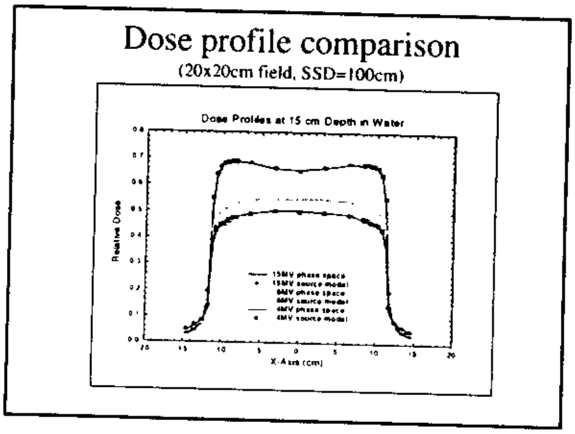

12 MeV electron beam from 2300C/D with 10x10 cone (SSD=100 cm)


2 MeV electron beam from 2300C/D with 10x10 cone (SSD=120 cm, depth=3.2 cm)



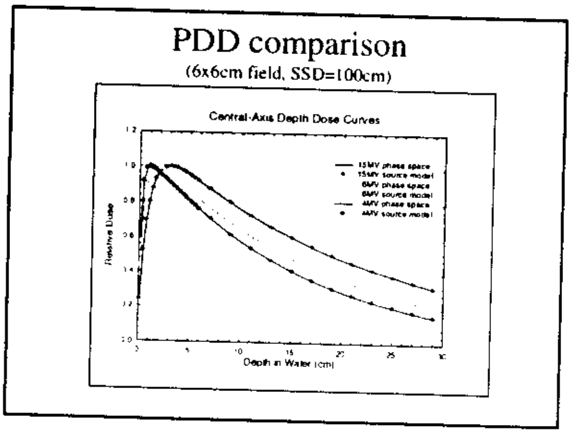
PDD comparison

(20x20cm field, SSD=100cm)



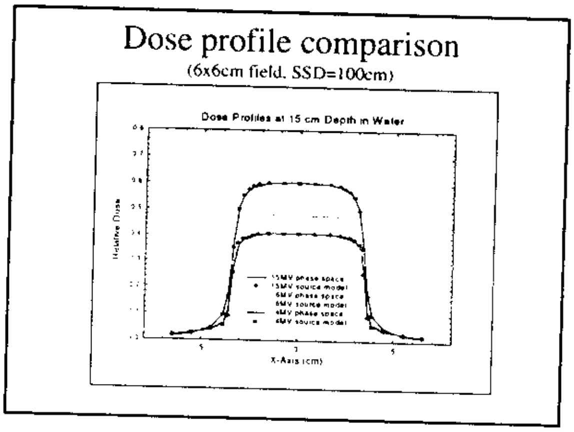
Dose profile comparison

(20x20cm field, SSD=100cm)



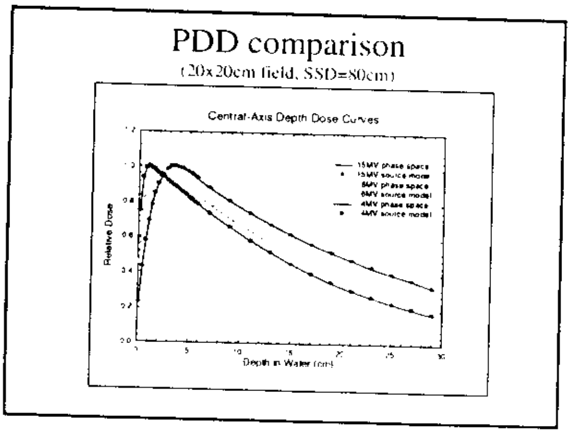
PDD comparison

(6x6cm field, SSD=100cm)



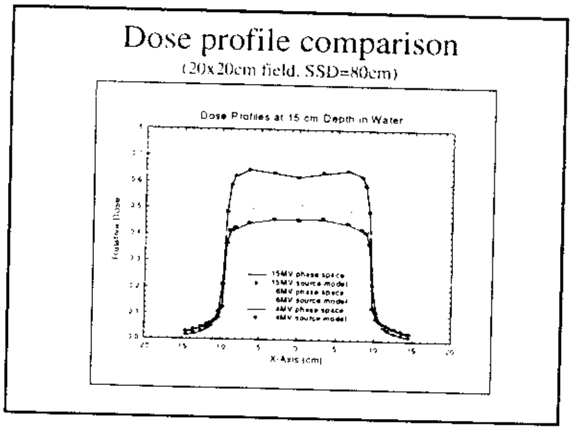
Dose profile comparison

(6x6cm field, SSD=100cm)



PDD comparison

(20x20cm field, SSD=80cm)



Dose profile comparison

(20x20cm field, SSD=80cm)

CT # ➡ phantom material conversion

$$CT\ \# = 1000(\mu - \mu_w)/\mu_w$$

Problems with CT phantoms:

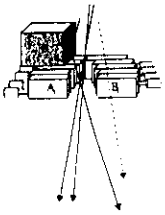
- CT resolution
- CT number and material type
- Voxel size and material density
- Artifacts in the CT data

[redacted]

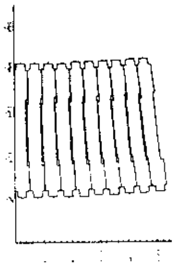
Density map Medium map

Modifications for IMRT dose calculations

- Intensity profile reconstructed from MLC leaf sequencing file
- Head scatter (except for MLC leaf scatter) included
- Leaf leakage partially included



Simulation of MLC leaf leakage



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Improvement of computing efficiency

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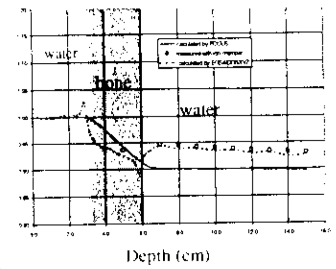
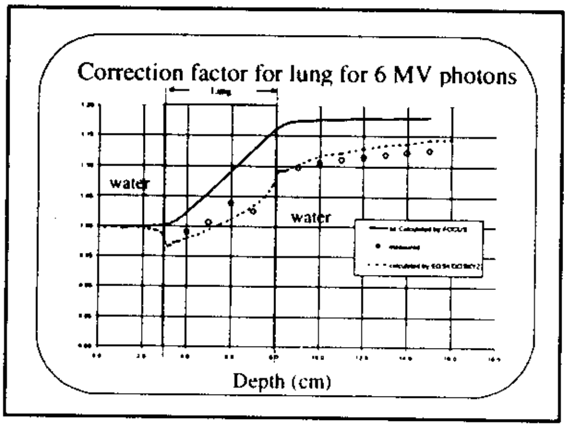
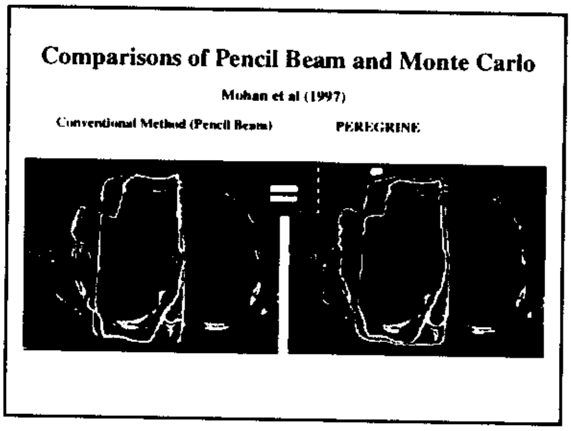
Correction factor for bone for 6 MV photons





Correction factor for lung for 6 MV photons

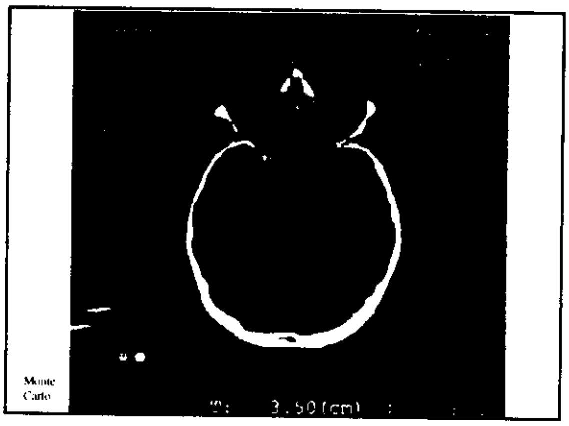


Comparisons of Pencil Beam and Monte Carlo

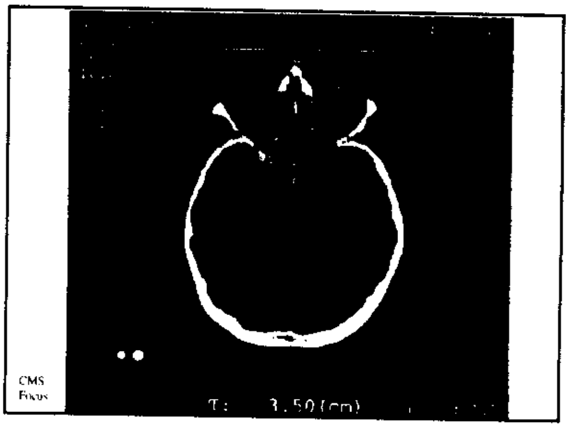
Mohan et al (1997)

Conventional Method (Pencil Beam)

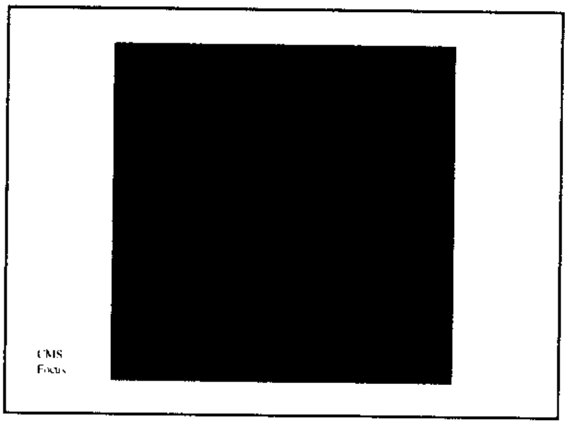
PEREGRINE



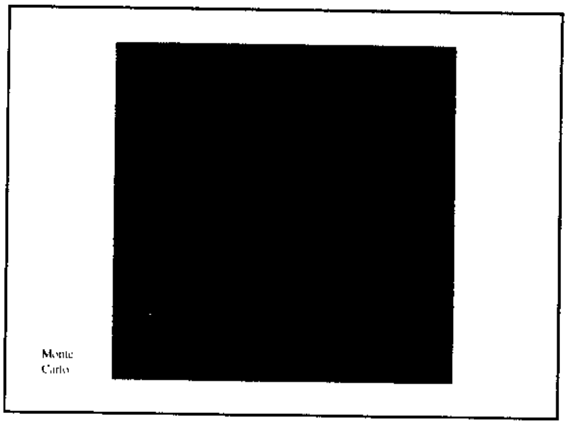
Monte
Carlo



CMS
Focus



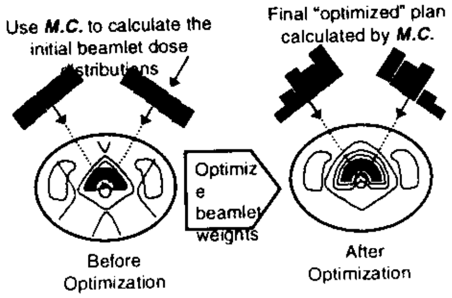
CMS
Focus



Monte
Carlo

Beamlet Dose Distributions

IMRT Planning



Use ***M.C.*** to calculate the initial beamlet dose distributions

Final "optimized" plan calculated by ***M.C.***

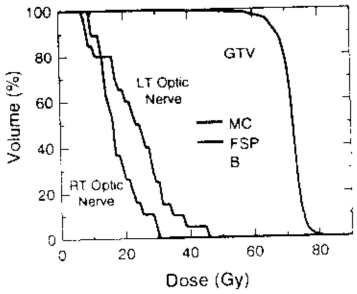
Optimize beamlet weights

Before Optimization

After Optimization

Dose Distributions

DVHs



Conclusions

- Monte Carlo is a useful tool for radiotherapy treatment planning & dose verification
- Monte Carlo calculations of dose distributions for radiotherapy clinically possible
- High accuracy, high efficiency, low cost
- More work is needed to make it clinically available

The Stanford Monte Carlo Team

Charlie Ma
Gary Luxton
David Findley
Todd Koumrian
Steve Jiang
Jinsheng Li
Ajay Kapur
Grisel Mora
Thomas Guerrero
Art Boyer
Ed Mok
Sam Brain
Michael Luxton
Todd Pawlicki
Jun Deng
Michael Lee
Natalia Luckau