DEPARTMENT OF
Medical Physics
UNIVERSITY OF WISCONSIN SCHOOL OF MEDICINE AND PUBLIC HEALTH

RED
RADIOLOGICAL ENGINEERING & DESIGN LABORATORY

Calculation Techniques for Determining Non-Target Photon, Electron and Neutron Doses

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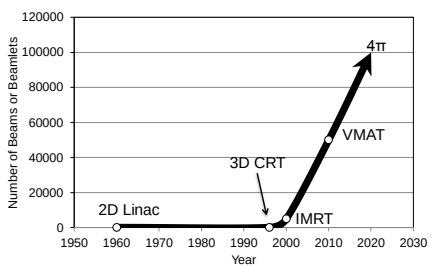
July 16, 2015

Background



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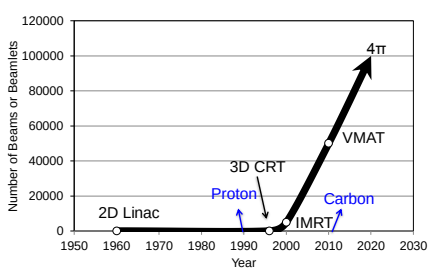

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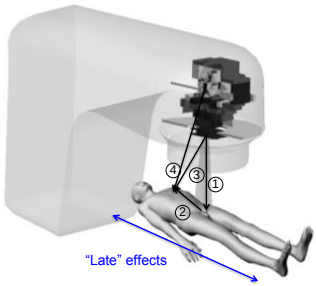

1. Primary
2. Patient scatter
3. Collimator scatter
4. Leakage

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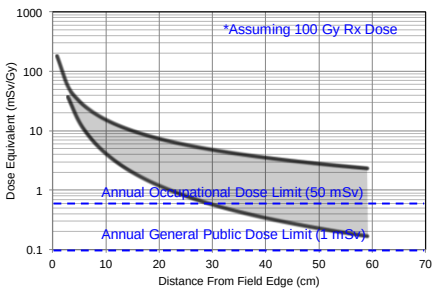

If we want to estimate dose to a non-target region in the patient, do we have the tools to do so?

Calculation Techniques

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1. Treatment Planning System
2. Empirical Methods
3. Monte Carlo Methods

Treatment Planning System

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TPS inaccurate in out-of-field regions because:

1. Beam Modeling
2. Dose Calculation Algorithm
3. Neutrons

High-Energy Photons | Protons/Carbon

Treatment Planning System

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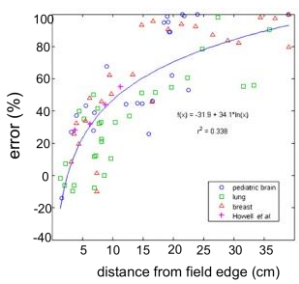

Huang JY, Followill DS, Wang XA, Kry SF. (2013) *J Appl Clin Med Phys. 14(2) 4139*

Analytical Methods

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Measurements or Monte Carlo calculations can be used to produce empirical or semi-empirical models.

6-parameter double Gaussian

$$D = \frac{\alpha_1}{\sqrt{2\pi\sigma_1^2}} e^{-\frac{(r-\mu_1)^2}{2\sigma_1^2}} + \frac{\alpha_2}{\sqrt{2\pi\sigma_2^2}} e^{-\frac{(r-\mu_2)^2}{2\sigma_2^2}}$$

Parameter	MD Anderson model fit	AUBMC model fit
α_1 (cm-cGy Gy^{-1})	148.3	224.8
μ_1 (cm)	−3.89	−2.16
σ_1 (cm)	3.57	1.57
α_2 (cm-cGy Gy^{-1})	196.7	224.3
μ_2 (cm)	−6.80	−7.43
σ_2 (cm)	8.58	10.28

"With four parameters I can fit an elephant, and with five I can make him wiggle his trunk."

John von Neumann

Taddei, P. J., W. Jalbout, et al. (2013) Physics in Medicine and Biology **58**(21): 7463-7479.

Monte Carlo Methods

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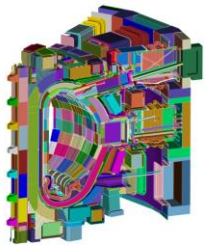
Monte Carlo radiation transport is a stochastic method used to simulate particles through phase-space using a random walk method.

$$\mathcal{H}\psi(\hat{r},\hat{\Omega},E) = q(\hat{r},\hat{\Omega},E)$$

$$\mathcal{H} = \hat{\Omega}\cdot\nabla + \Sigma(\hat{r},E) - \int dE' \int d\Omega \Sigma_s(\hat{r},E' \rightarrow E,\hat{\Omega}'\cdot\hat{\Omega})$$



ITER C-Lite SDR model

Monte Carlo Methods

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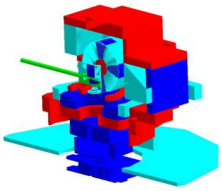
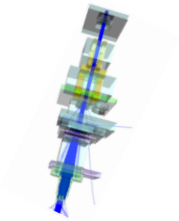
Detailed Monte Carlo models of the source provide the highest level of fidelity.



(a) Varian 2100C



(b) MGH Proton Nozzle

Bednarz, B. and X. G. Xu (2009) Phys Med Biol **54**(4): N43-57
Paganetti H (2012), Phys. Med. Bioil. 57 R99

Monte Carlo Methods

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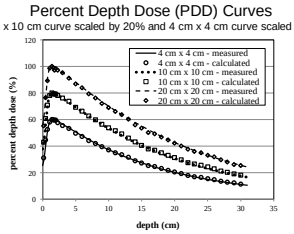
In-field and out-of-field Monte Carlo simulations should be benchmarked to measurements.

Percent Depth Dose (PDD) Curves
(10 cm x 10 cm curve scaled by 20% and 4 cm x 4 cm curve scaled by 40%)



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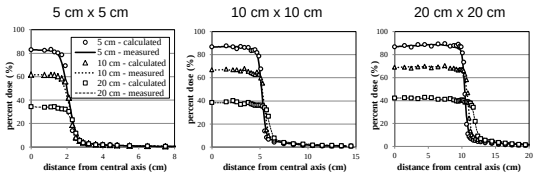
In/Cross-plane Dose Profile Curves



Bednarz, B. and X. G. Xu (2009) Phys Med Biol **54**(4): N43-57

Monte Carlo Methods

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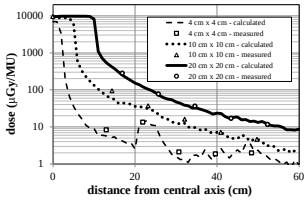
Extended Dose Profile Curves



Bednarz, B. and X. G. Xu (2009) Phys Med Biol **54**(4): N43-57

Monte Carlo Methods

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In-field and out-of-field Monte Carlo simulations should be benchmarked to measurements.

Suggested modeling benchmarks:

In-field

- Central-axis depth doses within 0.5% for depths between d_{max} and 20 cm
- Central-axis depth doses within 1.0% for depths greater than 20 cm
- Central-axis depth doses within 5.0% for depths less than d_{max}
- Off-axis dose profiles within 2.0% of central-axis value
- Off-axis dose profiles in penumbra reproduced to within 2 mm of measured values.

Out-of-field

- In-plane extended dose profiles with 10% of measured data on average
- Cross-plane extended dose profiles within 10% of measured data on average

*Photon and proton modeling should follow clinical TPS commissioning benchmarks.

Monte Carlo Methods

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In-field and out-of-field Monte Carlo simulations should be benchmarked to measurements.

In-air Neutron Fluence

Field size (cm^2)	Distance (cm)	Calculated Fluence (10^3 n/cm²/MU) This study†	Reported by Kry et al. (2007)	% difference	Measured Fluence (10^3 n/cm²/MU) Reported by Kry et al. (2007)	% difference
0 x 0	+ 60	82.3	98	16.0	78	5.60
	+ 30	98.5	103	4.40	75	31.3
	+21	85.8	--	26.0	--	--
	0	85.9	103	16.0	89	3.50
	-30	91.0	93	2.20	83	9.60
5 x 5	+21	97.7	--	15.0	--	--
9 x 9	+60	88.8	95	6.50	109	18.5
	+30	111.2	104	6.90	80	39.0
	-30	99.8	93	7.40	74	34.9
10 x 10	+21	106	--	0.0	--	--
20 x 20	0	204.5	174	17.5	160	27.8
	-50	92.7	86	7.80	102	9.10

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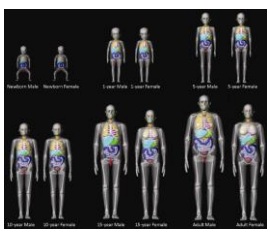
Anatomically-realistic phantoms provide information that cannot be measured.



Lee, C., D. Lodwick, et al. (2010). Phys Med Biol **55**(2): 339-363.
Ding A. et al (2012) Phys. Med. Biol. 57(9) 2441

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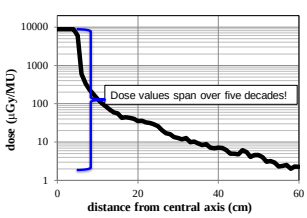
Deep-penetration transport problems such as this are problematic for analog Monte Carlo.



Variance reduction refers to a class of methods that improve efficiency of MC calculations by modifying particle behavior in order to preferentially sample events that result in tally scores.

- Source biasing
- Particle splitting
- Energy/range cut-offs
- Global VR (weight-window generator)

If implemented incorrectly could bias results

Monte Carlo Methods

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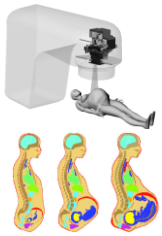
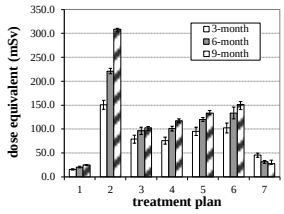
Advanced modeling and simulation can help address clinical needs.





Over 3,500 pregnant patients are diagnosed with cancer in US each year.

Bednarz, B and Xu, XG. (2008) Med. Phys. 35(7) 3054-3061

Acknowledgements

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