Requirements for Monte Carlo simulation in radiotherapy

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Outline

- Introduction
- Requirements of Monte Carlo systems for external beam radiotherapy with electrons and x-rays
  - Performance categories
  - Requirements for treatment planning
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- X-ray and electron fluence benchmarks
  - Treatment head simulation
  - Clinical beams
- Conclusions

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The Monte Carlo method applied in external beam radiotherapy

Monte Carlo simulation is indispensable in radiotherapy

EGS/BEAM

- ***Intricate geometries***
- ***Exquisite detail in calculated quantities***
- ***High accuracy, rivaling measurement***

D. W. O. Rogers, B.A. Faddegon, G. X. Ding, C.-M. Ma, J. We, and T. R. Mackie, BEAM: A Monte Carlo code to simulate radiotherapy treatment units. Med. Phys. 22(5):503 (1995)

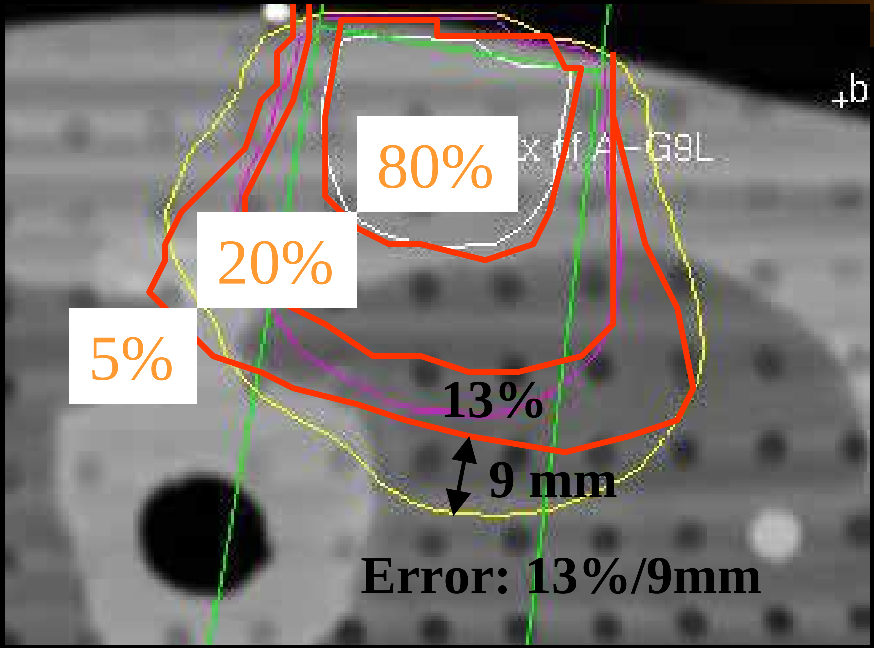
Requirements depend on application…

- Dose calibration factors (TG-51)
- Treatment head design (target, flattening filter, scattering foils, MLC, wedges, applicator)
- Beam modeling and commissioning
- Dose planning and dose-effect planning (RBE)
  - electron planning
  - x-ray pencil beam and dose kernels for superposition, IMRT
  - MLC leakage and scatter
  - influence of implants and objects in the beam path
- Complement measurement for complex patient-specific problems: surface dose, narrow fields, motion, implants, transmission measurement
- MV x-ray imaging and dose reconstruction to calculate detector response, scatter, etc, (IGRT)

Three performance categories

Speed	Accuracy	Functionality
Time to calculate quantity (e.g., dose in 1 mm width cube) to required precision (<< accuracy)	Relative value Fluence and Dose Relative and absolute difference Distance to region with same fluence or dose	Ease to implement and upgrade, ease of use, I/O (source, geometry, results), quantities to calculate, etc

Accuracy specification



Film

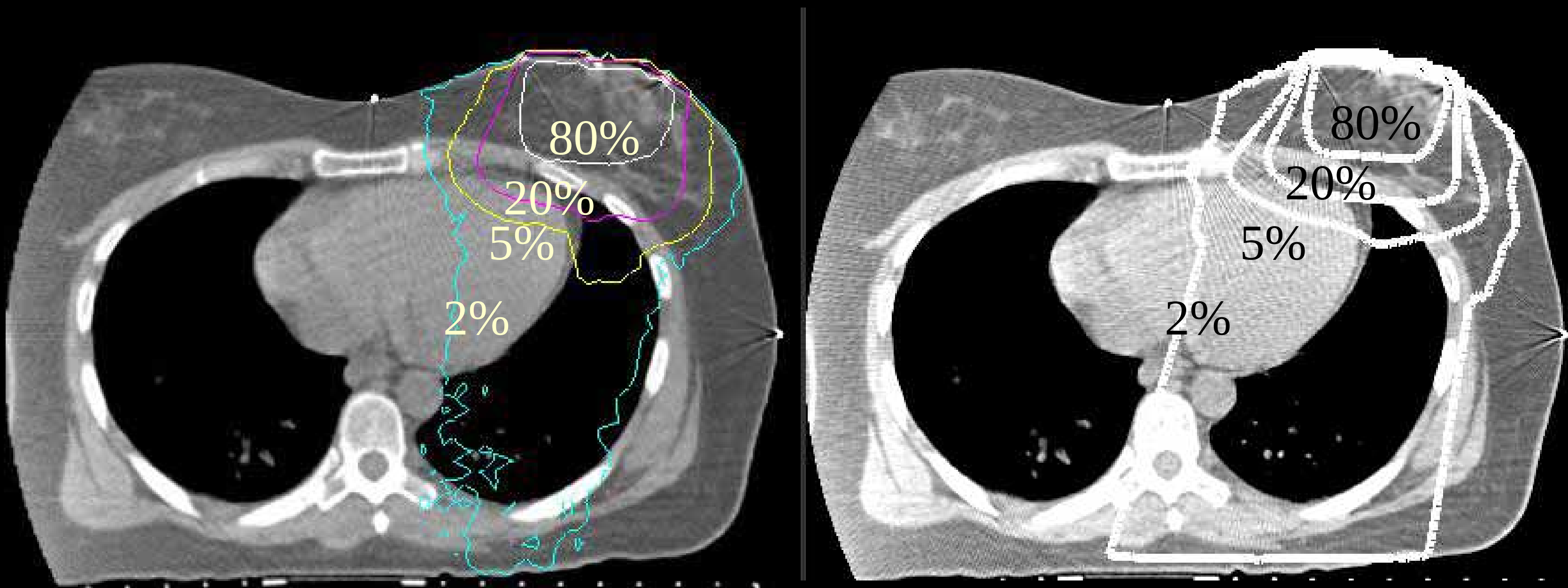
Hogstrom

Treatment planning examples

- Electron breast boost
- X-ray POP with stent in duodenum

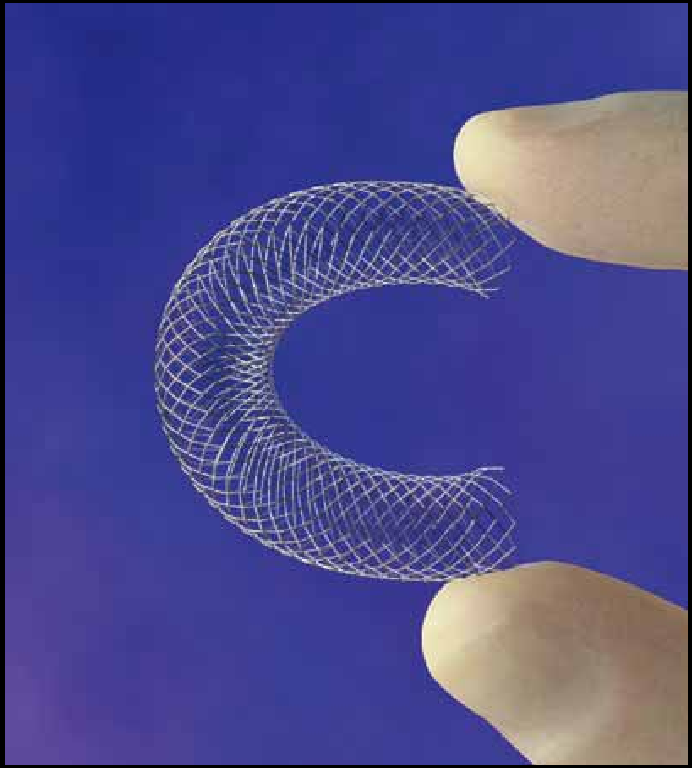
15 MeV breast boost

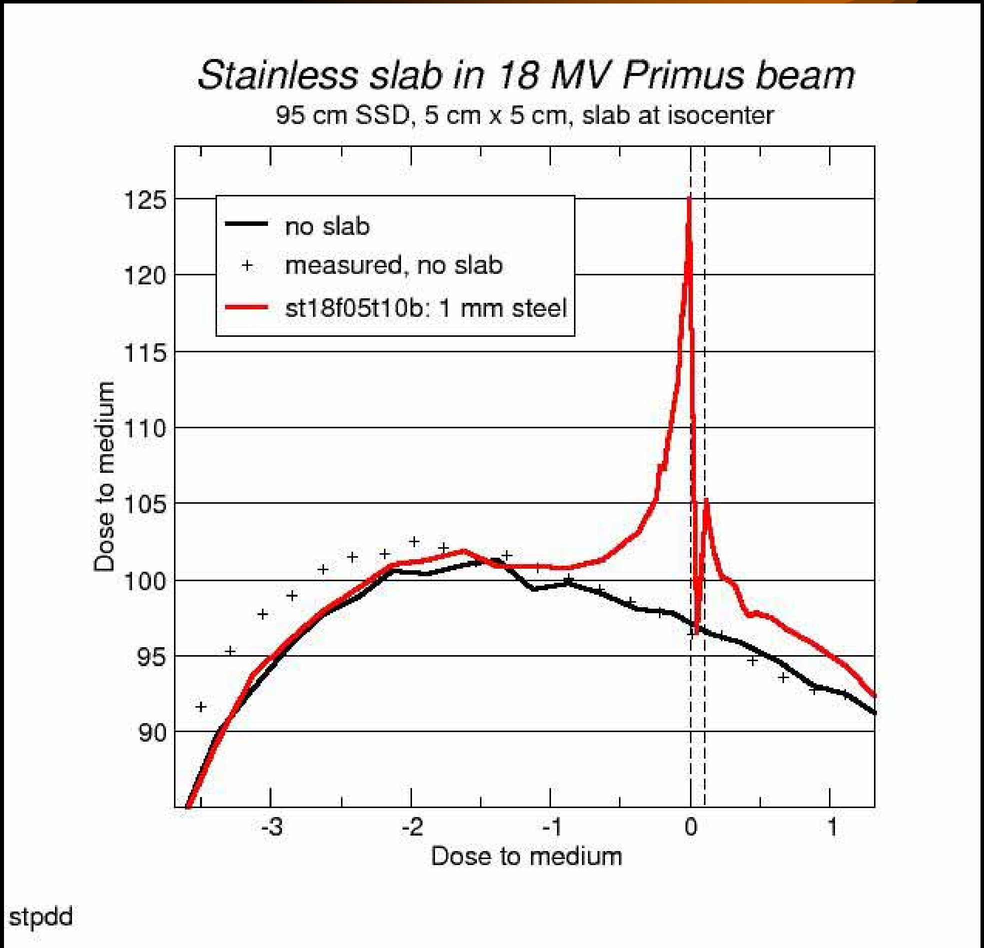
EGS4 Pinnacle



J. Coleman, Joy, C. Park, J.E. Villarreal–Barajas, P. Petti, B. Faddegon. "A Comparison of Monte Carlo and Fermi-Eyges-Hogstrom Estimates of Heart and Lung Dose from Breast Electron Boost Treatment," Int. J. Onc. Biol. Phys., Volume 61(2):621-628, 2005

Stent in duodenum



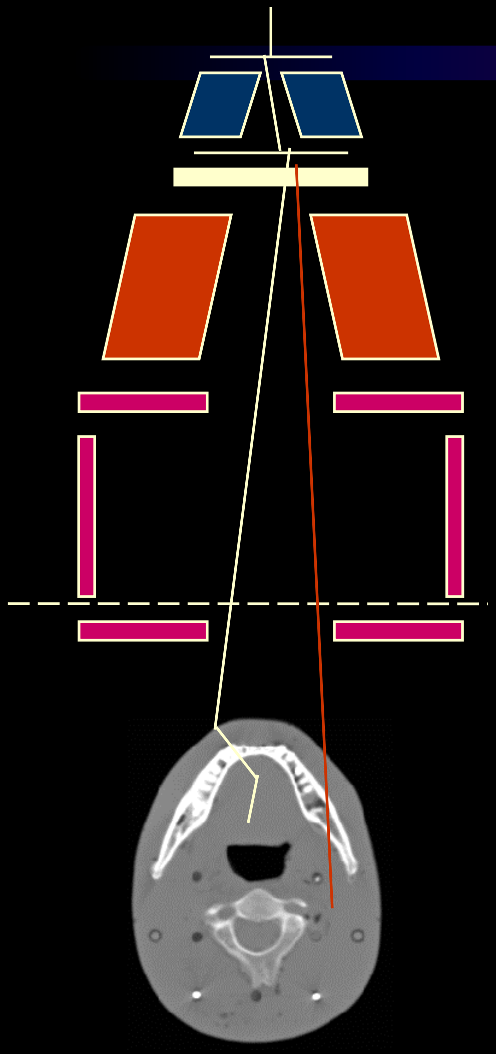


System requirements for treatment planning

Quantity Calculated	Speed	Accuracy	Importance
Few-field dose distribution	10 min per field	2%/2mm	Electrons: Moderate X-rays: Low
IMRT or EMRT dose distribution	1 hour per plan	3%/1mm	Electrons: High X-rays: Moderate
IGRT Dose distribution	1 min per plan	4%/1mm	Moderate
IGRT scattered fluence	1 hr per plan	10%/5mm	Moderate

- Absolute speed within factor of 10, relative accuracy within factor of 2

Examples of Functionality: Treatment Planning

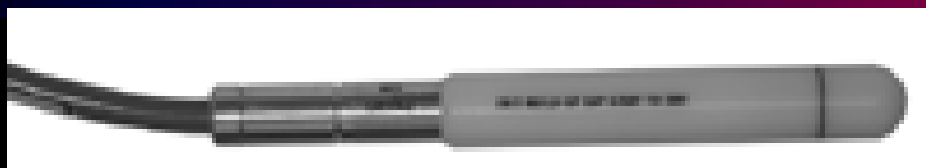


- Interface to treatment planning system for choosing fields, further data processing (IMRT, DVH) and display (dose distributions, DVH)
- Input phase-space or generate phase-space from beam model
- Input geometry of treatment head between position of phase-space and patient (collimation, wedge, trays, blocks, cut-outs, bolus, etc)
- CT conversion to medium and density prior to dose calculation
- Calculate dose to medium as well as dose to Bragg-Gray cavity of any medium (water, active region of detector, etc)

Non-planning examples

- Detector response
  - Calibration correction factors
- Treatment head component design
  - Target design

Detector calibration



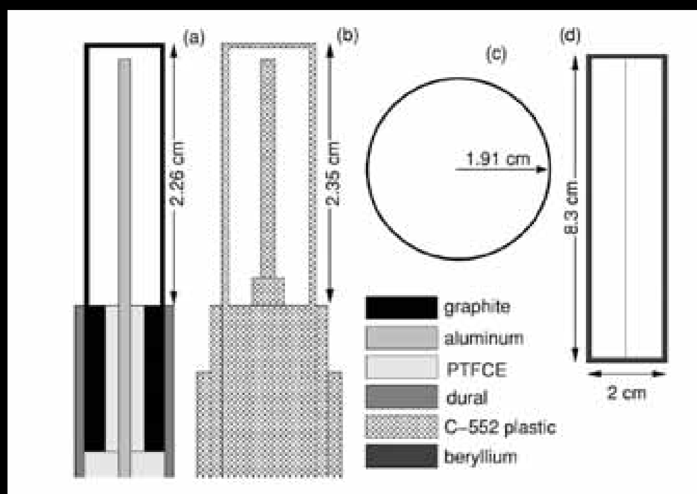


FIG. 1. EGSnrc models of (a) an NE 2571 chamber with 0.061 g/cm² thick graphite walls and a cavity and Al electrode with 0.68 and 0.1 cm diameters, respectively. A 0.59 g/cm² thick delrin buildup cap was included for calculations in a ^{60}Co beam; (b) An Exradin A12 chamber with 0.088 g/cm² thick

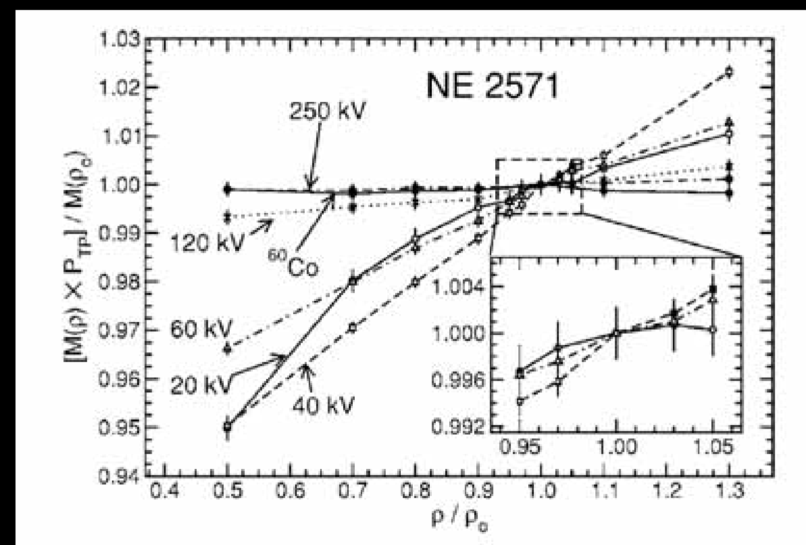
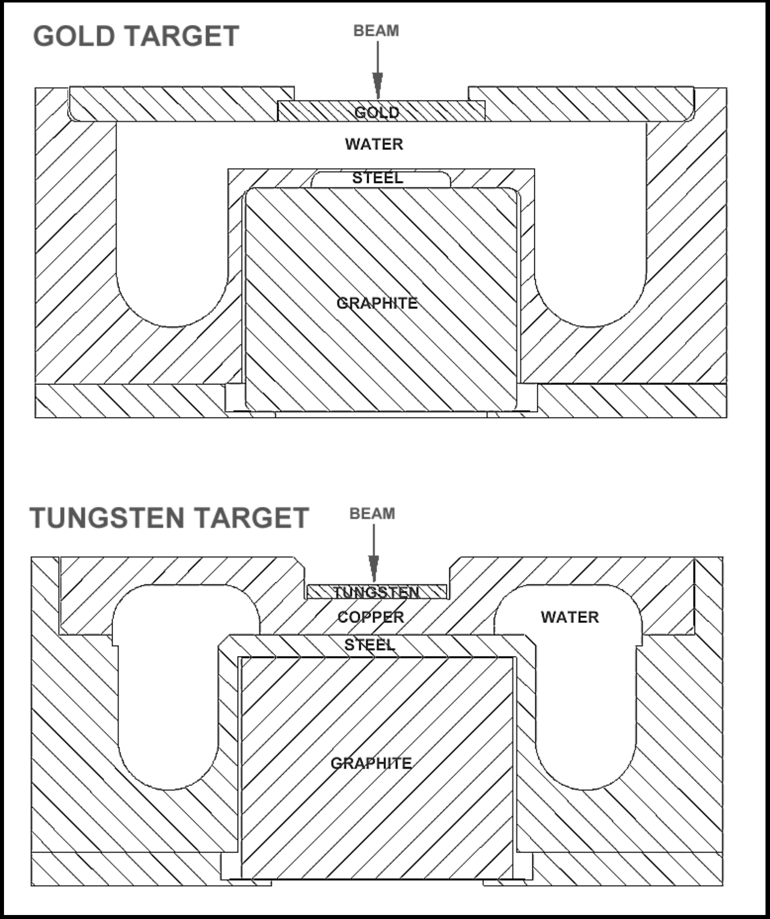
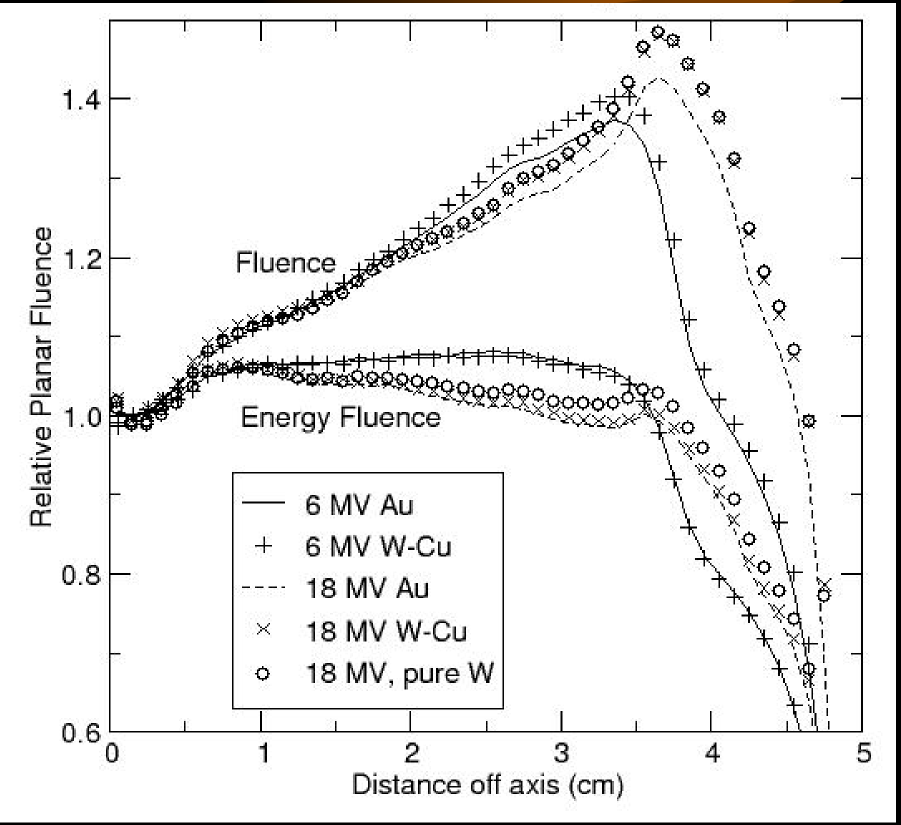


FIG. 3. EGSnrc-calculated responses of the NE 2571 chamber [Fig. 1(a)] as a function of air density for five PTB x-ray beam qualities and ^{60}Co. The data points are inherently corrected for temperature and pressure (P_{TP}) and

D.J. La Russo and D.W.O. Rogers, "An EGSnrc Investigation of the Ptp Correction Factor for Ion Chambers in Kilovoltage X-Rays," Med. Phys. 33:4590 (2006)

Target design





B. Faddegon, B. Egley, T. Steinberg. "Comparison of Beam Characteristics of a Gold X-ray Target and a Tungsten Replacement Target," Med. Phys. 31(1):91, 2004

System requirements for more general applications

Application	Quantity Calculated	Speed	Accuracy	Importance
Beam modeling	Fluence	5 hrs per beam	1%/1mm	High
Detector design	Response of flat panel imager	1 day for full range of energies	1%	High
Detector calibration	Correction factors	1 day per beam per detector	0.2%	High
Treatment head design	Dose distribution	5 hrs per beam	2%/2mm	High
	Fluence	5 hrs per beam	1%/1mm	High

- Absolute speed within factor of 10, relative accuracy within factor of 2

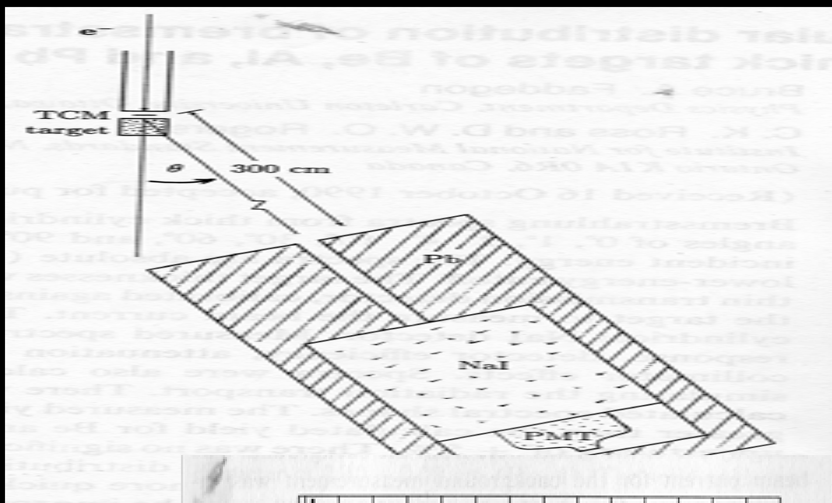
Examples of Functionality: General Applications

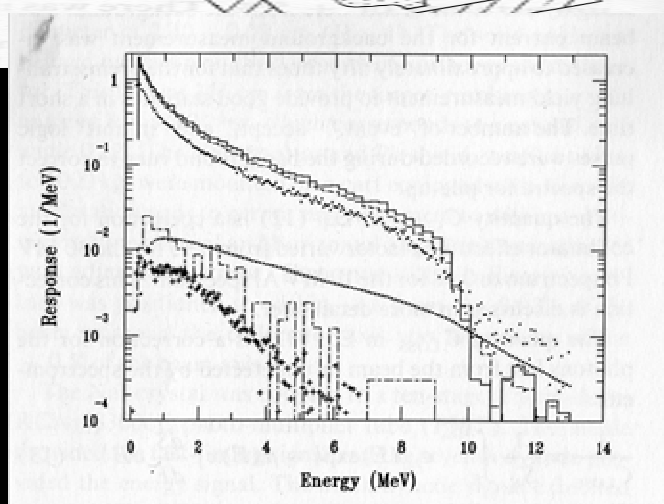
- Input detailed geometry of treatment head, detector
- Output phase-space on surface (plane perpendicular to beam axis sufficient for most situations): particle type, position, energy, direction, and select information on the path the particle followed and interactions it was involved in
- Region-dependent energy cut-offs, especially for response function calculation

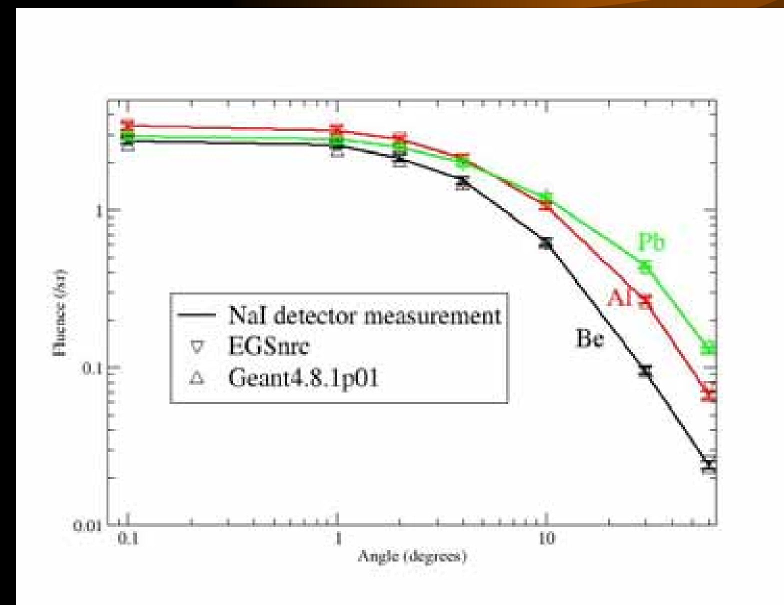
Accuracy first!

- Fluence benchmarks of treatment head simulation
  - X-rays: Thick-target bremsstrahlung
  - Electrons: Scatter
    - Clinical linac treatment head
    - Simplified source and geometry at NRCC
- Fluence benchmarks of clinical beams

Thick-target bremsstrahlung benchmark measurement at 10-30 MV



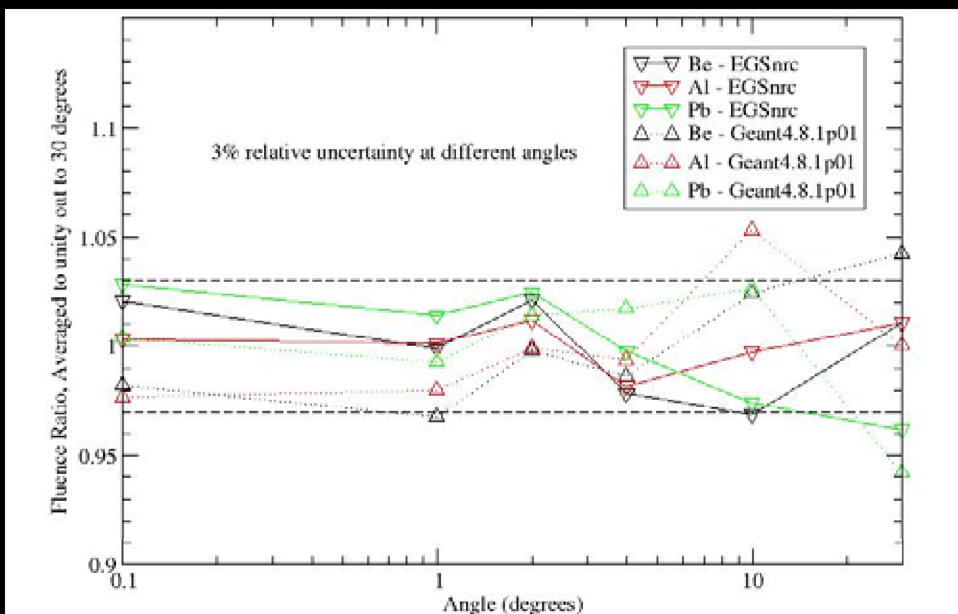


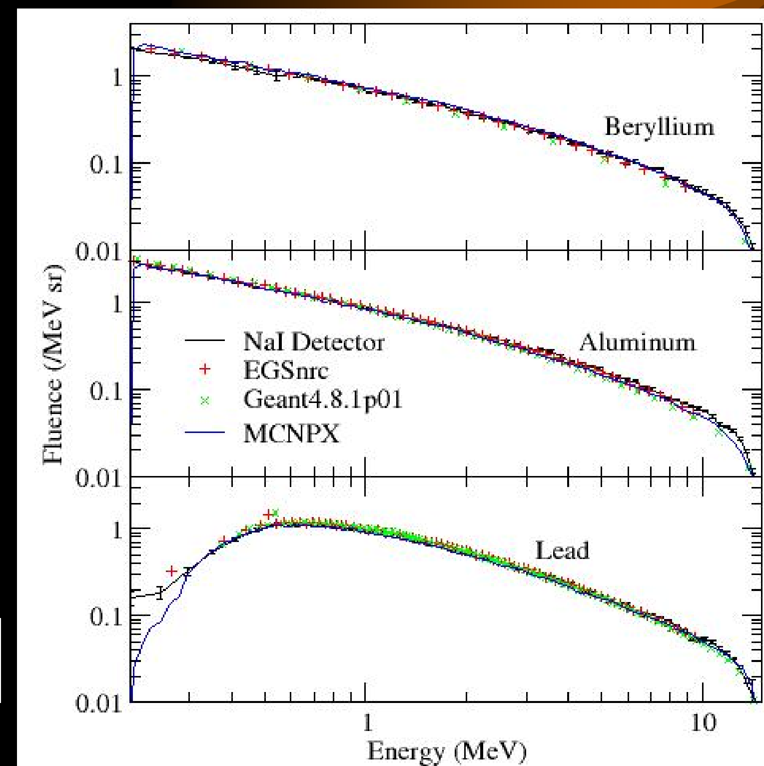


- Subtract pile-up spectrum and bkg
- Add counts lost to pulse pile-up
- Unfold detector response
- Add counts lost to attenuation and detector efficiency
- Collimator effect

BA Faddegon, CK Ross, DWO Rogers, Medical Physics 17(5):773-785, 1990
BA Faddegon, CK Ross, DWO Rogers, Medical Physics 18(4):727-739, 1991

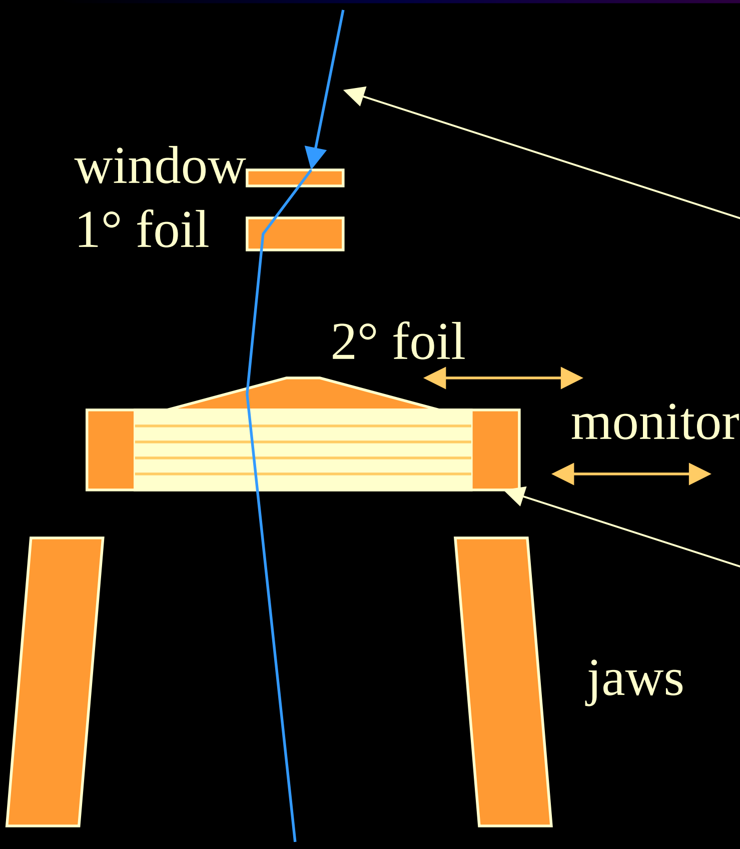
Thick-target bremsstrahlung benchmark

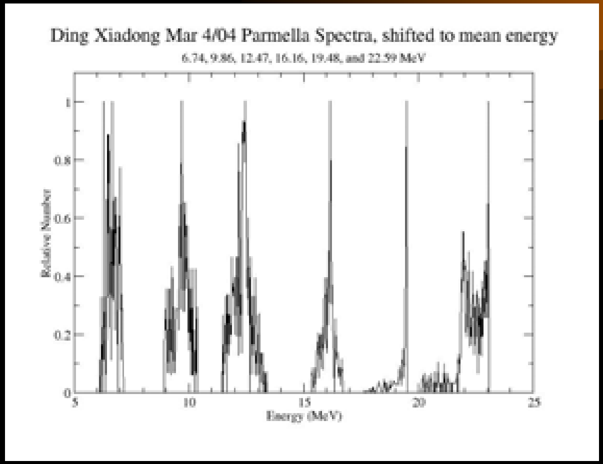


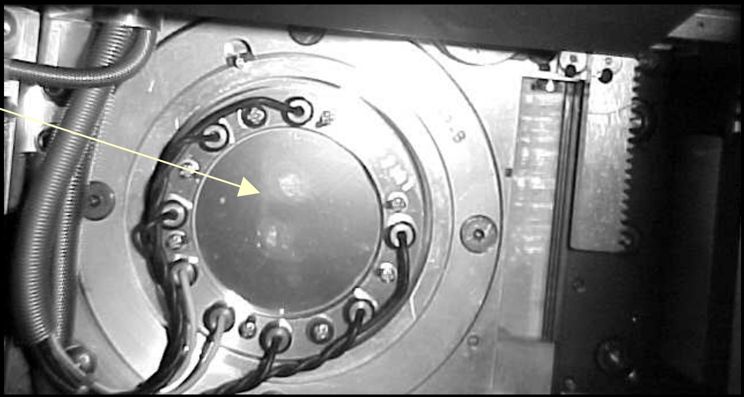


B Faddegon, E Traneus, J Perl, J Tinslay, M Asai, "Comparison of Monte Carlo Simulation Results to an Experimental Thick-Target Bremsstrahlung Benchmark," Submitted to AAPM annual meeting, July, 2007.

Electron benchmark: Primus linac

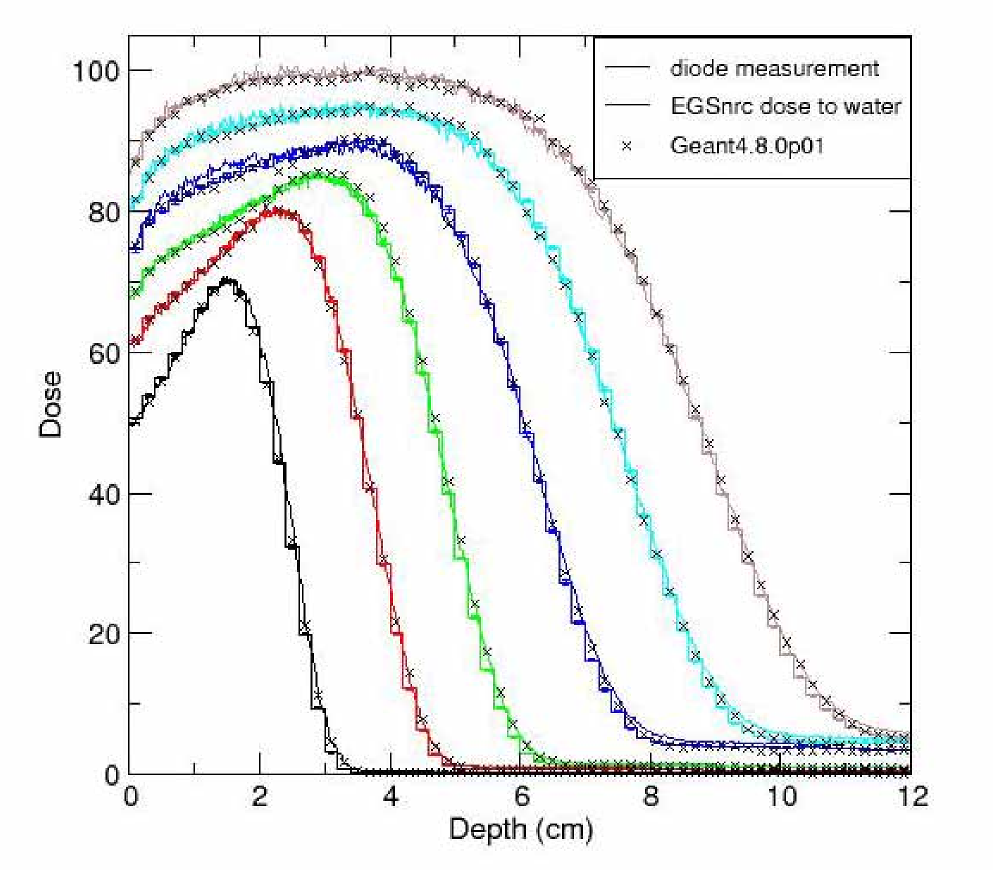






B.A. Faddegon, E. Schreiber, X. Ding. "Monte Carlo simulation of large electron fields," Phys. Med. Biol. 50 (2005) 741-753.

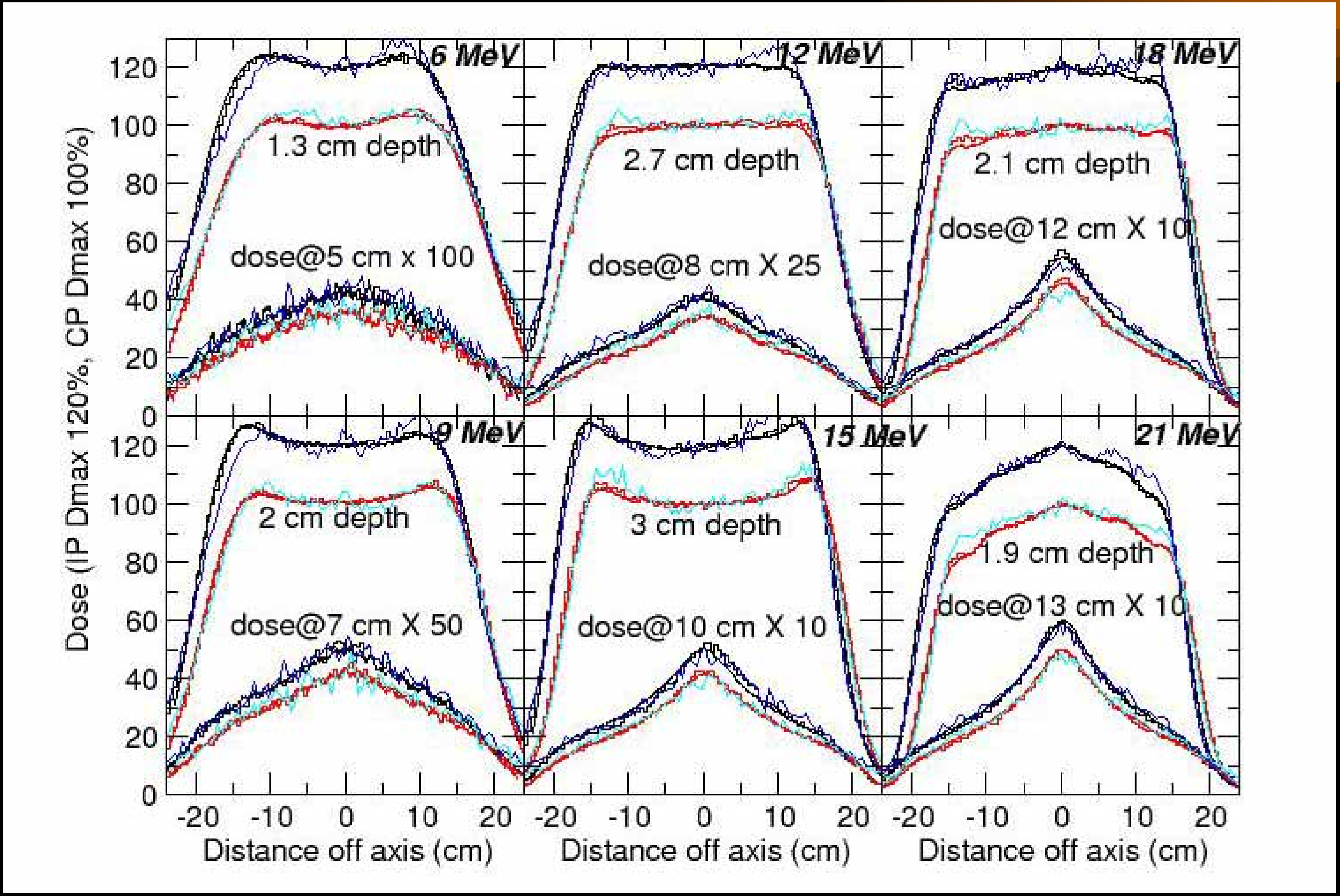
Electron benchmark: Primus linac



J. Perl , B. Faddegon, J. Tinslay, M. Asai, "Comparison of Geant4 Results to EGSnrc and Measured Data in Large Field Electron Dose Distributions," Third McGill Workshop on Monte Carlo Techniques in Radiotherapy Delivery and Verification, Montreal, June, 2007.

Electron benchmark: Primus linac

Measurements (IP - black line, CP - red line) vs EGSnrc (steps) and Geant4.8.1 (blue lines)

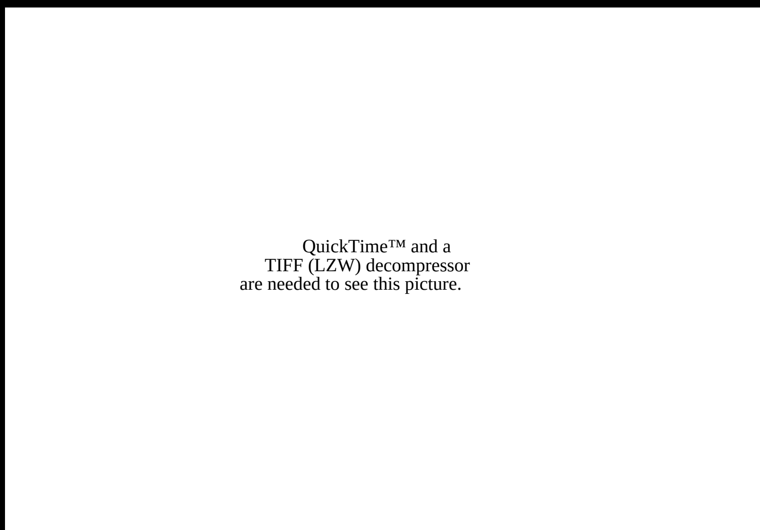


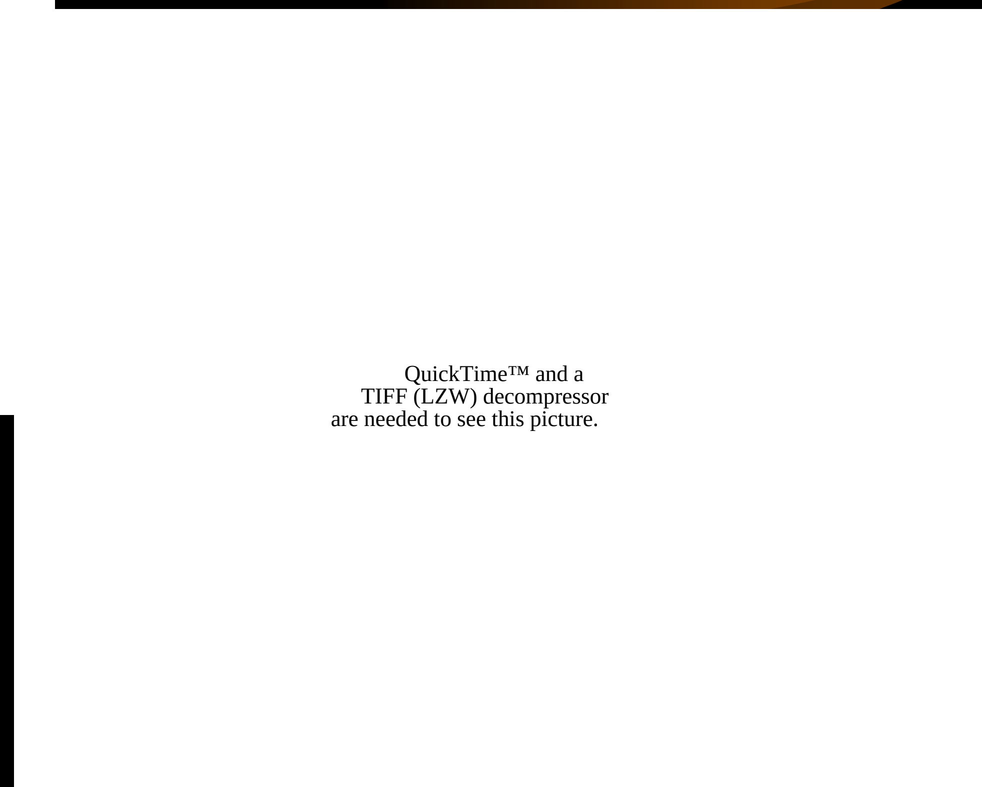
Perl et al, Third McGill Workshop on Monte Carlo, Montreal, June, 2007.

New electron scatter benchmark

A McDonald, M McEwen, B Faddegon, C Ross, "High Precision Data Set For Benchmarking of Electron Beam Monte Carlo," Submitted to AAPM annual meeting, July, 2007.

New fluence benchmark for clinical beams





J Chen, E Traneus, J Lehmann, E Schreiber, B Faddegon, "Development of a fluence benchmark for clinical electron beams," Submitted to AAPM annual meeting, July, 2007.

Conclusions

- Monte Carlo systems have advanced in speed, accuracy and functionality to the extent where they are indispensable in the field of radiation therapy. Codes both freely and commercially available have been used to resolve problems encountered in the clinic, industry, and research, with Monte Carlo simulation impacting the practice of radiotherapy physics on a daily basis.

Conclusions

- Two classes of codes have emerged: commercial and general use. For the moment, codes in both classes are necessary.
- The commercial codes are superior for their specific application, ie, treatment planning, maintaining the required accuracy in reasonable calculation times (minutes per beam).
- The best general use codes are superior for applications outside of routine treatment planning, providing the flexibility needed to simulate the linacs, patients and detectors encountered in radiotherapy and to fully understand the results. Companies have not developed general use codes.
- Further work is needed to meet the requirements for simulation in radiotherapy of speed, accuracy and functionality.