DWO Rogers: 2004 AAPM Symposium on MCTP: Physicist and Physician Perspectives Pittsburgh

Monte Carlo for radiotherapy treatment planning

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AAPM Pittsburgh Meeting

Symposium: Monte Carlo Treatment Planning: Physicist and Physician Perspectives

Tuesday July 27, 2004

http://www.physics.carleton.ca/~drogers

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Disclosure

I used to work for, and still receive some royalty income from the National Research Council of Canada which has licensing agreements re Monte Carlo software with:
Elekta Philips/ADAC NOMOS
Nucletron Varian

The following companies are supporting the Monte Carlo lab I am setting up at Carleton University:
Nucletron Canada TomoTherapy Inc
Philips/ADAC MDS Nordion Varian

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2/32

What is Monte Carlo transport?

- simulate paths of many particles
  - use random numbers
  - known probability distributions
    - from physics of interactions
- keep track of physical quantities
  - learn average properties
  - stochastic distributions of events

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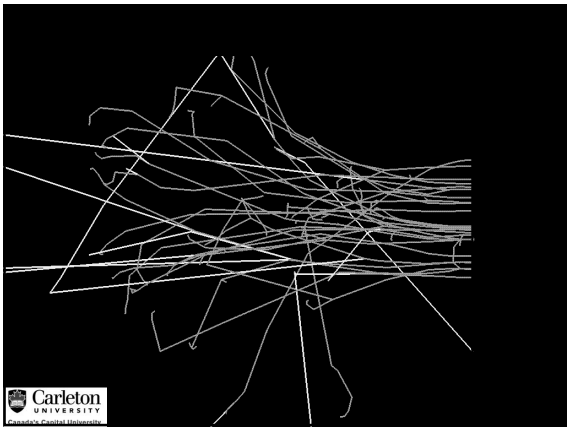

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Simple photon simulation

- say: $\Sigma_{total} = \Sigma_{compton} + \Sigma_{pair}$ cm^{-1}
- select 2 random numbers R1, R2
  - uniform between 0 and 1
  - whole careers devoted to doing this
  - cycle length now $10^{>40}$

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Photon transport (cont)

How far does photon go before interacting?

$X = -\ln(R1) \; / \; \Sigma_{total}$ cm

is exponentially distributed $[0,\infty)$

with a mean of $1/\Sigma_{total}$

Photon transport (cont)

After going x, what interaction occurs?

$$\text{if } R2 < \frac{\Sigma_{compton}}{\Sigma_{total}}$$

then a compton scatter occurs

otherwise
a pair production event occurs

How is simulation used?

- score whatever data wanted
  - average distance to interaction
  - how many of each type
  - energy deposited by each type
  - etc
- more useful in complex cases

Monte Carlo in radiotherapy

- Monte Carlo calculations are the basis of much of clinical dosimetry for years.
  - AAPM's dosimetry protocols
  - TG-51 (and earlier TG-21) accelerator dosimetry
  - TG-43 brachytherapy dosimetry
  - TG-61 x-ray dosimetry

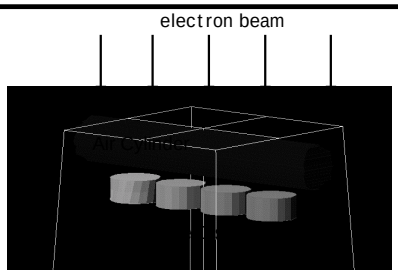
Monte Carlo transport: major codes

- Berger 1963/ ETRAN/ CYLTRAN/ ITS/ MCNP
- EGS3 1978/ EGS4/ PRESTA/ EGSnrc
- MCPT (photon only – brachytherapy)
- PENELOPE 1995
- VMC 1995/ XVMC/ VMC++
- BEAMnrc for modelling accelerators

Why is Monte Carlo important for treatment planning?

- In principle, Monte Carlo gives us the right answer
- There are no significant approximations
  - no approximate scaling of kernels is needed
  - electron transport is fully modelled
  - geometry can be modelled as exactly as we know it
  - metals, bones, air cavities all properly handled
- there are many experimental benchmarks showing Monte Carlo calculations can be very accurate

Cygler's Trachea and Spine Phantom



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9 MeV: Trachea & Spine measurements vs pencil beam

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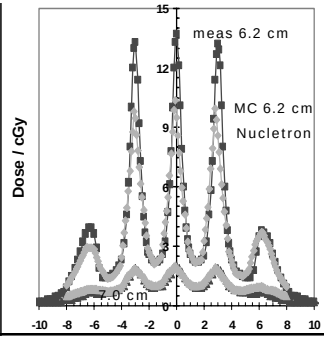
Ding, Cygler et al, Med Phys 26(1999)2571-2580

9 MeV beam: Trachea and spine

Cygler et al,
Med Phys
31(2004) 142



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Monte Carlo treatment planning research

- Many groups have published about research systems capable of doing full Monte Carlo treatment planning
  - Medical College of Virginia
  - Fox Chase Cancer Center
  - Stanford Medical Center
  - Seville, Spain,
  - Tuebingen, Germany
  - University of Michigan
  - etc, etc
- Many others have active MC research programs
  - RMH, MDACC, MSKCC, Maryland

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Where can I get electron Monte Carlo?

*Thanks to vendor representatives

from
Paul Keall,
Medical College of Virginia Hospitals
(2003)

Vendor	Date	Code
ADAC	Mid-2004	DPM++
BrainLab	No announced plans	
CMS	Oct-2004	xVMC
MRC	Oct-2004	TBA
Nomos	No announced plans	
Nucletron	Mid-2002	VMC++
Tyco	No announced plans	
Varian	Oct-2003	BEAM/EGS/ MMC

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Where can I get photon Monte Carlo?

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Nomos	Oct-2000	Peregrine
Nucletron	2004/2005	VMC++
Tyco	No announced plans	
Varian	No announced plans	

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Major steps in MC treatment planning

- model/simulate the patient independent part of the radiation source (above jaws, MLC)
  - create a phase space (model or file)
- transport beam thru patient dependent part of collimation system
- import CT patient data into MC code
  - need densities and materials
- transport beam in patient and calculate dose
- possibly smooth data
- present results as in other systems

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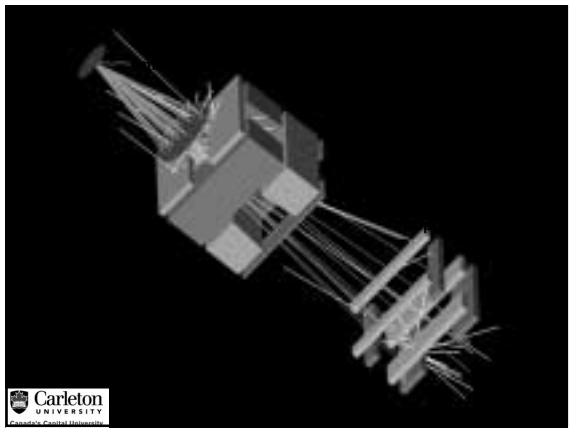
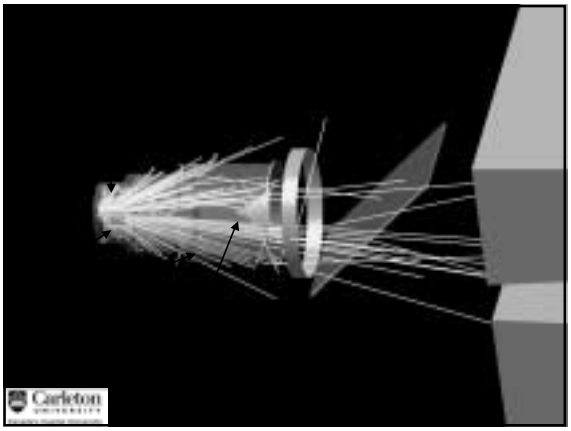
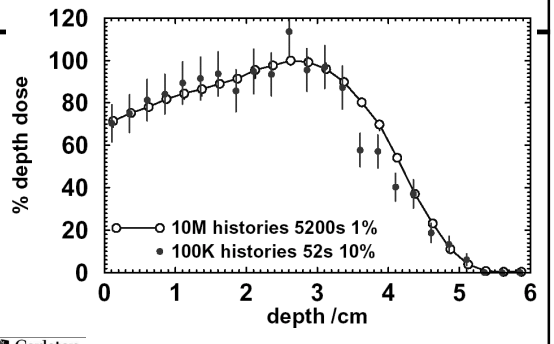




Issues related to Monte Carlo treatment planning

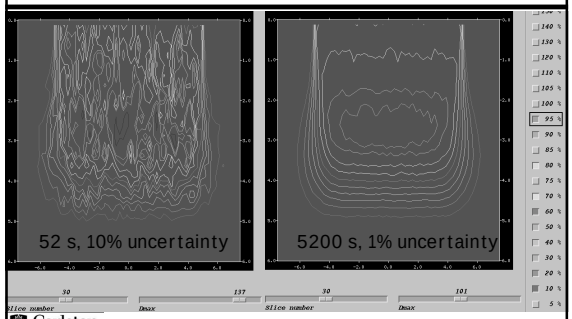
- Statistics
  - Smoothing
- Voxel sizes
- CPU time
- Accuracy of information about the accelerator if it is being modelled

10 MeV e- beam 10M and 100K histories



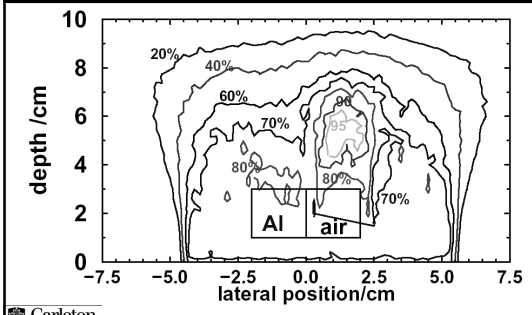
DOSXYZnrc/EGSnrc calculation

10 MeV e- beam 10K and 10M histories



DOSXYZnrc calculation

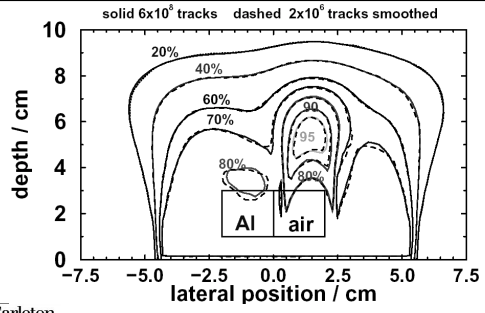
20 MeV e- beam - strong heterogeneities no smoothing: $2x10^6$ tracks



Kawrakow PMB 47 (2002)3087

25/32

20 MeV e- beam - strong heterogeneities smoothing



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How long does it take?

- MC gives entire distribution, not just a few points
- time for N beams is the same as for 1 beam
- timing is a complex question since it depends on
  - statistical uncertainty and how defined
  - voxel size
  - field size
  - beam energy and whether photons or electron
  - accuracy sought
  - speed of CPU and optimization of compiler
  - complexity of patient specific beam modifiers

27/32

ICCR 2000 benchmark

- a well specified case for comparing in-patient calculations
  - all of previous issues controlled
- Results: state-of-the-art codes are very fast
  - a few minutes for typical clinical situations to get 2% statistics
  - faster with smoothing

28/32

Typical calculation times and statistics (Nucletron VMC++)

- Ribs phantom 15x15x20 cm^3, 31 slices, 9 MeV e-,10x10 cm^2, 3x3x3 mm^3 voxels, # histories = 10 k/cm^2
  - Pentium II 450 MHz – 5.0 min
  - Pentium III 900 MHz – 2.5 min
  - Pentium 4 Xeon 2.2 GHz – 1.0 min

```
Average stat. errors:
  D > 20%:     2.0274%     17723 voxels
  D > 50%:     2.2175%     11881 voxels
  D > 90%:     2.5675%        81 voxels
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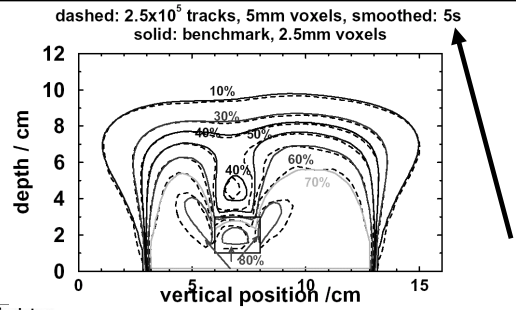
Cygler et al, Med Phys **31**(2004) 142

29/32

20 MeV e- beam – how fast can it be?



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30/32

Summary

- treatment planning based on Monte Carlo simulation is coming
- in principle it provides all the accuracy available from physics
- major issues
  - proper implementation
  - accurate beam models and how to commission the TPS for individual treatment machines
  - working with statistical uncertainties (which are obvious) vs systematic uncertainties in older methods (which are not so obvious)

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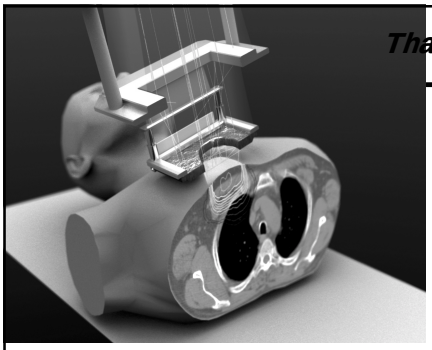
Thank you



and thanks to Iwan Kawrakow, Joanna Cygler and Paul Keall for providing slides.

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