Monte Carlo simulations for brachytherapy

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ICTP,Trieste, Nov 15, 2007

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Brachytherapy

Radiation *therapy given at a short distance*

- Radioactive seeds or sources implanted either permanently or temporarily ***inside*** tumours

- Commonly used for prostate, breast, cervical and ocular cancers.

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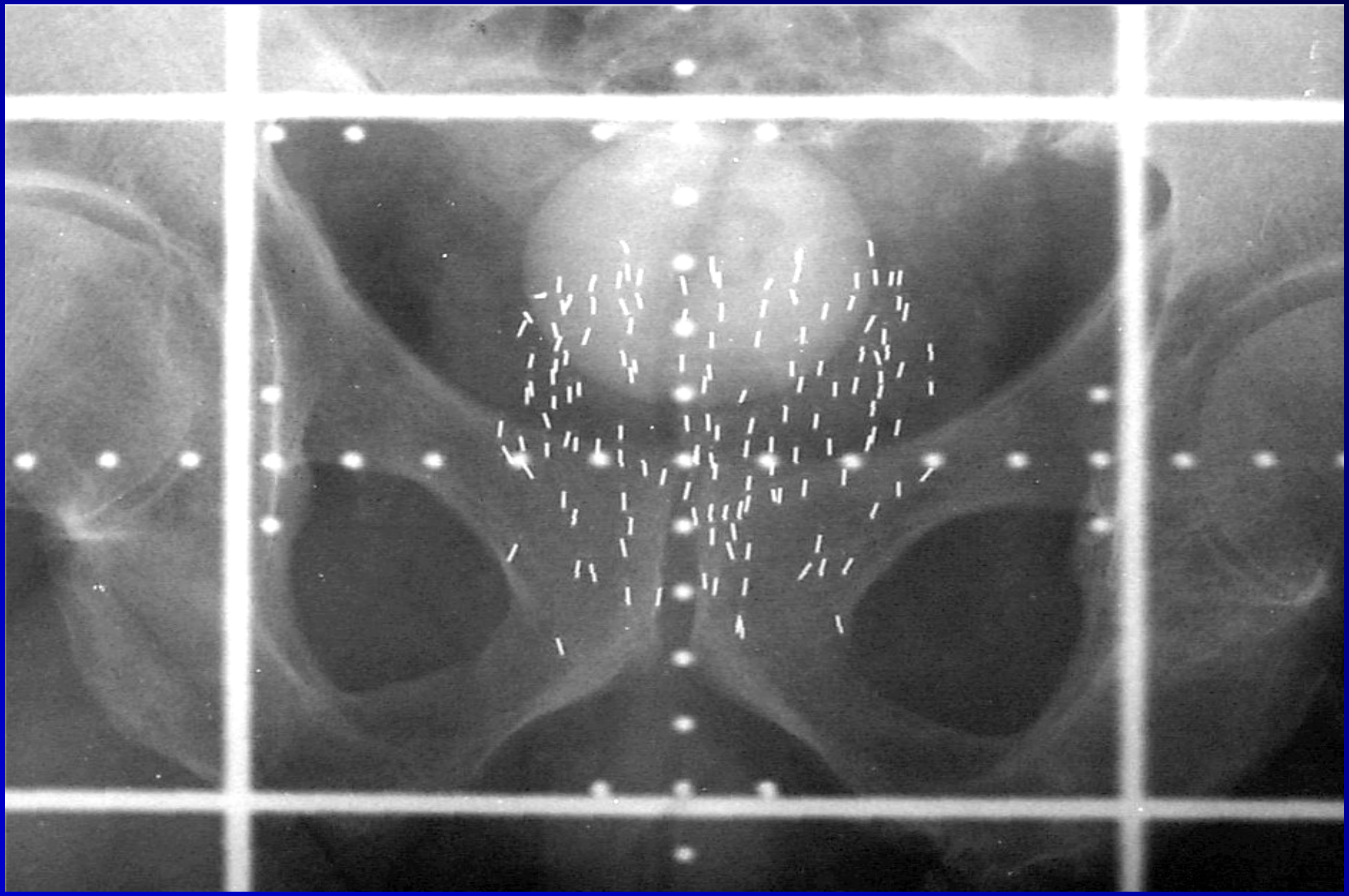
Typical Prostate Implant

Prostate implant of ~150 ^{125}I brachytherapy seeds



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Characteristics of isotopes used in brachytherapy

missing
Cs-131
Yb-169

Isotope	Average photon energy (MeV) [a]	Half-life	*HVL* in lead (mm)	Γ_{AKR} [b,d] $\left(\frac{\mu Gy \cdot m^2}{GBq \cdot h}\right)$	Λ [c,d] $\left(\frac{cGy \cdot h^{-1}}{cGy \cdot cm^2 \cdot h^{-1}}\right)$
Co-60	1.25	5.26 yr	11	309	1.11
Cs-137	0.66	30 yr	6.5	77.3	1.11
Au-198	0.41	2.7 d	2.5	56.2	1.13
Ir-192	0.38	73.8 d	3	108	1.12
I-125	0.028	60 d	0.02	-	-0.92-1.012
Pd-103	0.021	17 d	0.01	-	-0.63- 0.69

(a) These are only approximate values, depending on source make and filtration
(b) Γ_{AKR} is the air-kerma rate constant
(c) Λ is the dose rate constant.
(d) Using generic values of the air-kerma rate constant or dose rate constant for low energy photon source may lead to substantial errors in the dose calculations. They are therefore not given here for iodine-125 and palladium-103.

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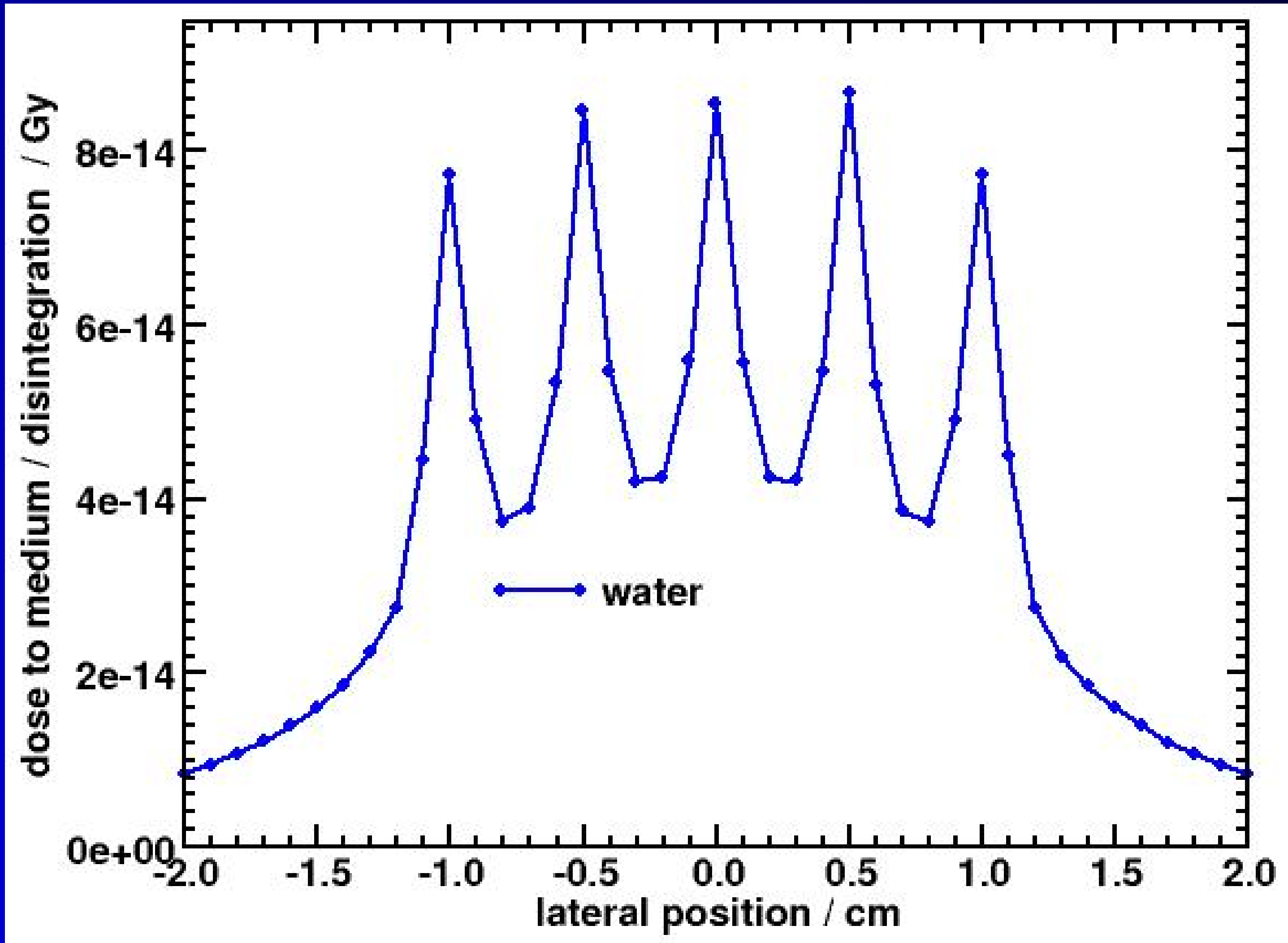
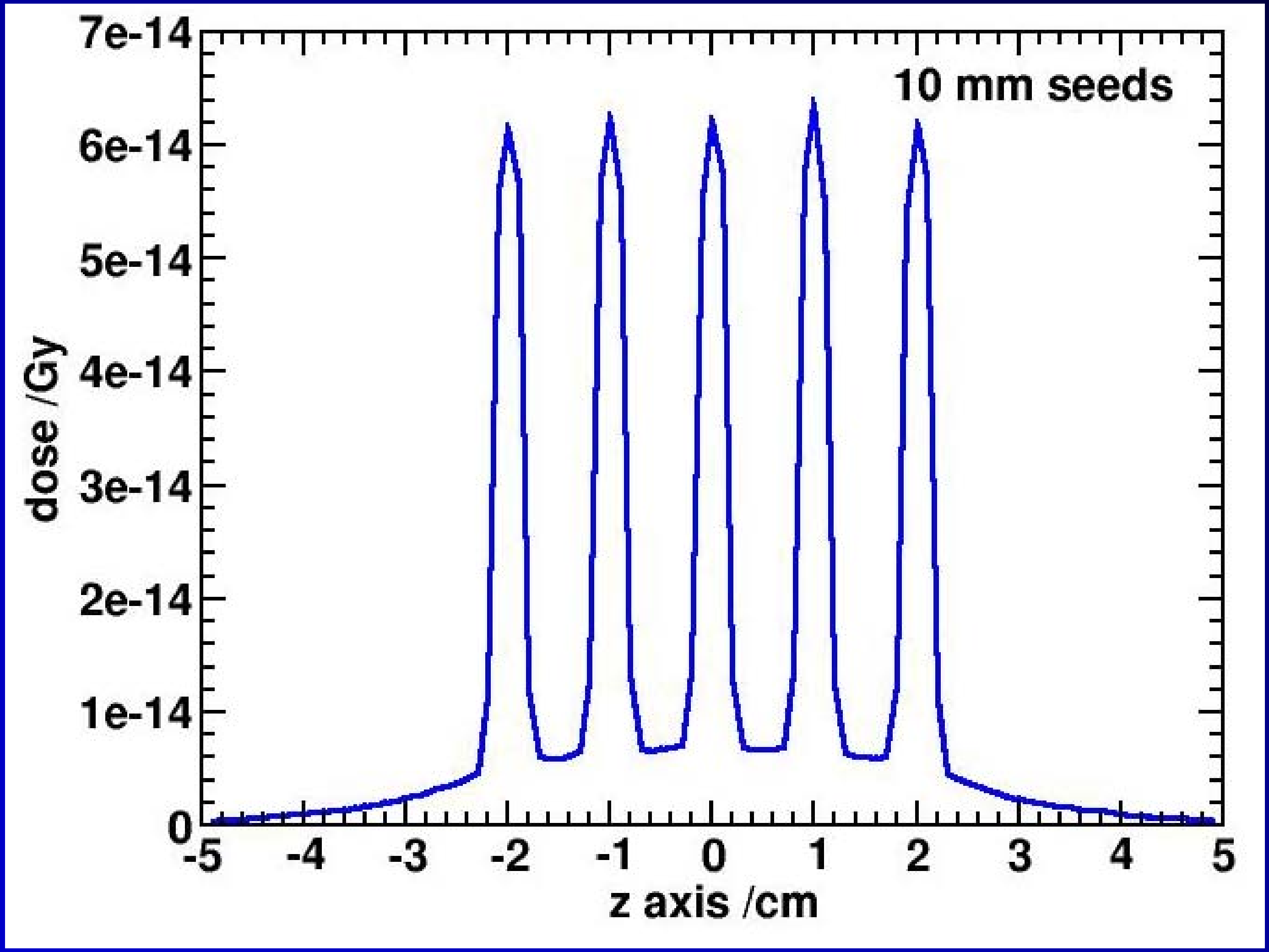
from IAEA Review of Radn Oncology Physics, E Podgorsak editor

I-125 seeds cause hot spots



125 seeds 5mm spacing -along length of seeds

10 mm spacing => 9 to 1 ratio



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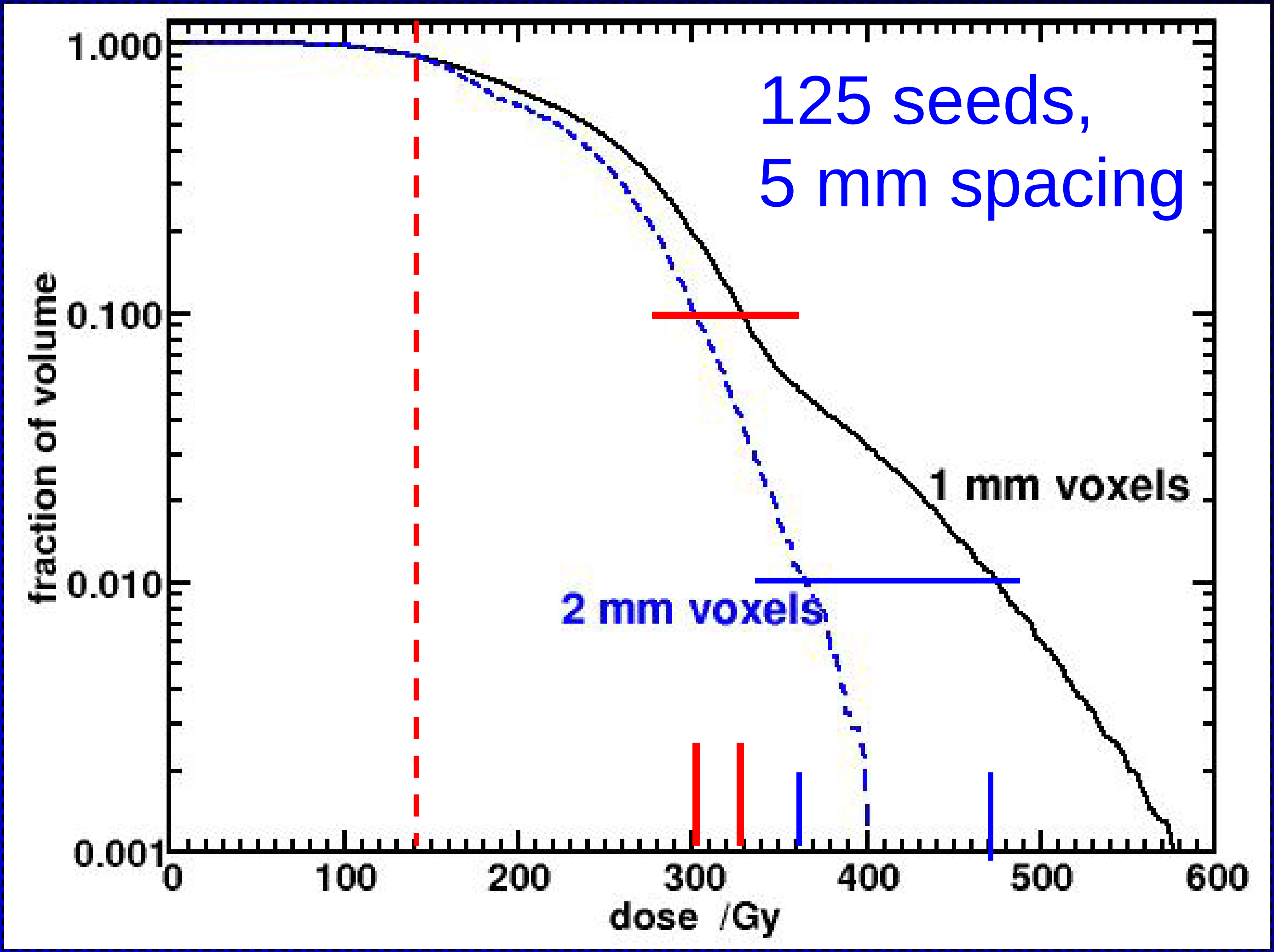
90% of volume receives > 140 Gy

DVH

dose volume histogram

fraction of volume of interest (eg prostate) receiving at least the dose on the x-axis



Details depend on size of voxel in calculation

Large variety of seeds (4-5mm overall)

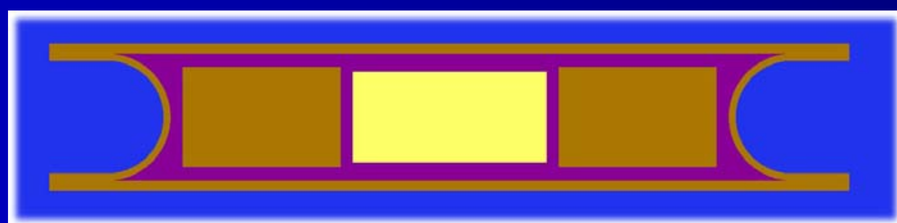
^{125}I

Amersham 6711

^{103}Pd

Best 2335

^{103}Pd

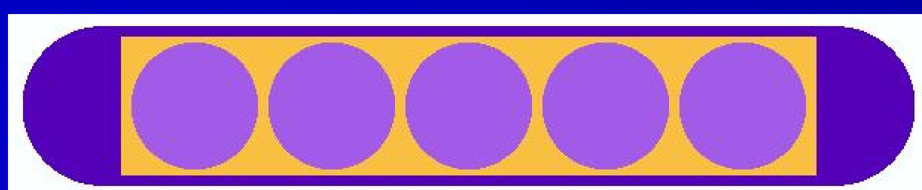


Theragenics 200

^{125}I

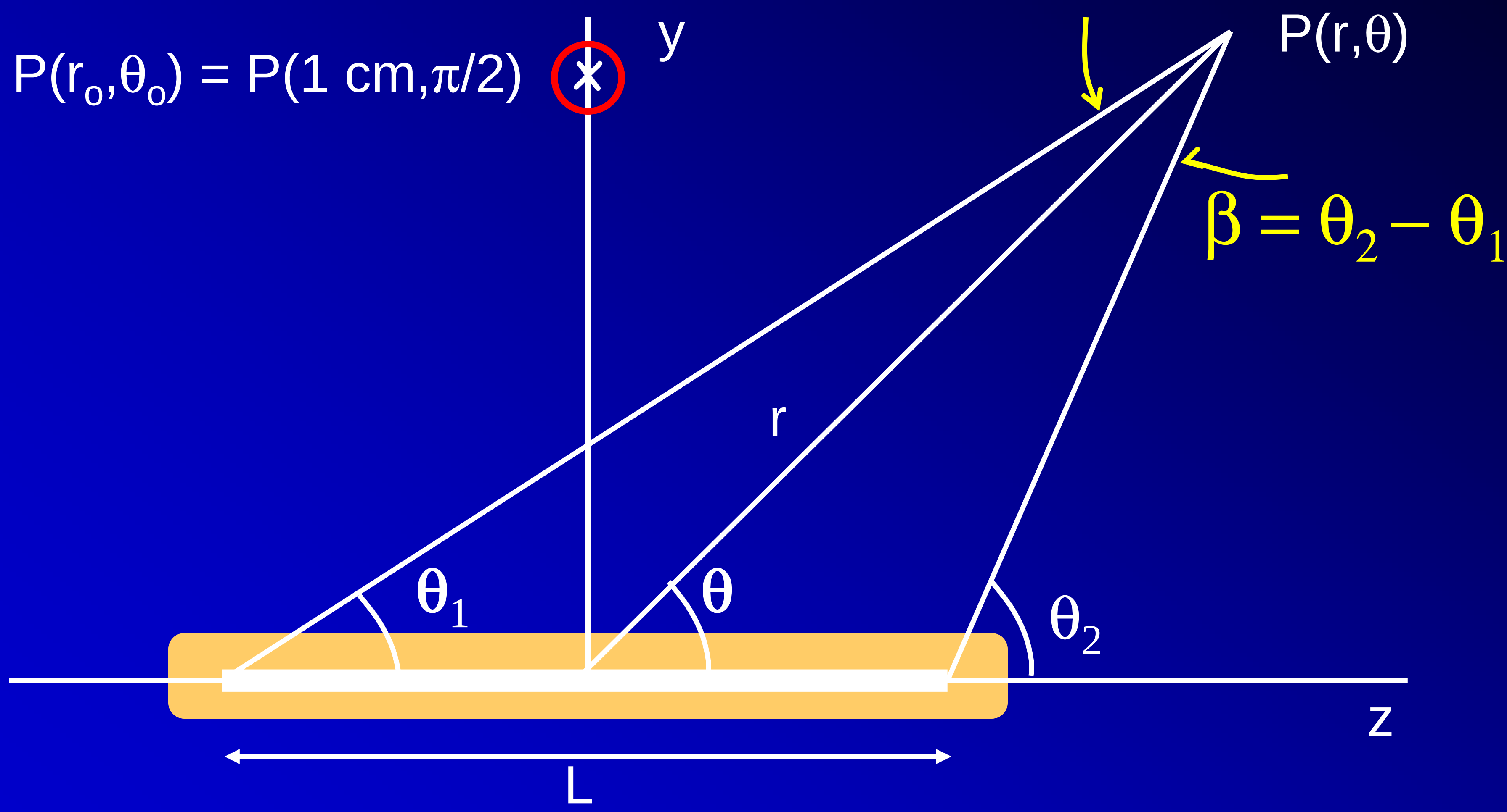
Source Tech Medical STM125I

^{125}I



Imagyn isoStar 12501

TG-43 coordinate system for calculations



TG43 references at end of slides

What are pure geometry effects?

- Consider the source in vacuum. What is the fluence of particles at (r,θ)? just $1/r^2$

$$G_X(r,\theta) = \frac{\int_V \frac{\rho(\vec{r'})}{|\vec{r'}-\vec{r}|^2} dV'}{\int_V \rho(\vec{r'}) dV'}$$

- for a point source

$$G_p(r,\theta) = \frac{1}{r^2}$$

- for a line source

$$G_l(r,\theta) = \begin{cases} 1/\left(r^2 - L^2/4\right) & \theta = 0 \\ \beta/\,Lr\sin\theta & \text{if } \theta \neq 0 \end{cases}$$

$$\beta = \theta_2 - \theta_1 = \tan^{-1}\left(\frac{r\sin\theta}{r\cos\theta - L/2}\right) - \tan^{-1}\left(\frac{r\sin\theta}{r\cos\theta + L/2}\right)$$

or (faster)

$$\beta = \begin{cases} \tan^{-1}\left(\frac{Lr\sin\theta}{r^2 - L^2/4}\right) & r > L/2 \\ \tan^{-1}\left(\frac{Lr\sin\theta}{r^2 - L^2/4}\right) + \pi & r < L/2 \\ \pi/2 & r = L/2 \end{cases}$$

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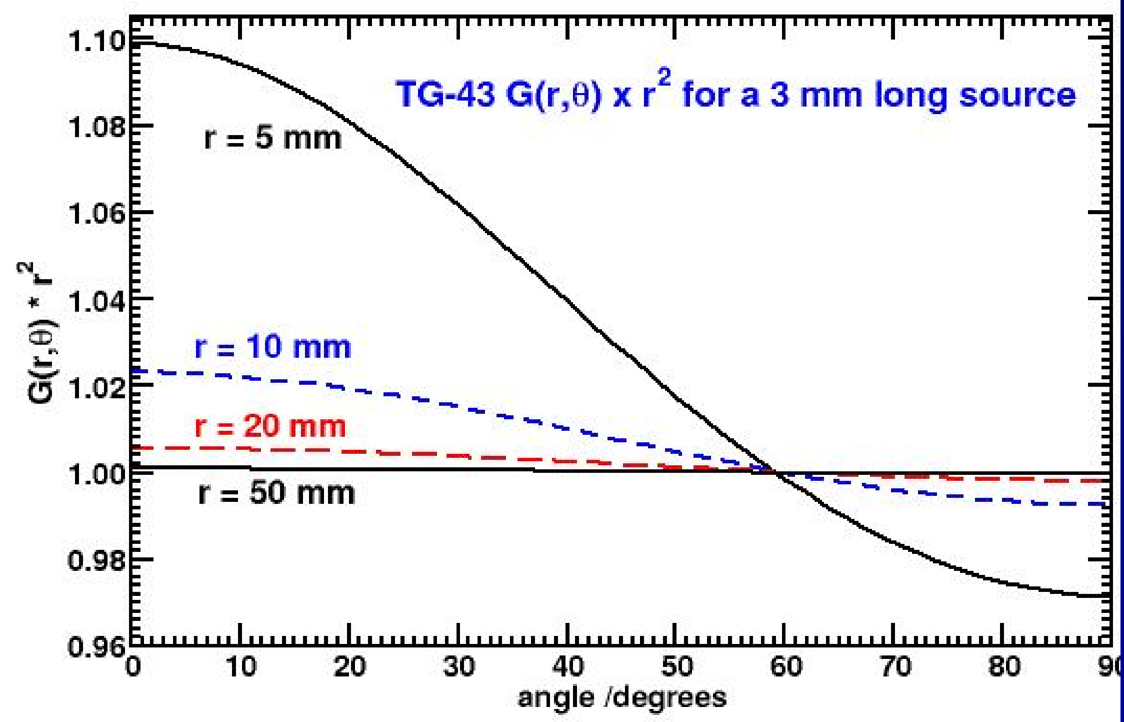
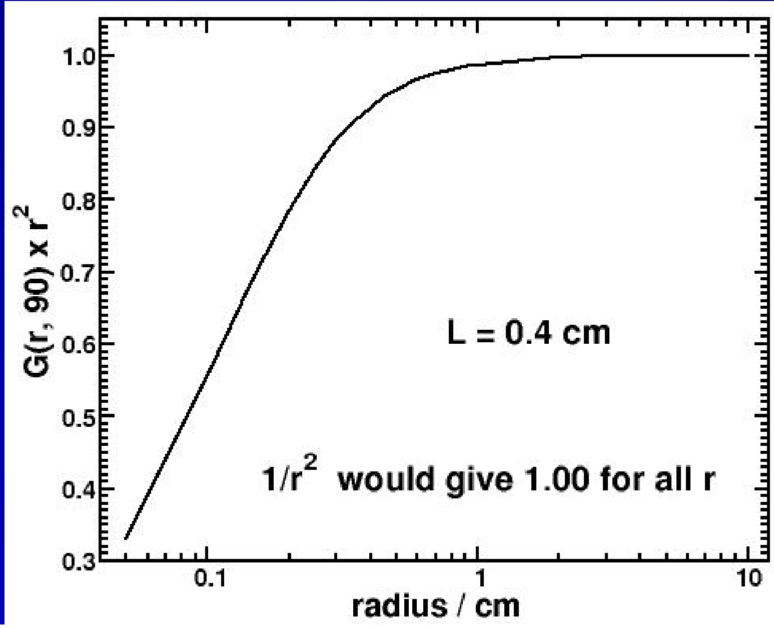
How big is the geometry factor?



Pure $1/r^2$ would be unity in both plots



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TG43

$$\dot{D}(r,\theta) = S_k \cdot \Lambda \cdot \frac{G(r,\theta)}{G(r_o,\theta_o)} \cdot g(r) \cdot F(r,\theta)$$

Air-kerma strength

$$S_K = \dot{K}_\delta(d)d^2$$

1U = 1mGy m^2h^{-1} =1 cGy cm^2h^{-1}

$\dot{K}_\delta(d)$ -the air kerma rate at distance d

-in vacuum (i.e., no air attenuation or scatter)

-for photons > δ (no effect on dose but has effect on K, typically 5 keV)

S_K is defined to be independent of d (for d>>L).

Numerically = reference air kerma rate of ICRU 38/60

This is a measured quantity.

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TG43

$$\dot{D}(r,\theta) = S_k \cdot \Lambda \cdot \frac{G(r,\theta)}{G(r_o,\theta_o)} \cdot g(r) \cdot F(r,\theta)$$

Dose-rate constant (DRC)

$$\Lambda = \frac{\dot{D}(r_0,\theta_0)}{S_K}$$

r_o=1 cm, θ_o = 90°

cGyh^{-1}/U = cm^{-2}

depends on radionuclide & source model

DRCs are measured or calculated by Monte Carlo

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TG43

$$\dot{D}(r,\theta) = S_k \cdot \Lambda \cdot \frac{G(r,\theta)}{G(r_o,\theta_o)} \cdot g(r) \cdot F(r,\theta)$$

Radial dose function

$$g_X(r) = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \frac{G_X(r_0\theta_0)}{G_X(r,\theta_0)}$$

X = P or L (point or line) $g(r_o) = 1$

Aside from geometry ($1/r^2$), g(r) accounts for dose fall off on transverse axis due to photon attenuation and scatter.

For a point source:

$$g_p(r) \equiv \frac{\dot{D}(r)r^2}{\dot{D}(r_o)r_o^2}$$

Radial dose functions are measured and calculated by Monte Carlo

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TG43

$$\dot{D}(r,\theta) = S_k \cdot \Lambda \cdot \frac{G(r,\theta)}{G(r_o,\theta_o)} \cdot g(r) \cdot F(r,\theta)$$

Dose anisotropy function

$$F(r,\theta) \quad = \quad \frac{\dot{D}(r,\theta)}{\dot{D}(r,\theta_o)} \frac{G_L(r,\theta_o)}{G_L(r,\theta)}$$

$F(r,\theta)$ describes variation in dose vs polar angle relative to transverse plane (above G_L variations)

$F(r,\theta_o) = 1.0$

Dose anisotropy functions are mostly calculated by Monte Carlo

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TG43

$$\dot{D}(r,\theta) = S_k \cdot \Lambda \cdot \frac{G(r,\theta)}{G(r_o,\theta_o)} \cdot g(r) \cdot F(r,\theta)$$

$$S_K \Lambda = D(r_o,\theta_o)$$

$$D(r_o,\theta_o) \cdot g(r) = D(r,\theta_o) \cdot \mathrm{geom}$$

$$D(r,\theta_o) \cdot F(r,\theta) \cdot \mathrm{geom} = D(r,\theta)$$

i.e. the TG-43 formalism is an identity,

- holds independently of what $G(r,\theta)$ is.

Clinically, get measured S_K for your individual seeds and use Monte Carlo or measured values for Λ, $g(r)$, and $F(r,\theta)$

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Monte Carlo for TG43 parameters

- Jeffrey F Williamson - PTRAN_CCG
  - this code is responsible for most of the published values (MCNP and EGS4/EGSnrc have also been used)
  - references at end

- Monte Carlo for brachytherapy is, in general a photon transport problem since so low in energy
- Dose = Kerma (strictly the collision kerma)

$$D_{\mathrm{med}} \overset{CPE}{\equiv} K_{\mathrm{col,med}} = E_\gamma \, \phi \left(\frac{\mu_{en}}{\rho} \right)_{\mathrm{med}}$$

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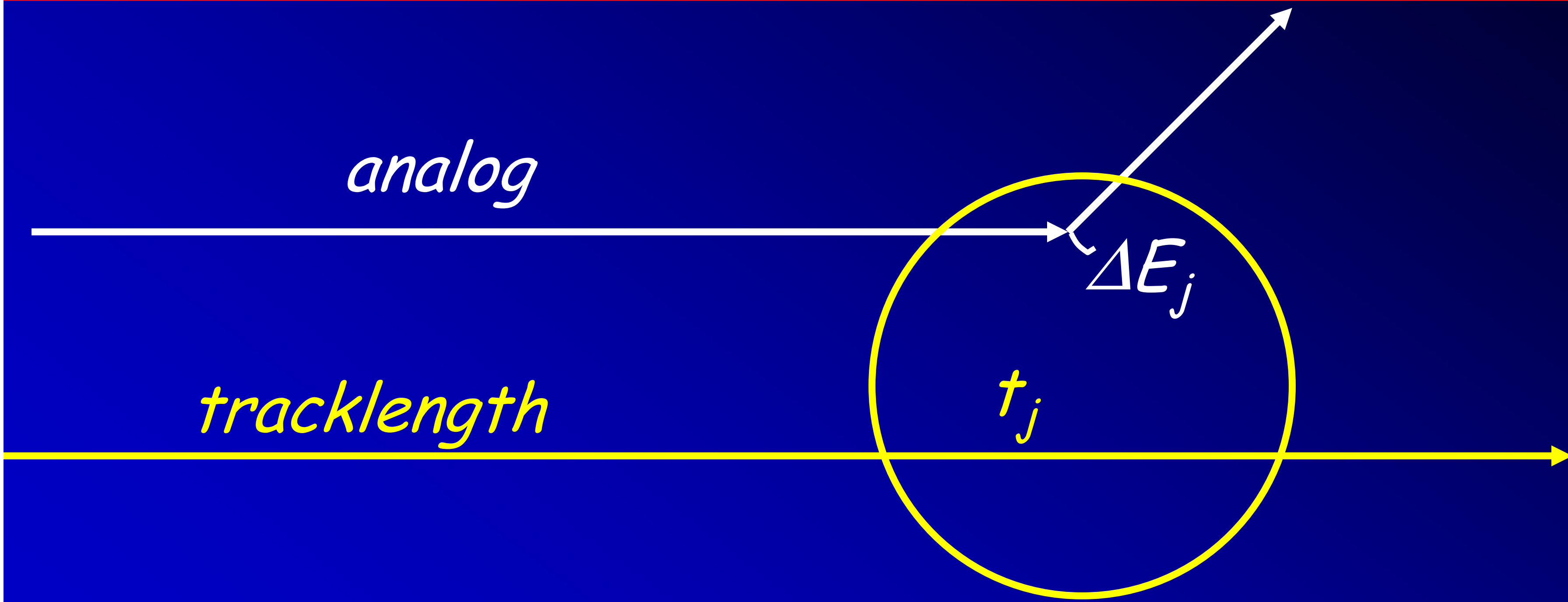
Kerma estimators



Kerma estimators

- Analog estimator $K_i = \frac{1}{m_i} \sum_j \Delta E_j$ — i-th region; j-th interaction region i
- Tracklength estimator $K_i = \frac{1}{V_i} \sum_j E_j t_j \left(\frac{\mu_{en}}{\rho} \right)_j$

-uses relationships between fluence ϕ and total tracklength per unit volume $\phi = \frac{1}{V} \sum_j t_j$ — t_j tracklengths in i-th region

and between kerma and fluence $K_{\rm col,med} = E_\gamma \, \phi \left(\frac{\mu_{en}}{\rho} \right)_{\rm med}$

Tracklength estimator: much more efficient - it uses all paths through a volume, not just interactions in it

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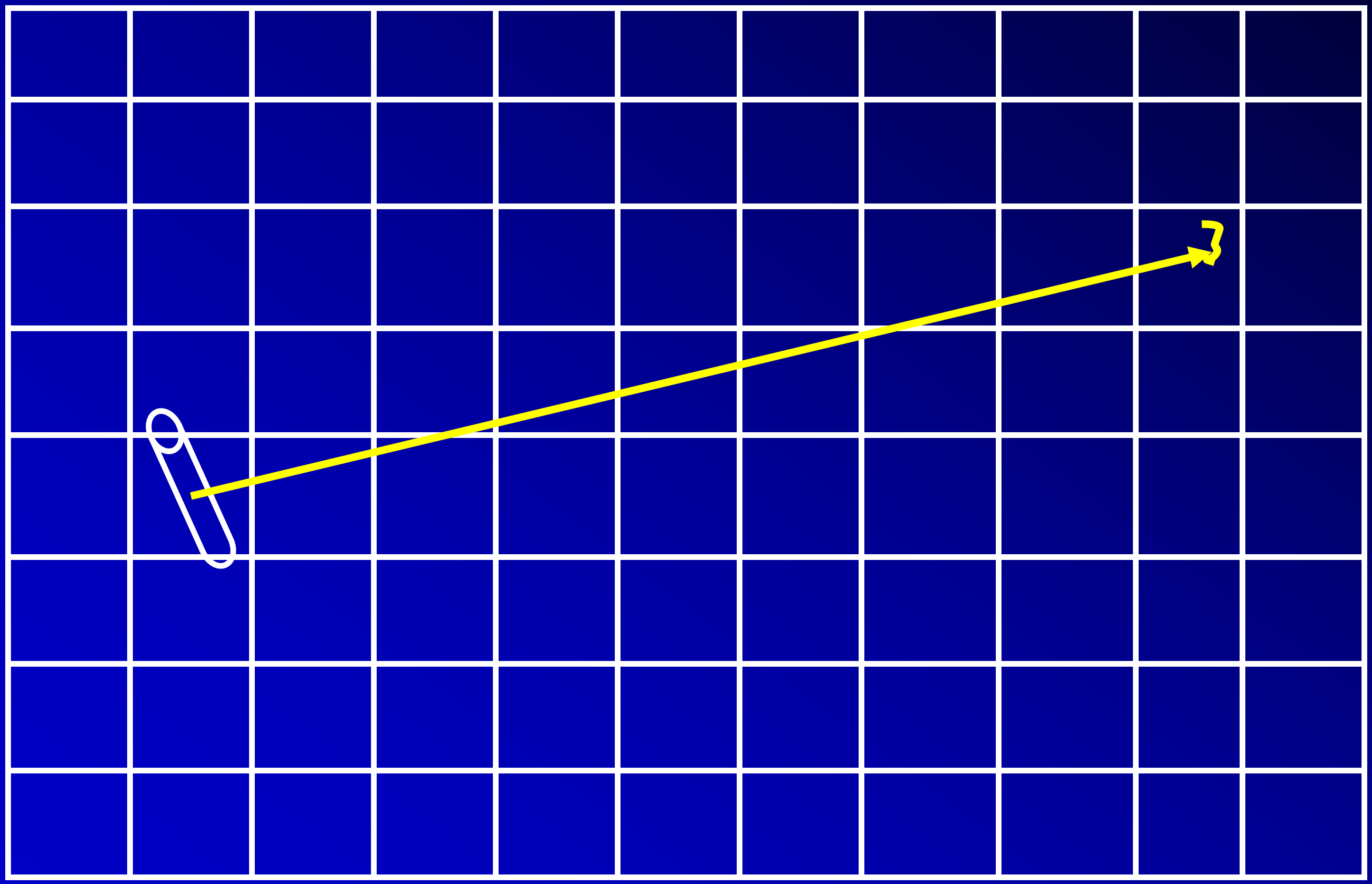
Analog vs pathlength estimators



analog estimator (interaction) contributes to 1 voxel
pathlength estimator contributes to 11 voxels

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Efficiency increase from tracklength estimator

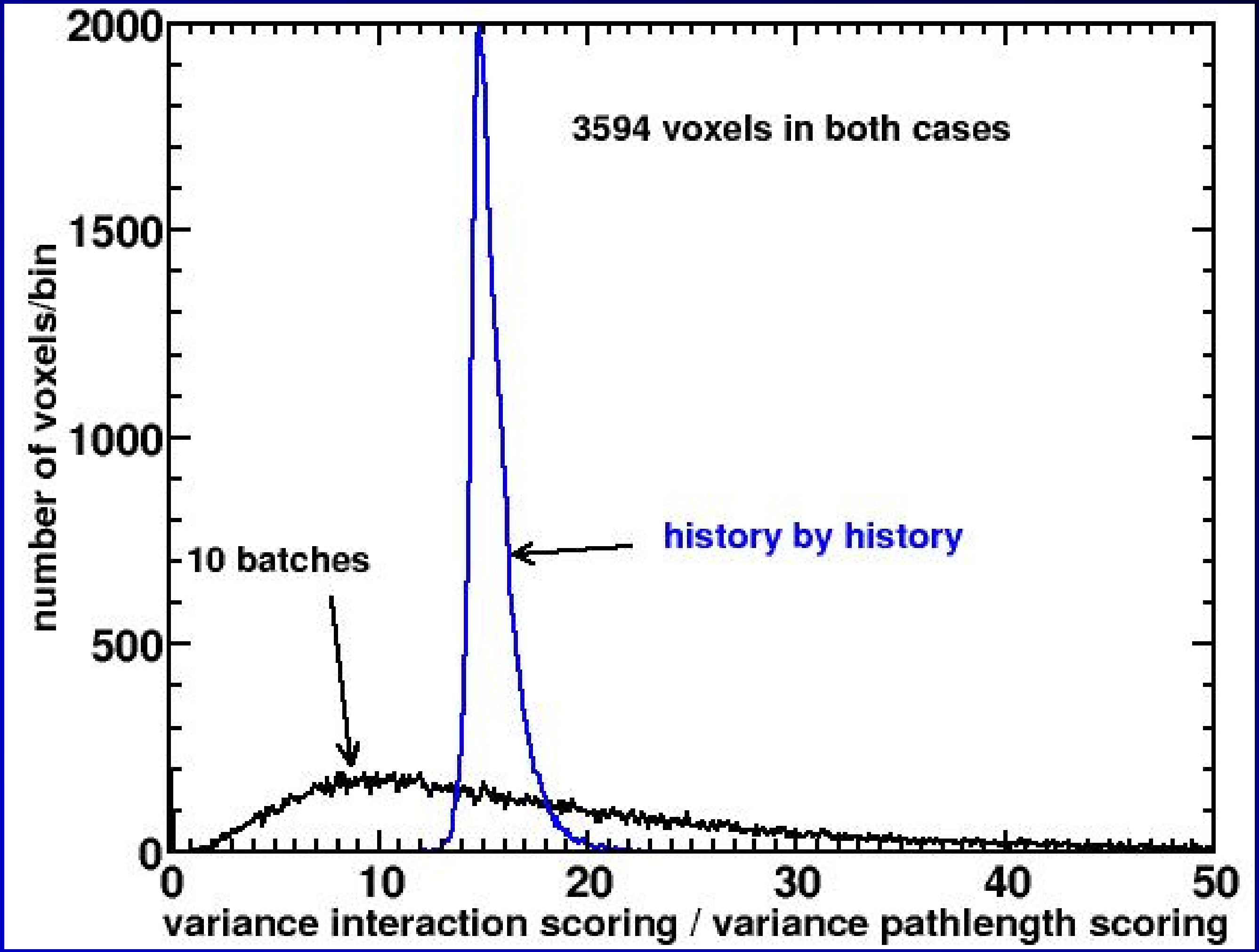
125 ^{125}I seeds,

5 mm spacing

2 mm voxels

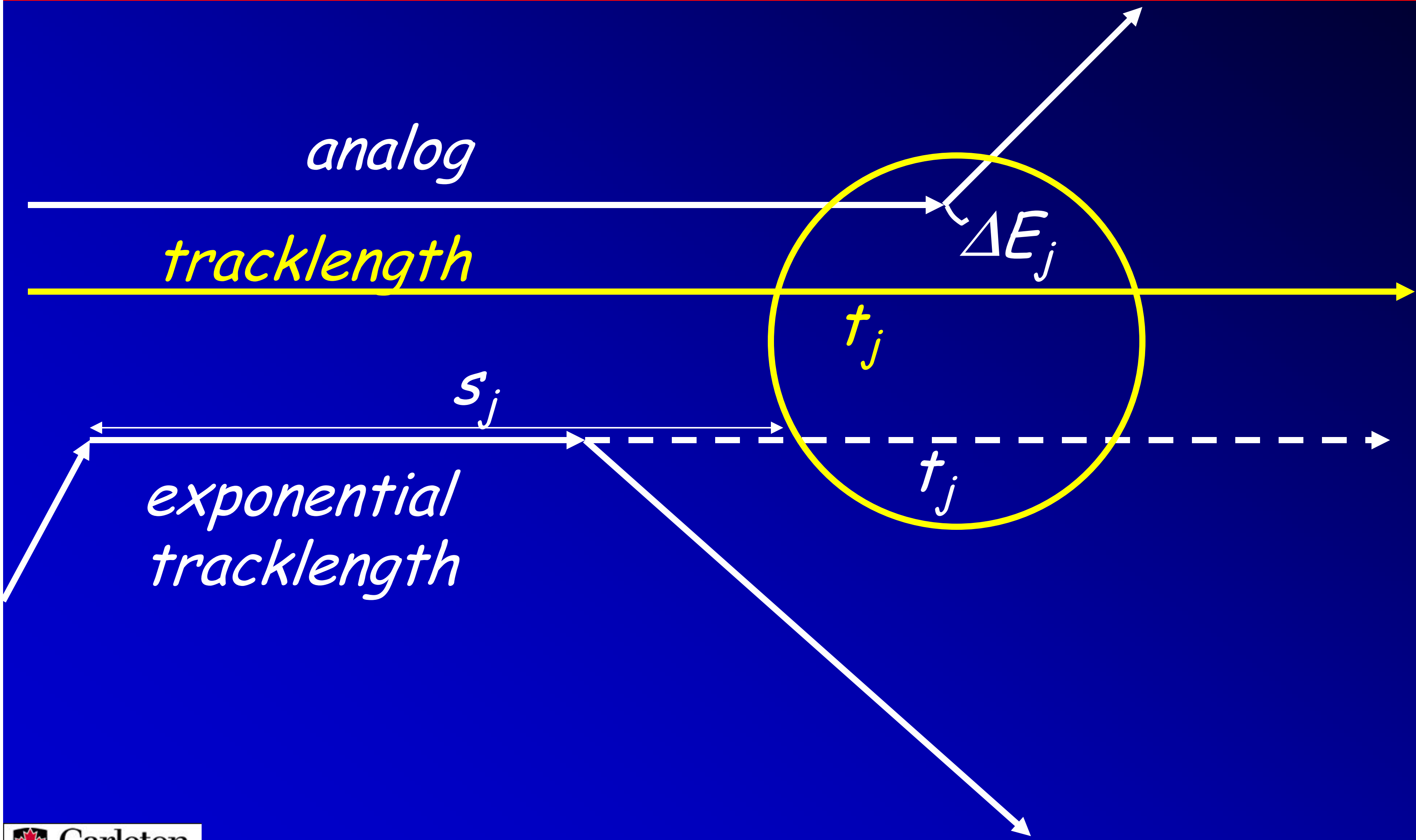
CPU time same

BrachyDose code



⟹ use history by history scoring

Kerma estimators



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Exponential tracklength estimator

$$K_i = \frac{1}{m_i} \sum_j E_j \left(\frac{\mu_{en}}{\mu}\right) e^{-\mu s_j} \left(1 - e^{-\mu t_j}\right)$$

- tracklength estimator scores for every track which actually crosses the region
- exponential tracklength estimator scores on every track which would have crossed the region
- if interaction in or past volume $s_j = 0 \Rightarrow e^{-\mu s_j} = 1.0$
- 'thin voxel' $\Rightarrow \mu t_j \ll 1 \Rightarrow \left(1 - e^{-\mu t_j}\right) \approx \mu t_j$
- for interaction in a thin voxel, same as tracklength estimator

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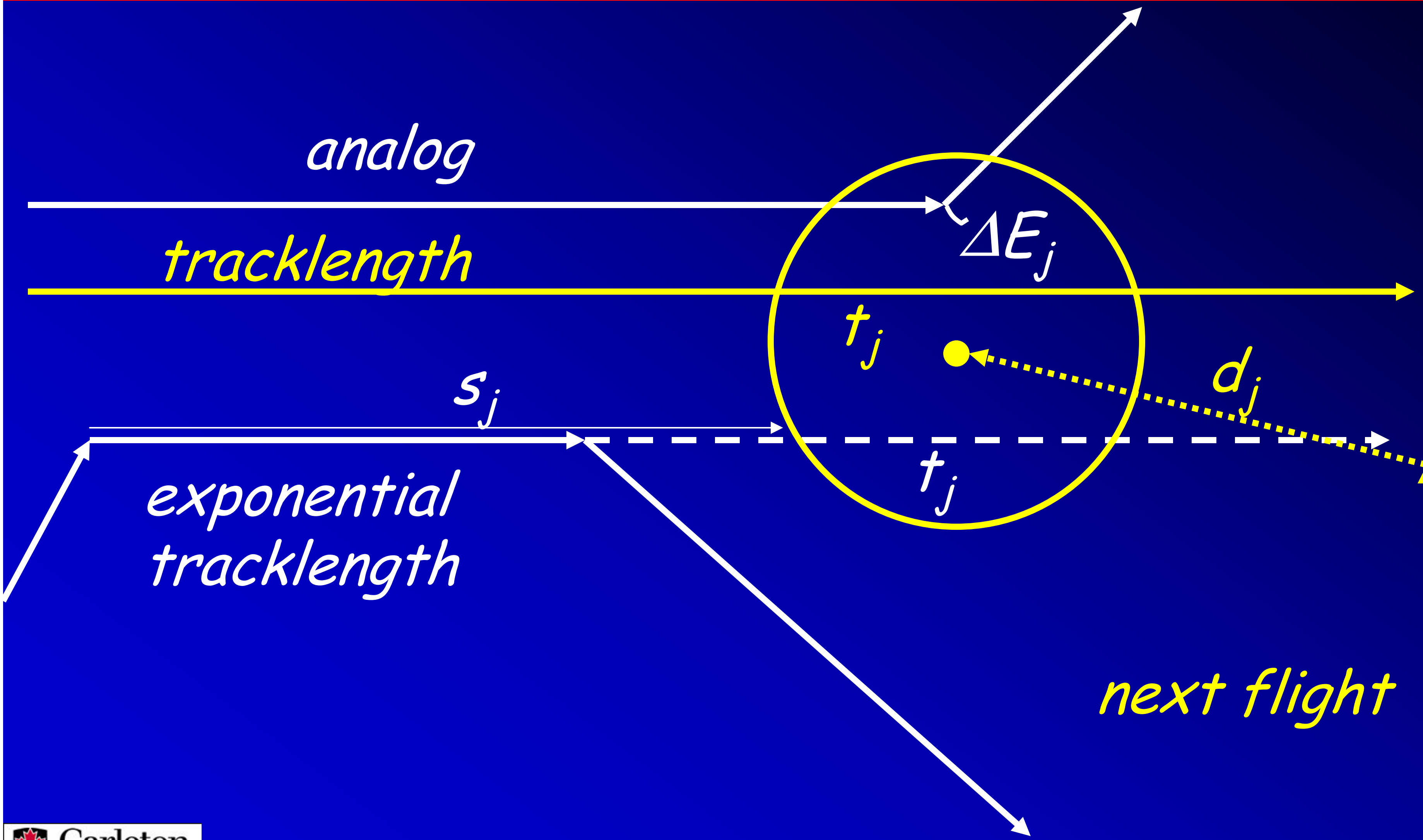
Next flight estimators



Next flight estimators (cont)

$$K = \frac{\sum_i E(\theta_i) P(\theta_i | E_{i-1}) e^{-\mu d_i} \left(\frac{\mu_{en}}{\rho}\right)}{d_i^2}$$

Estimates the kerma at a point - previous are voxel averages

At each interaction, determine angle, θ_i, to point of interest & probability per unit solid angle of a photon of energy E_{i-1} scattering to that direction. Energy-angle relationship =>$E(\theta_i)$

$$P(\theta_i | E_{i-1}) = \frac{\frac{d\sigma}{d\Omega}(\theta_i, E_{i-1})}{\sigma}$$

Problem: interactions for which d_i near 0

=> large fluctuations

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Bounded next flight (BNF) estimators

Consider a sphere of radius R around point of interest

$d_i < R$

$$K = \frac{\sum_i 3E(\theta_i)P(\theta_i|E_{i-1})\left(1 - e^{-\mu R}\right)\left(\frac{\mu_{en}}{\rho}\right)}{\mu R^3}$$

$d_i > R$

$$K = \frac{\sum_i E(\theta_i)P(\theta_i|E_{i-1})e^{-\mu d_i}\left(\frac{\mu_{en}}{\rho}\right)}{d_i^2}$$

where we have replaced $e^{-\mu d}/d^2$ with its mean value within R, assuming there are uniform interactions within R.

This is the workhorse method used in Williamson's code for TG43 parameters.

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Once more collided flux estimators (OMCFE)

- BNF requires uniform interactions within R
  - does not work close to small sources with steep gradients
  - does not work near interfaces
- OMCFE is basically a next flight estimator
  - resamples a step if it ends within R
  - changes the weight and then does next flight estimate for that collision
  - but tracks the history using the originally sample collision point

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No photo-electric absorption

- improve efficiency by not terminating histories via photo-electric events
  - sample distance to interaction from σ_t
  - select interaction type ignoring σ_{pe}
  - reduce weight = probability particle has escaped a terminal event

$$W_i = W_{i-1}\left(1 - \frac{\sigma_{pe}(E_{i-1})}{\sigma_t(E_{i-1})}\right)$$

  - energy deposition

$$\Delta E = W_{i-1}E_{i-1} - W_i E_i$$

    - consider compton scatter

$$E_i \approx E_{i-1} \Rightarrow \Delta E = W_{i-1}E_{i-1}\frac{\sigma_{pe}}{\sigma_t}$$

  - other estimators, multiply by W_i

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Calculating TG43 parameters: S_K

K_{air} at 10 cm on the bisector, in vacuum

- issues
  - air attenuation or not? - definition is in vacuum
  - low energy (4.5 keV) Ti x-rays
    - no effect in water
    - large effect on K_{air} since (μ_{en}/ρ) large at 5 keV
    - decision to exclude using thin Al sheet
  - on-axis or area of wide angle free air chamber (WAFAC)
    - definition, TLDs, clinical ion chambers all on-axis
    - primary standard is WAFAC

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Calculating TG43 parameters: g(r),F(r,θ)

K_{water} throughout the medium D(r,θ)

$$g_X(r) = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \frac{G_X(r_0\theta_0)}{G_X(r,\theta_0)}$$

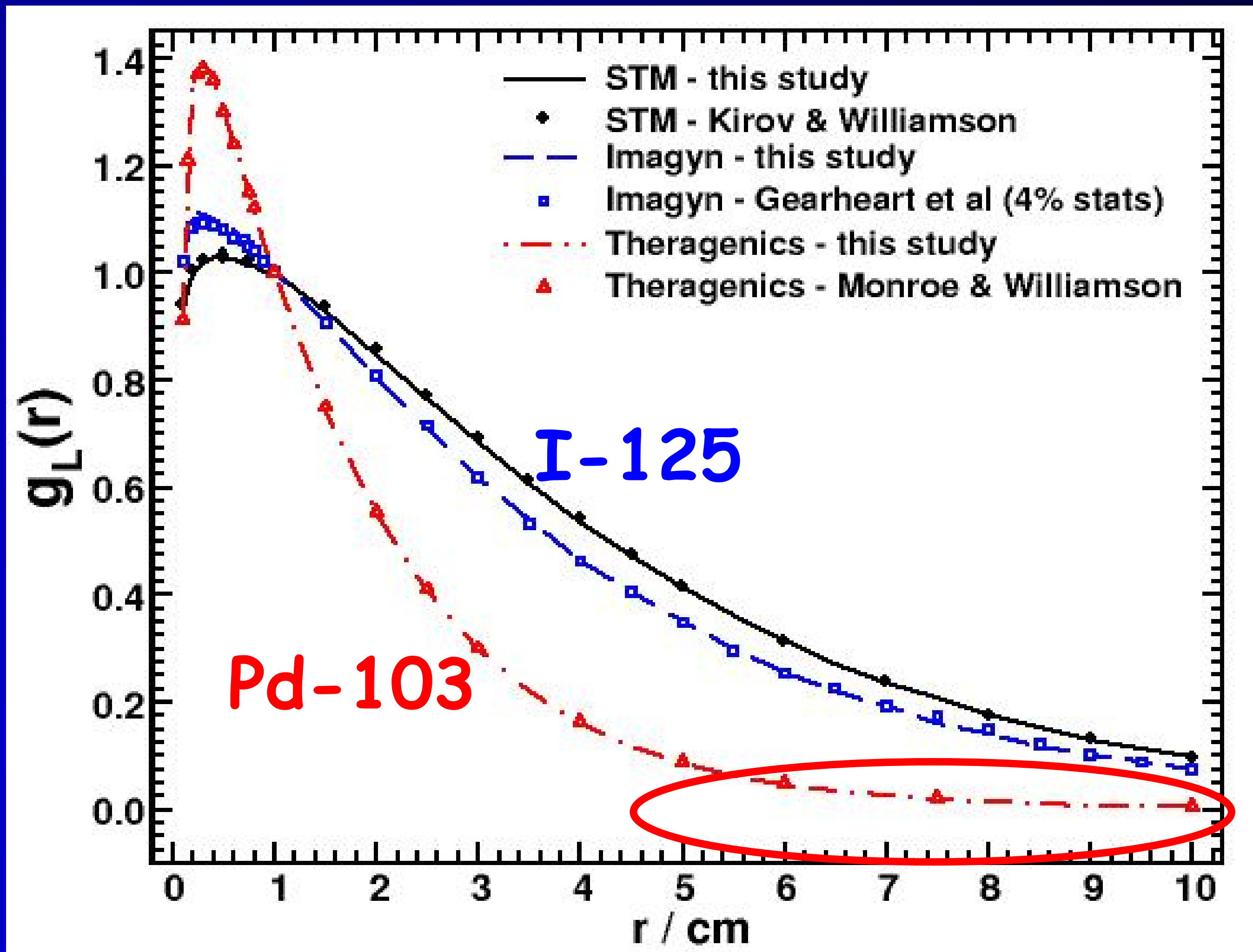
$$F(r,\theta) = \frac{\dot{D}(r,\theta)}{\dot{D}(r,\theta_o)} \frac{G_L(r,\theta_o)}{G_L(r,\theta)}$$

r_o = 1 cm, θ_o = 90°

- issues
  - what G(r,θ) to use: line or point: consistency critical
  - voxel size effects if using voxels
  - what is the medium?
    - water for the TG43 parameters (is this the best?)
    - experiments in plastics/"solid-virtual water" etc
  - size of phantom (must be big enough)

(see Melhus & Rivard Med Phys 33 (2006)1729-1737)

g(r) – radial dose function



Δ = 3%,6%, 16%

Taylor et al, Med Phys 34(2007) 445-457

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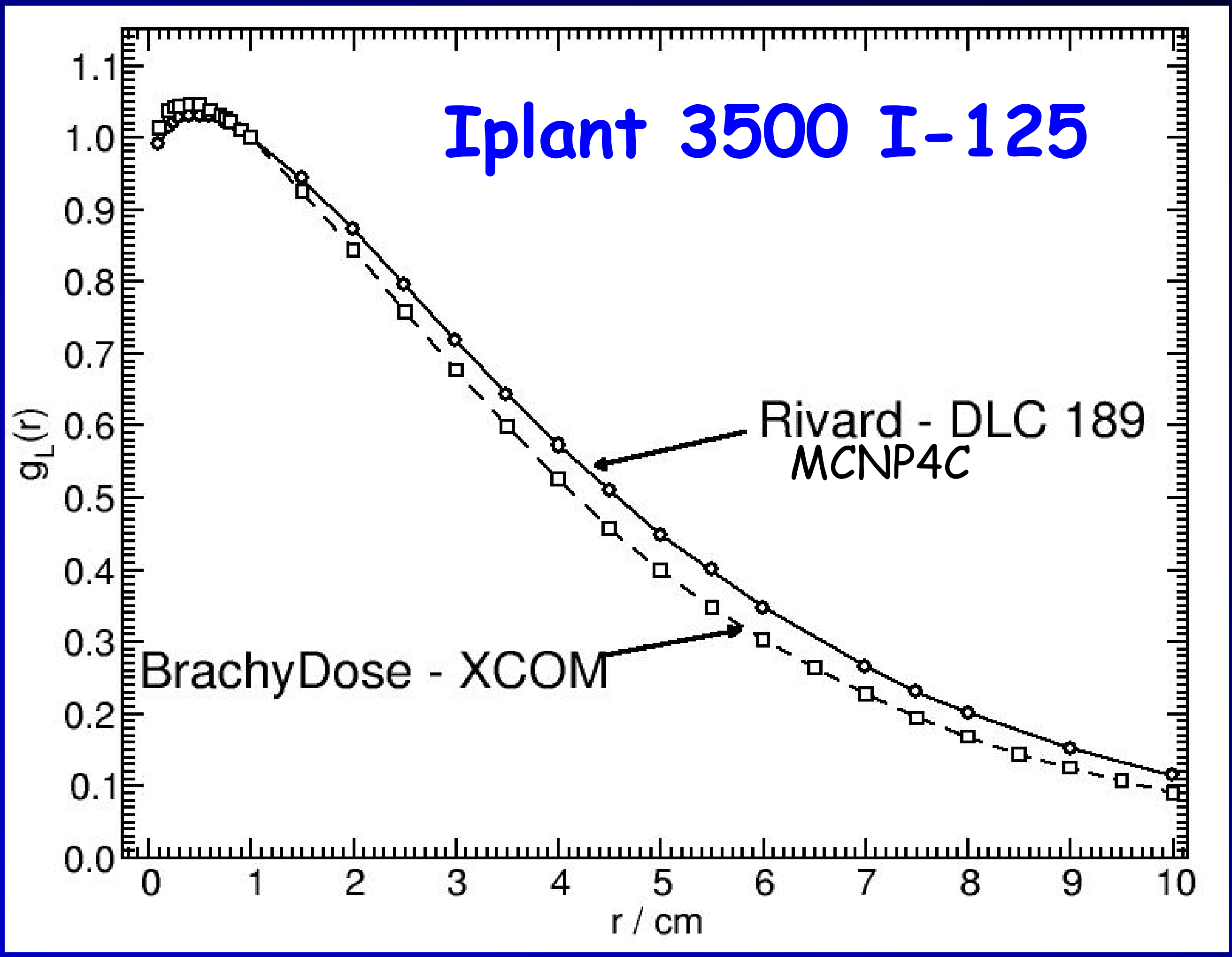
Effect of cross sections

DLC-189/200
in MCNP4B/C

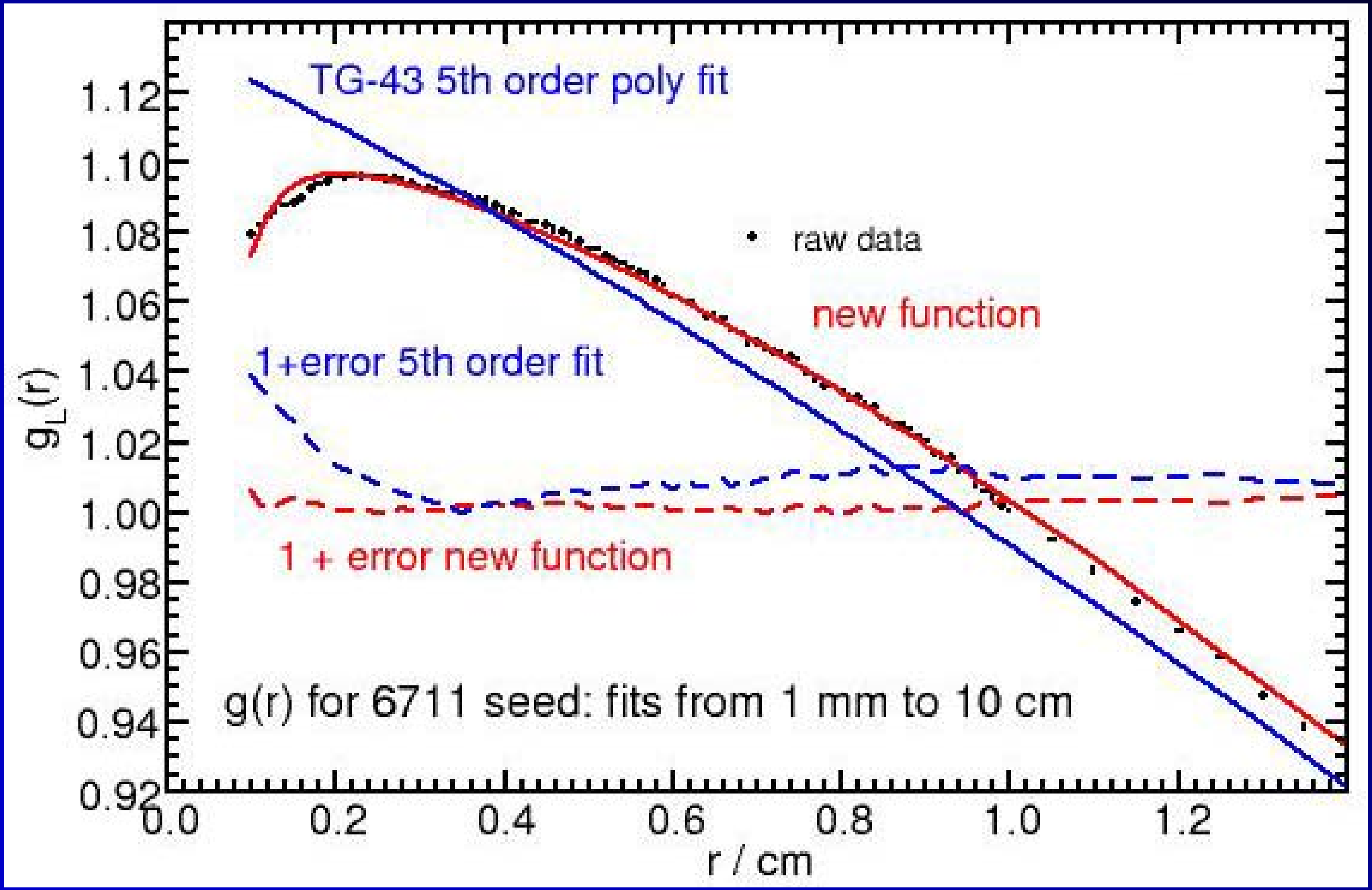
μ low by 5-6%
DeMarco et al
PMB **47** (2002)1321

XCOM
considered
state-of-art
(DLC-136/146/174)



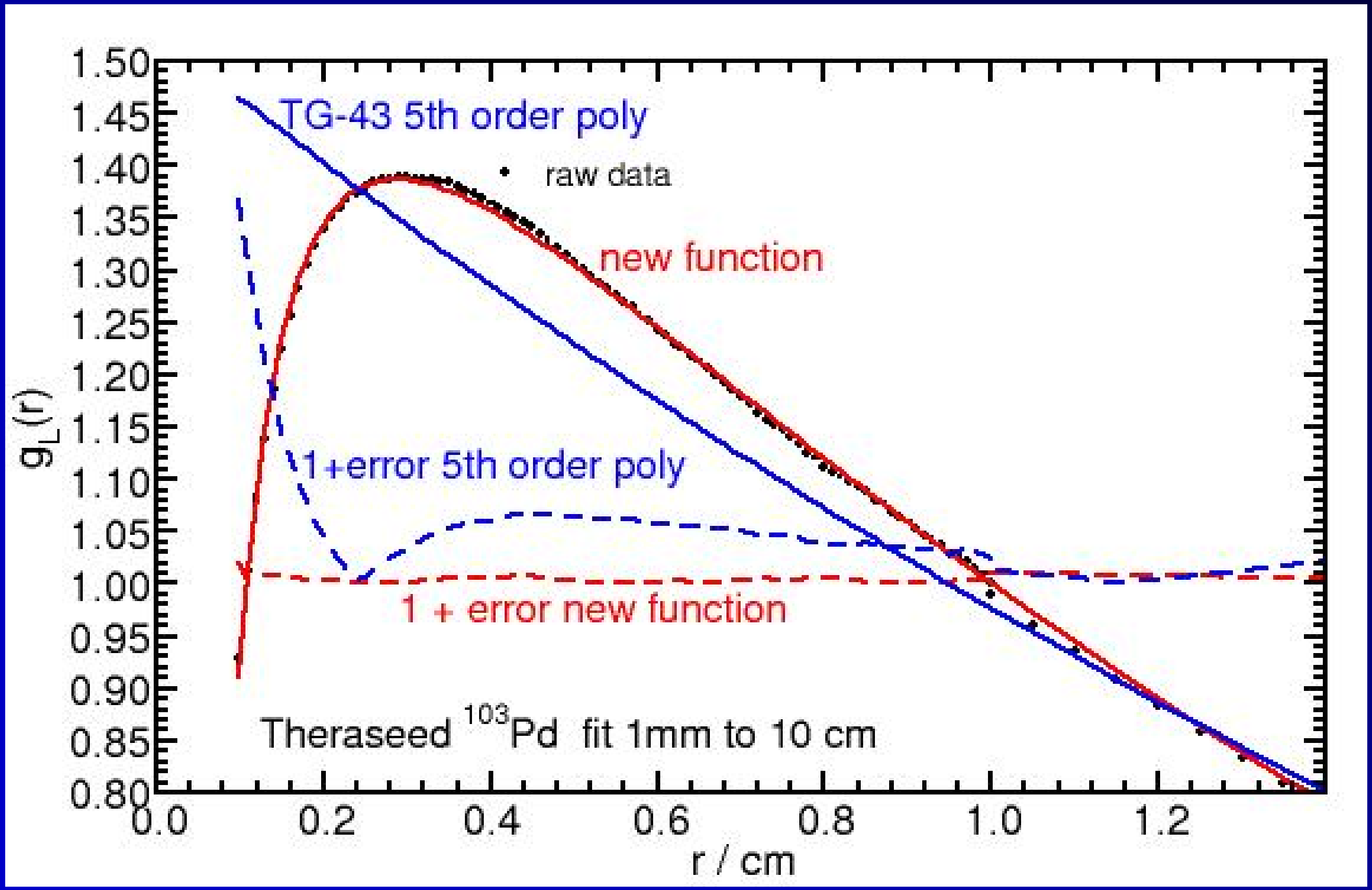
Λ is 2% too high for this seed with MCNP

Improved fitting function for g(r) data



Taylor and Rogers, in preparation, 2007

Improved fitting function for g(r) data



If fitting from 5 mm to 10 cm, then 5-th order polynomial is perfect.

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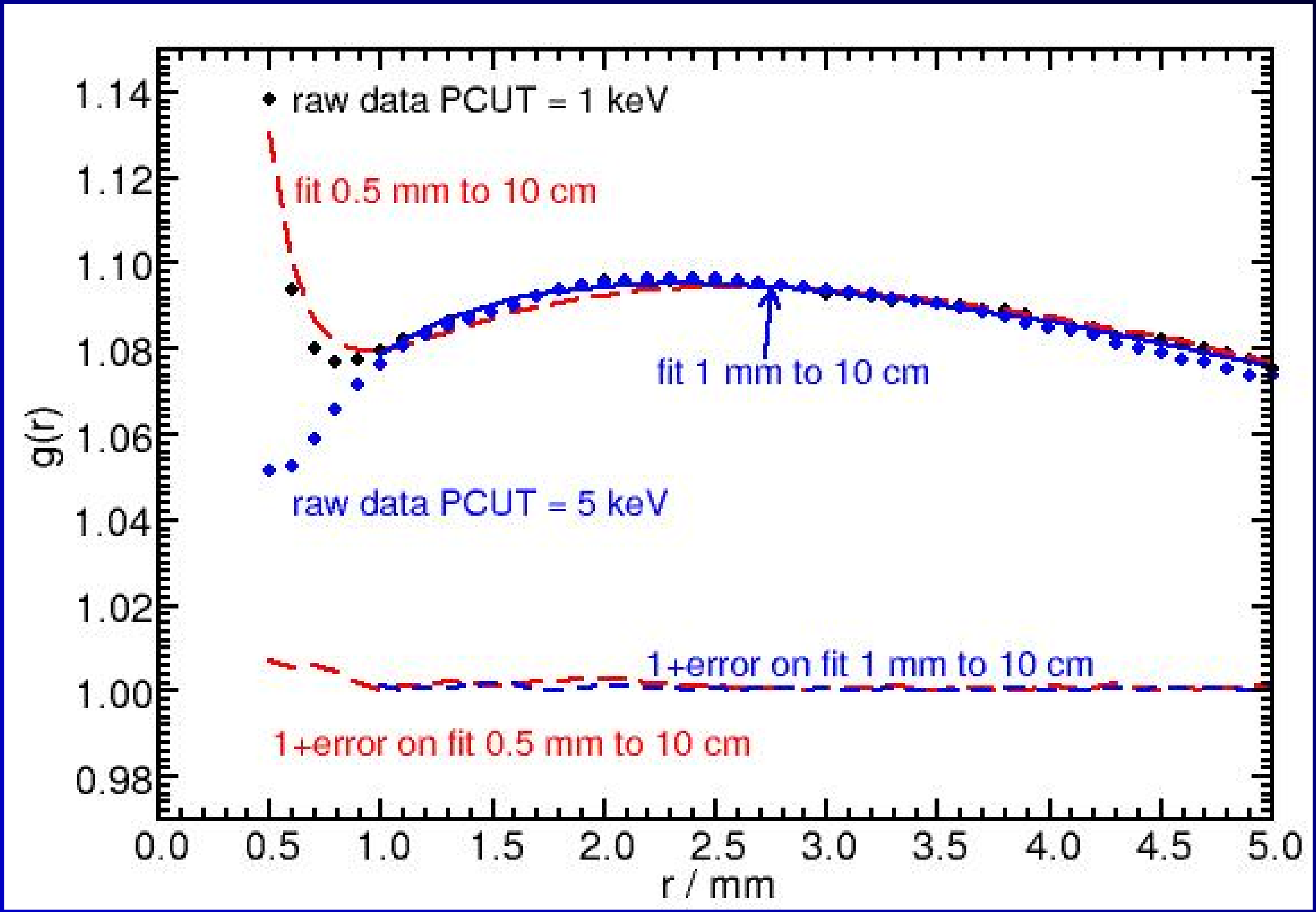
Improved fitting function for g(r) data

The new fitting function handles the upturn



Upturn is from Ti x-rays and/or from geometry effects

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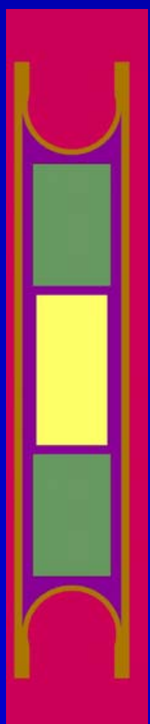
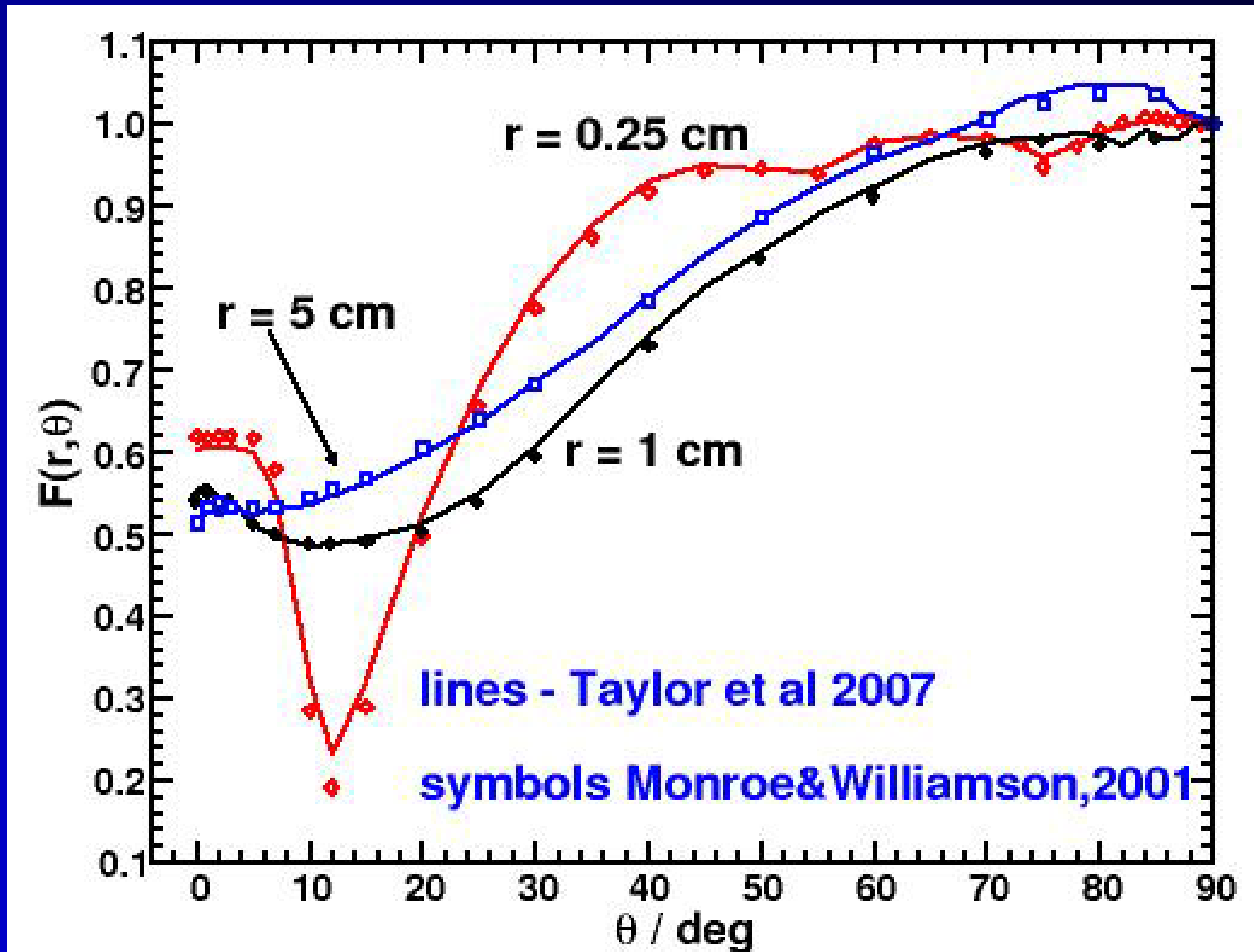
F(r,θ): Theragenics 200 Pd-103

^{103}Pd Source
Theragenics
Model 200





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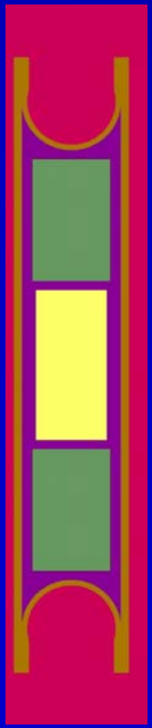
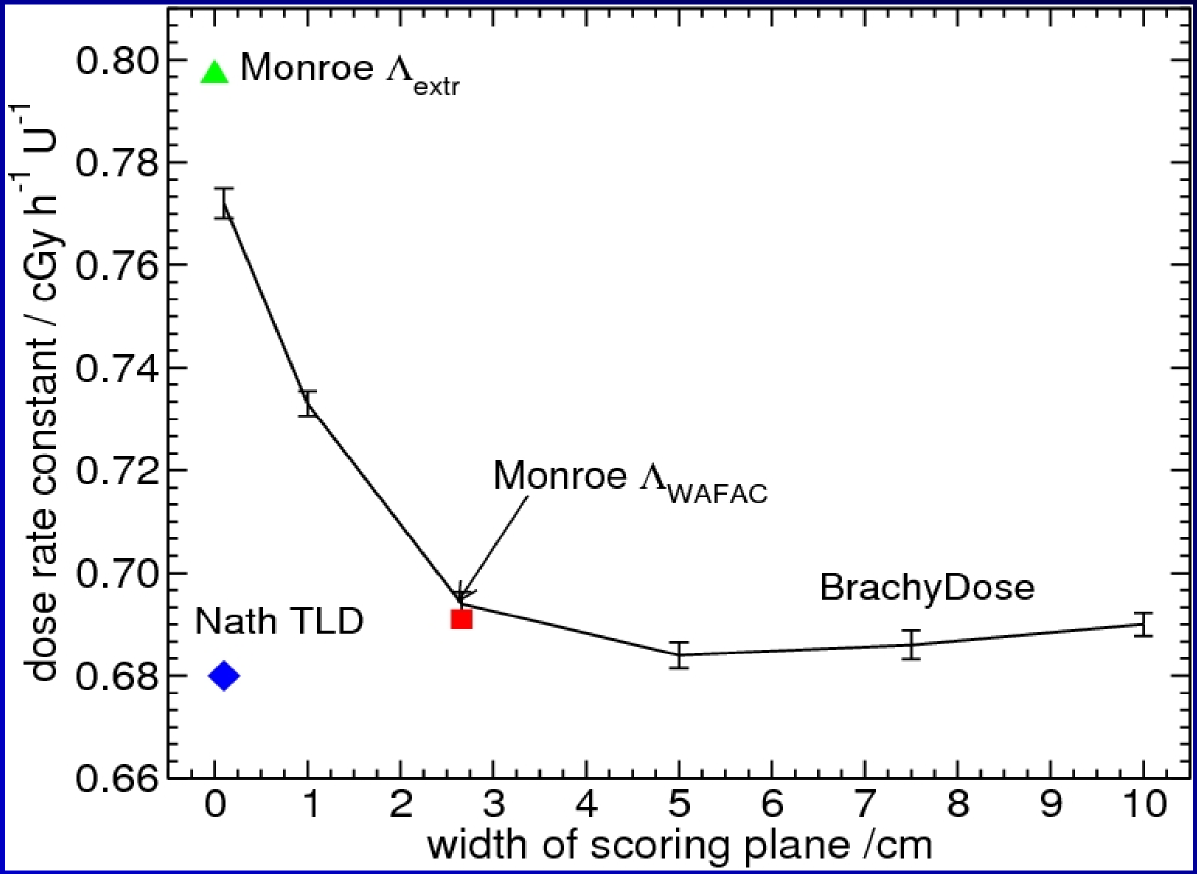
Taylor et al, Med Phys 34(2007) 445-457

Λ – dose-rate constant

Dose to water at reference point divided by air-kerma strength

^{103}Pd Source
Theragenics
Model 200





scoring plane at 10 cm from source

Taylor et al, Med Phys 34(2007) 445-457

BrachyDose

- a code for calculating dose distributions in a voxel CT phantom with brachytherapy sources
- code is based on Yegin's MG (multi-geometry) package and EGSnrc
- detailed models of multiple seed types at multiple locations and orientations
- can handle x-ray sources since based on EGSnrc
- code is very fast

Similar code: MCPI Chibani & Williamson

Med Phys 32(2005)3688-3698

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Yegin's Multi-Geometry package

Available online at www.sciencedirect.com

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Nuclear Instruments and Methods in Physics Research B 211 (2003) 331–338

NIM B
Beam Interactions with Materials & Atoms

www.elsevier.com/locate/nimb

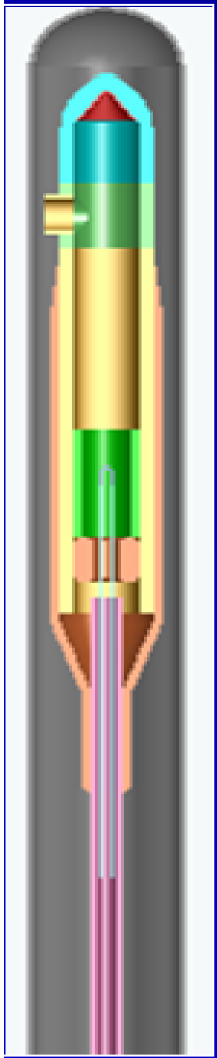
A new approach to geometry modeling for Monte Carlo particle transport: An application to the EGS code system

Gultekin Yegin *

Department of Physics, Faculty of Arts and Sciences, Celal Bayar University, TR-45030 Manisa, Turkey

Received 22 May 2002; received in revised form 10 April 2003

Features of BrachyDose



- have modelled most (all?) major seeds
- ability to extract TG-43 parameters easily
  - benchmarked against previous TG-43 work
  - studied voxel size effects (Taylor et al, Med Phys 34(2007) 445-457)
- ability to use a CT dataset
- scores spectrum in any voxel
- models 50 kV brachytherapy x-ray source
  - VRT increased efficiency by factor of 10^4
- ability to use a phase space source
- models Ir-192 HDR in catheters
- adjust cross sections for sensitivity analysis

BrachyDose: speed-up features

- use pathlength scoring (factor of 15 over analog)
- reuse photons escaping from one seed for every seed (20% for 1mm, 28% for 3mm)
- fast table lookups of mass energy absorption coefficients (5% speed up)
  - use same approach as EGSnrc (log interpolation, small energy increments)
  - use XCOM data base for EGSnrc
- virtual geometry to reduce checks on seeds (large speed up)

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BrachyDose: timing

- for average uncertainty of 2% on dose in each voxel in implant (g77 compiler - single 3.0 GHz 64 bit CPU)
  - 3 mm voxels: 14 s
  - 2 mm voxels: 30 s
  - 1 mm voxels: 228 s

i.e., 3.5 min for 1 mm voxels

- and with an Intel compiler it is expected to be faster based on previous experience

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Voxel size effects

- Williamson's code uses a point estimator
- when using voxels one must be careful

$$D_{\text{vox}} = \frac{1}{\Delta r} \int_{r_o - \frac{\Delta r}{2}}^{r_o + \frac{\Delta r}{2}} dr\, D(r)$$

i.e., dose is averaged over voxel

$$D_{\text{vox}} = D(r_o)\left[1 + \frac{D''(r_o)}{24 D(r_o)} \Delta r^2 + O(\Delta r^4)\right]$$

Kawrakow
MP 33(2006)1829

For $1/r^2$

$$D_{\text{vox}} \approx D(r_o)\left[1 + \frac{\Delta r^2}{4 r_o^2}\right]$$

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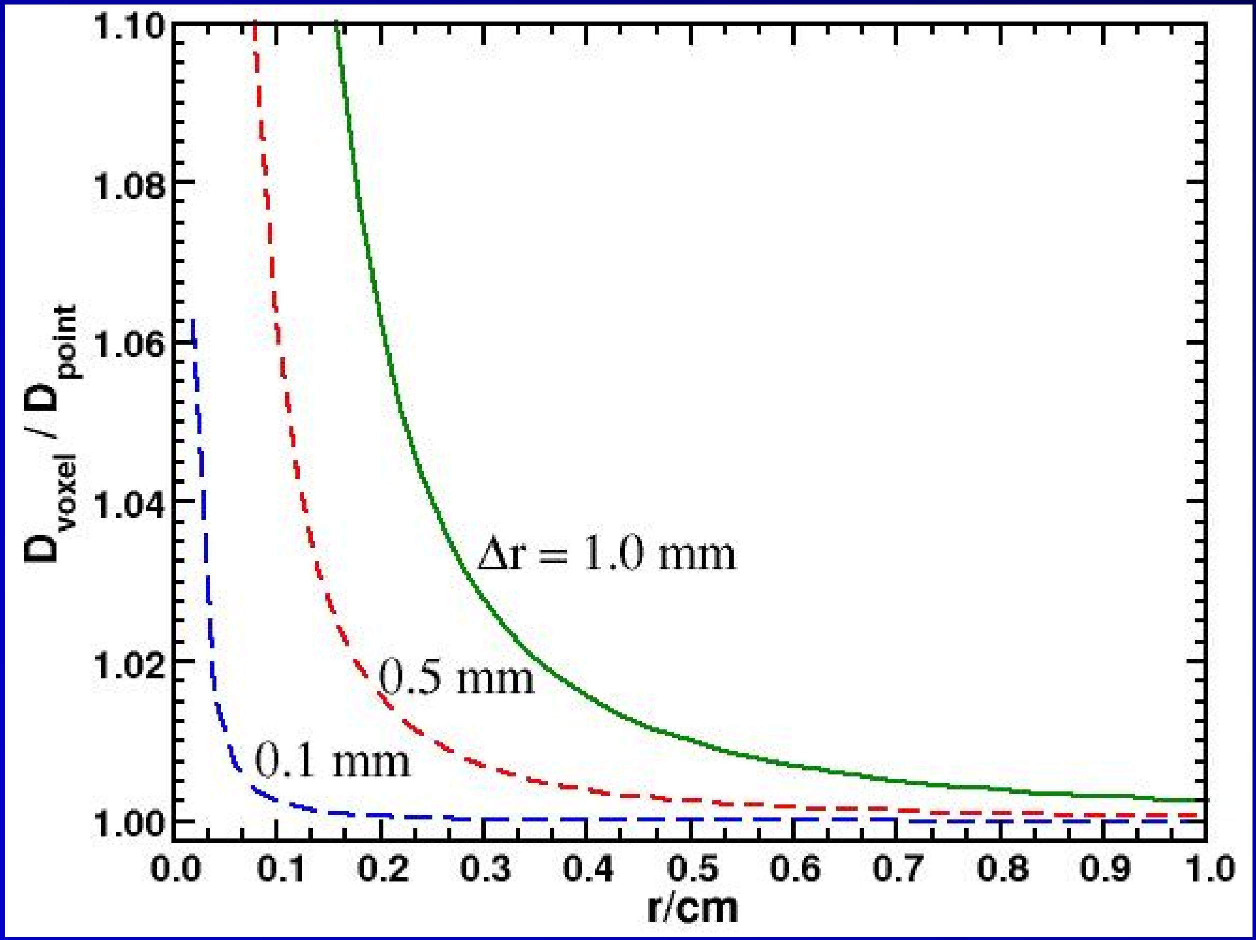
Voxel size effects

Size of error in associating the average dose in the voxel with the dose at the mid-point (near a point source)



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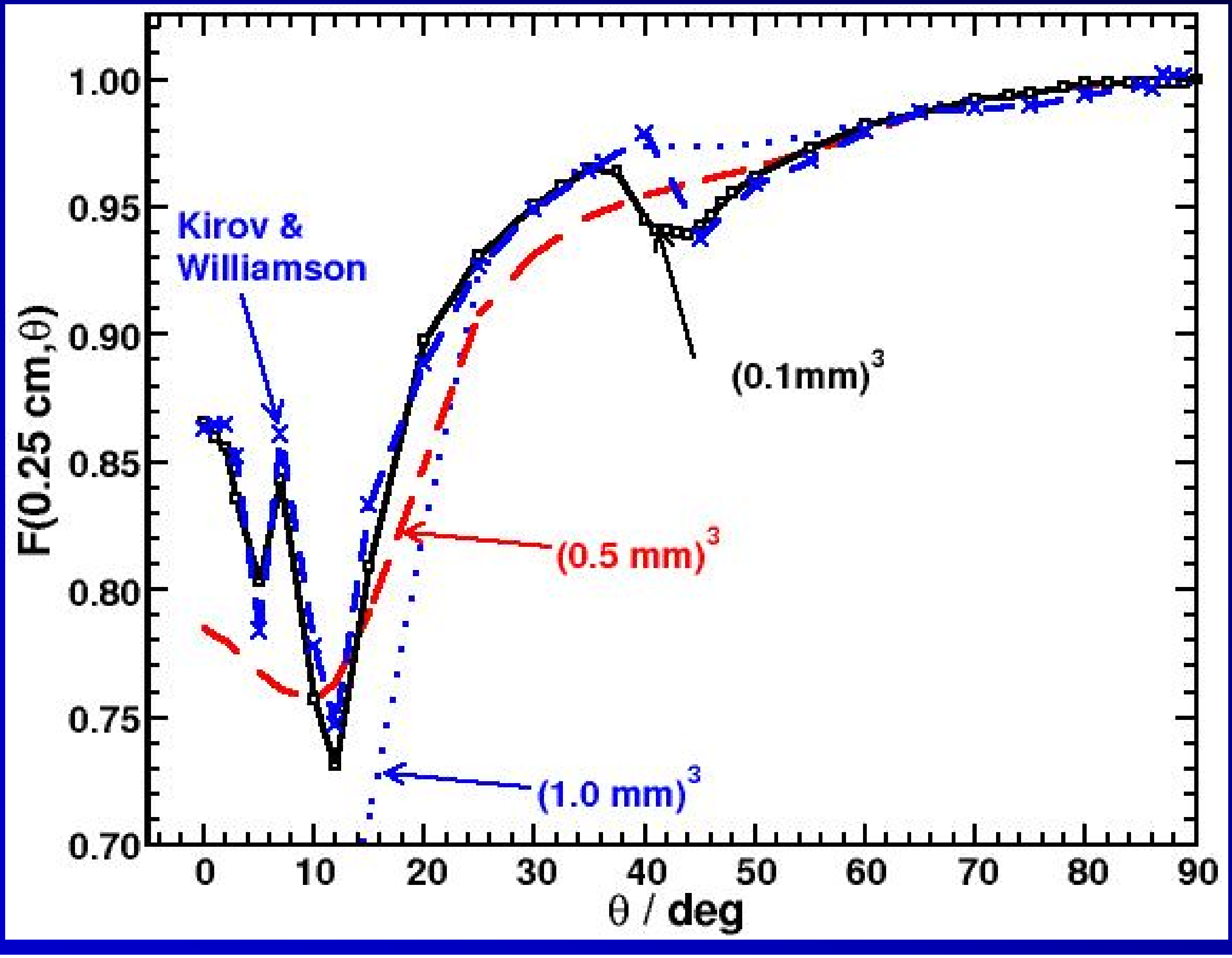
Voxel size effects

^{125}I

Source Tech Medical STM125I



Taylor et al, Med Phys 34 (2007) 445 - 457

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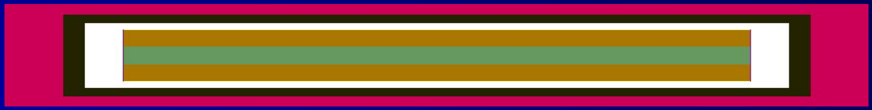
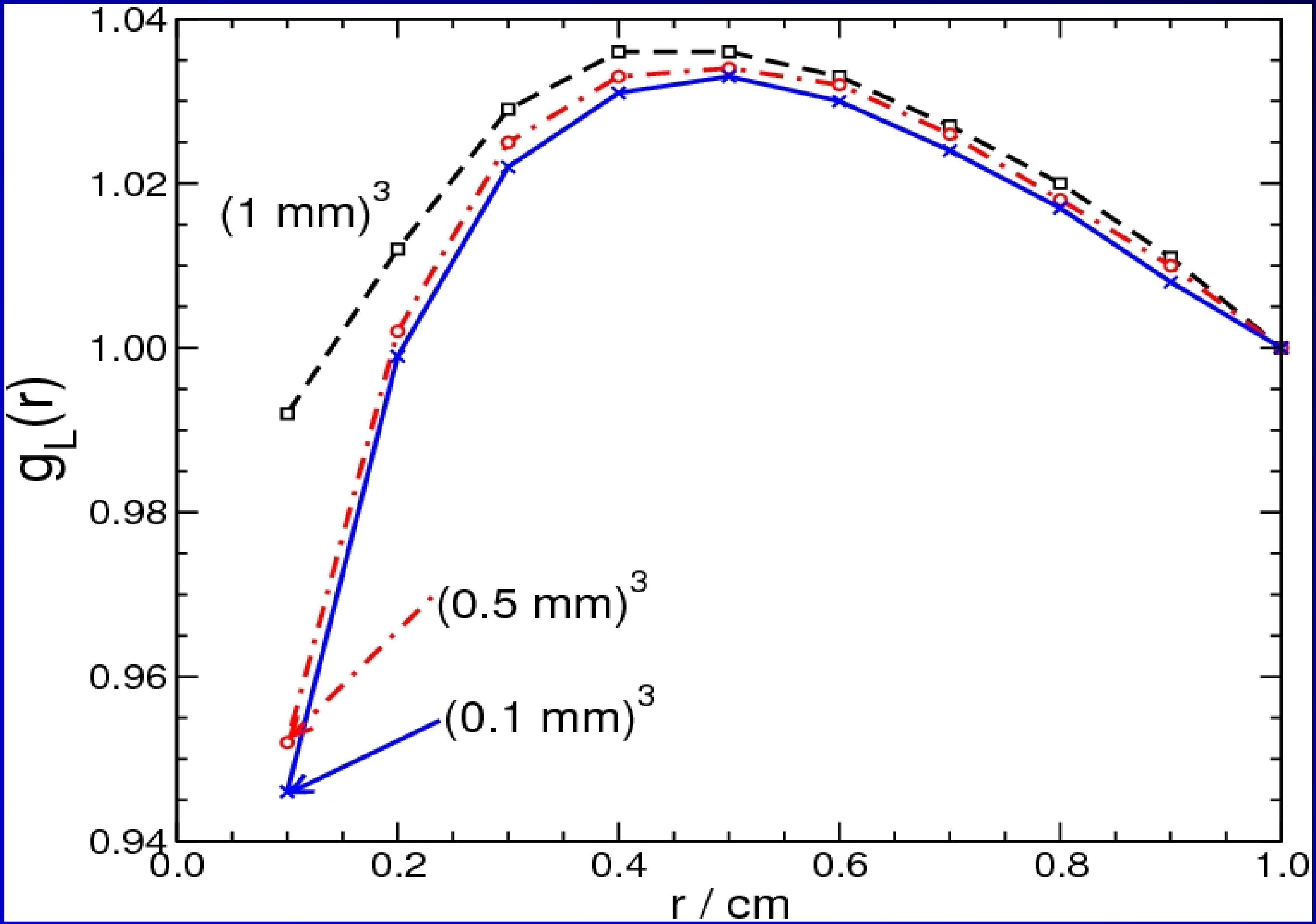
Voxel size effects

125I



Source Tech Medical STM125I



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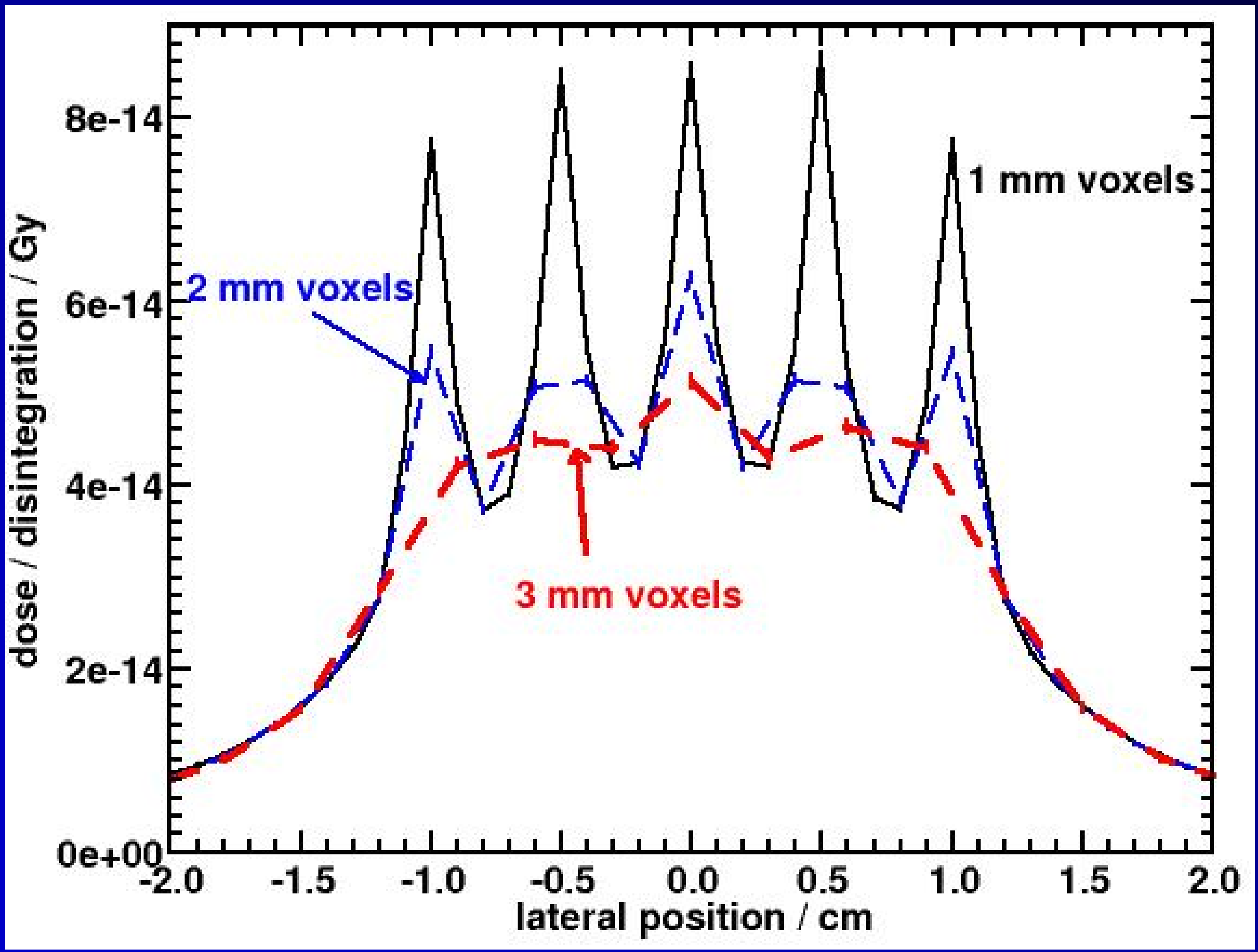
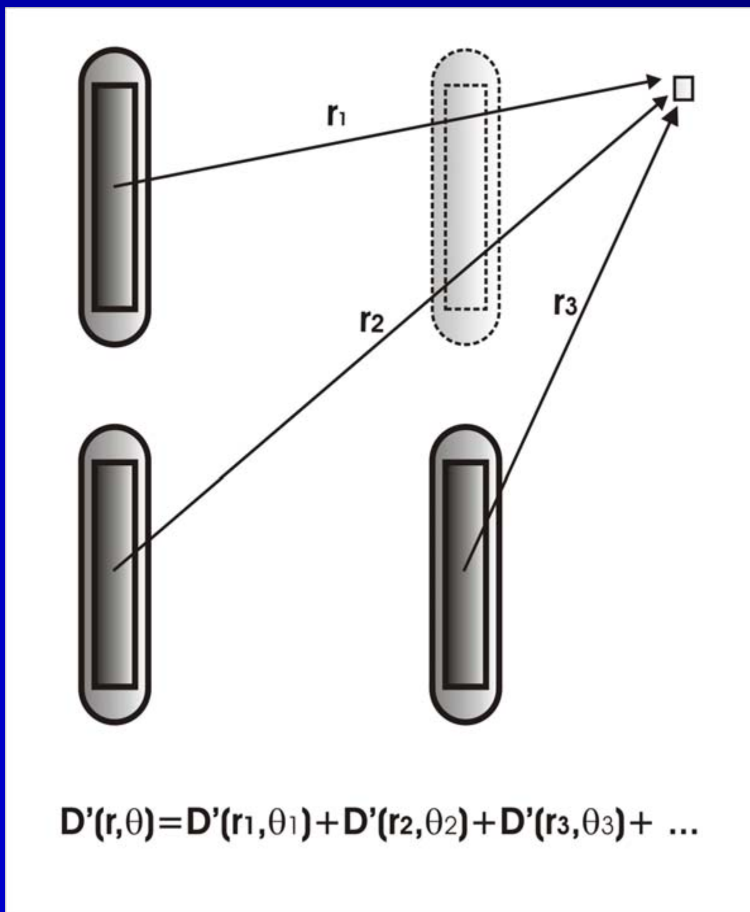
Voxel size effects



recall slide 7 showed voxel size effects on DVHs

Inter-seed effects in brachytherapy

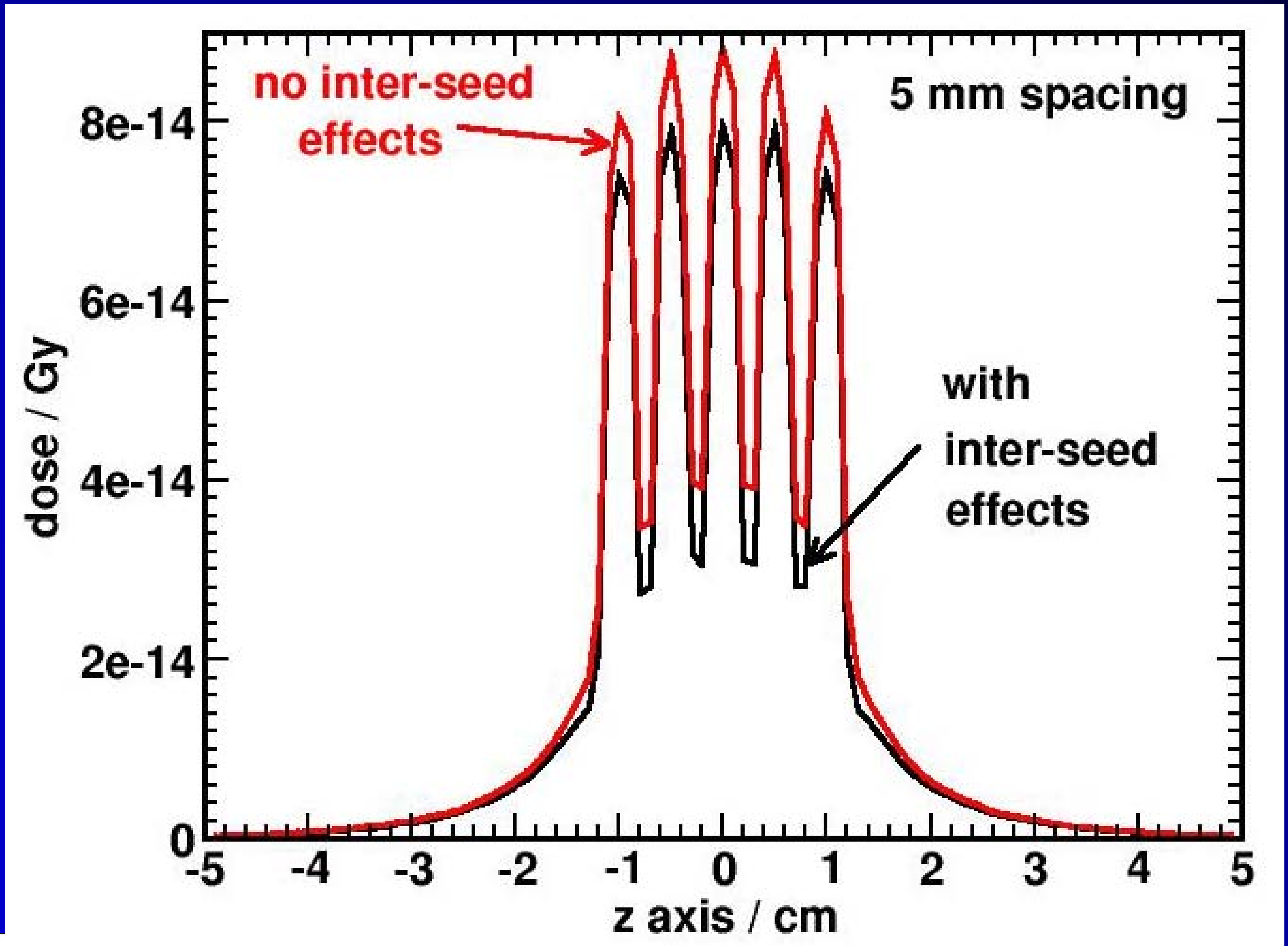


Standard planning systems ignore self-shielding

A few papers have investigated inter-seed effects.

Chibani and Williamson, (Med Phys 2005) used MCNP. Each calculation took 3 days.

central axis dose for 5 mm spacing



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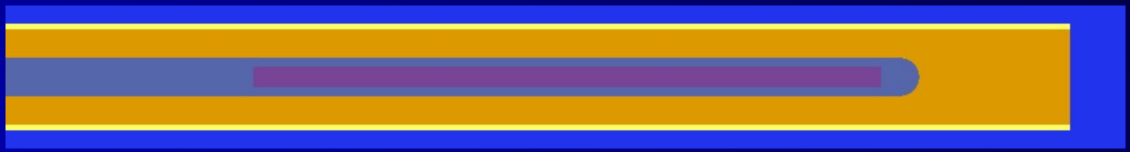
inter-seed effects

- doses vary by as much as
  - 27% in valley
  - 10% near peak
- can be misleading since volumes near peaks are often small in these regular patterns
- close to worst case (seeds are 3.6% of volume compared to 0.5% for 10 mm spacing)

inter-seed effects (cont)

- total energy deposited in implant
  - 5 mm spacing -down 13%
  - 10 mm spacing -down 2.8%
- total energy deposited in nearby "critical organ"
  - 5 mm spacing -down 13%
  - 10 mm spacing -down 3%
- difference is more important than the absolute value since dose prescription determined by experience

^{192}Ir source in catheters



- can model an HDR source inside a catheter
- the source moves to an arbitrary number of positions in an arbitrary number of catheters
- we see no significant effect of the catheters.

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Need for treatment planning

- TG-43 treatment planning assumes infinite water patient with one source at a time
- what are the magnitudes of the effects of
  - other tissues and calcifications
  - air surfaces (for breast treatments)
  - inter-seed attenuation (up to 5-10%)
- treatment planning with BrachyDose based on 3 D CT data sets handles all of these

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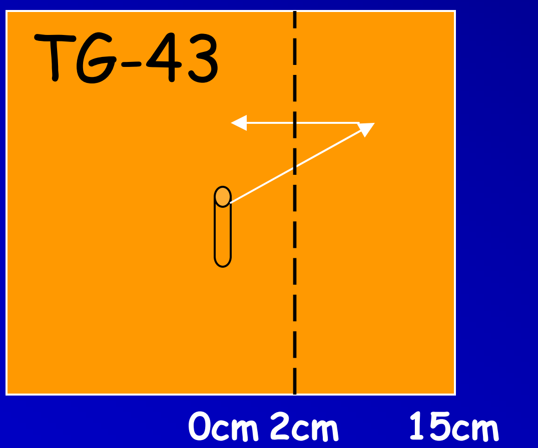
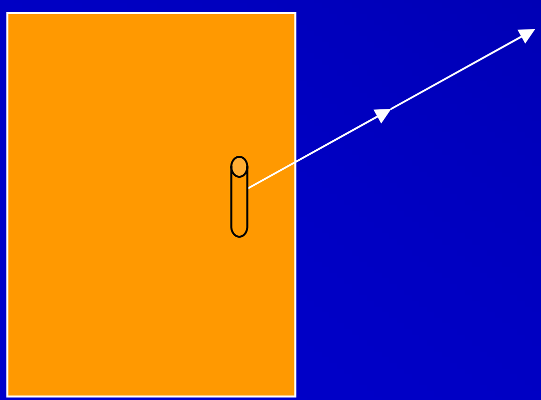
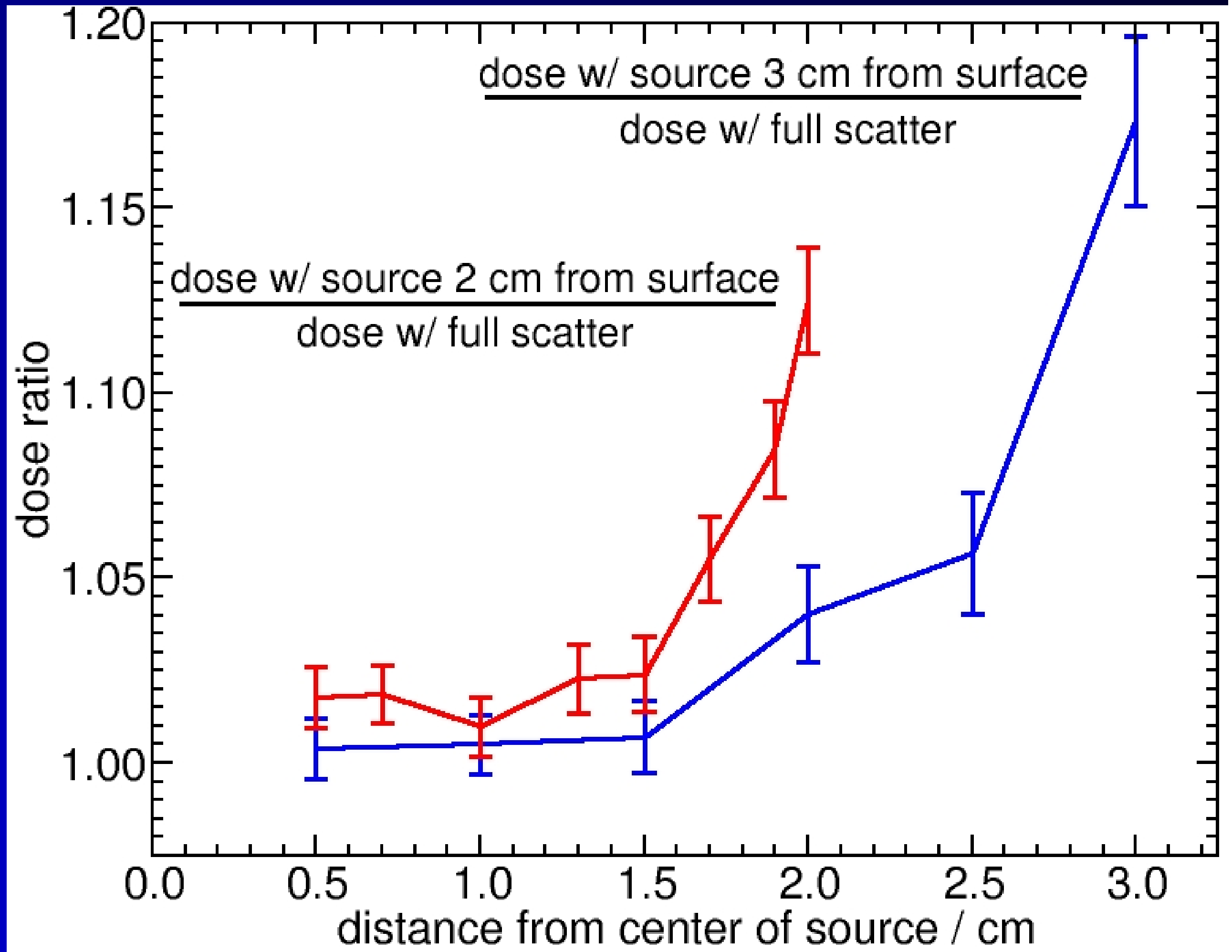
Effect of finite irradiated volume

50kV X-Ray Source







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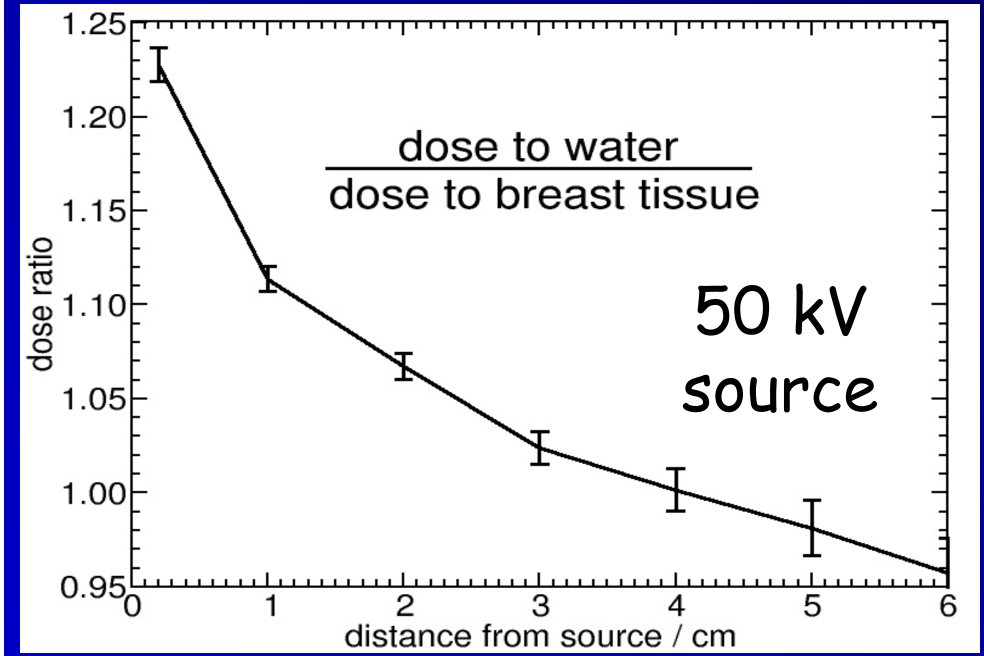
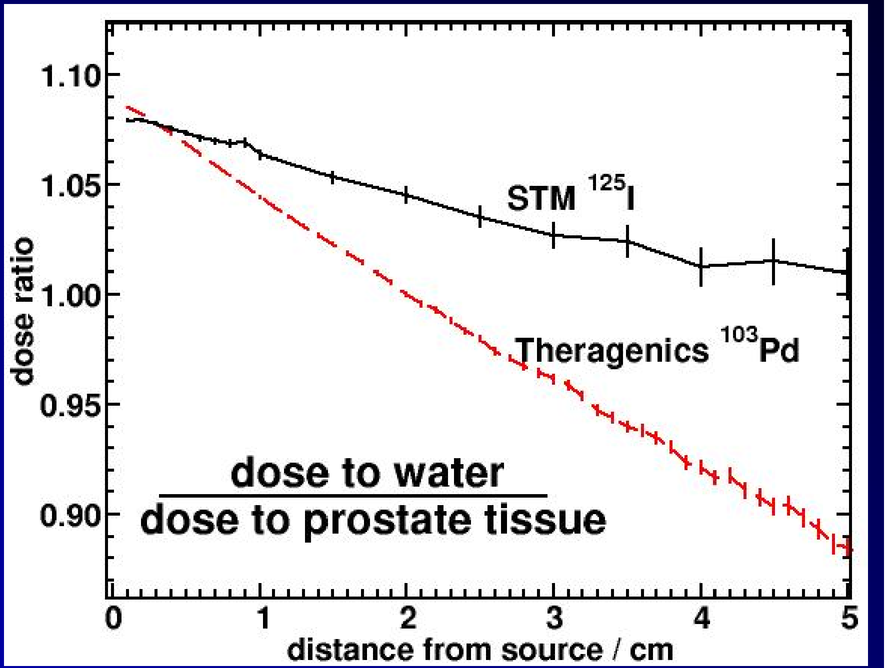
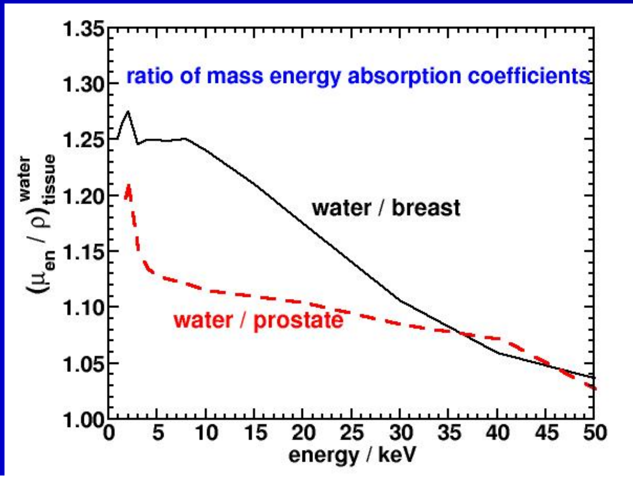
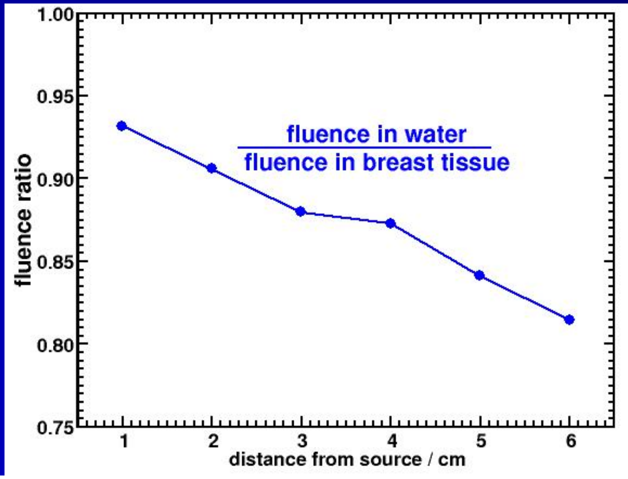
Similar effects for ^{125}I & ^{103}Pd seeds

Effect of realistic tissue









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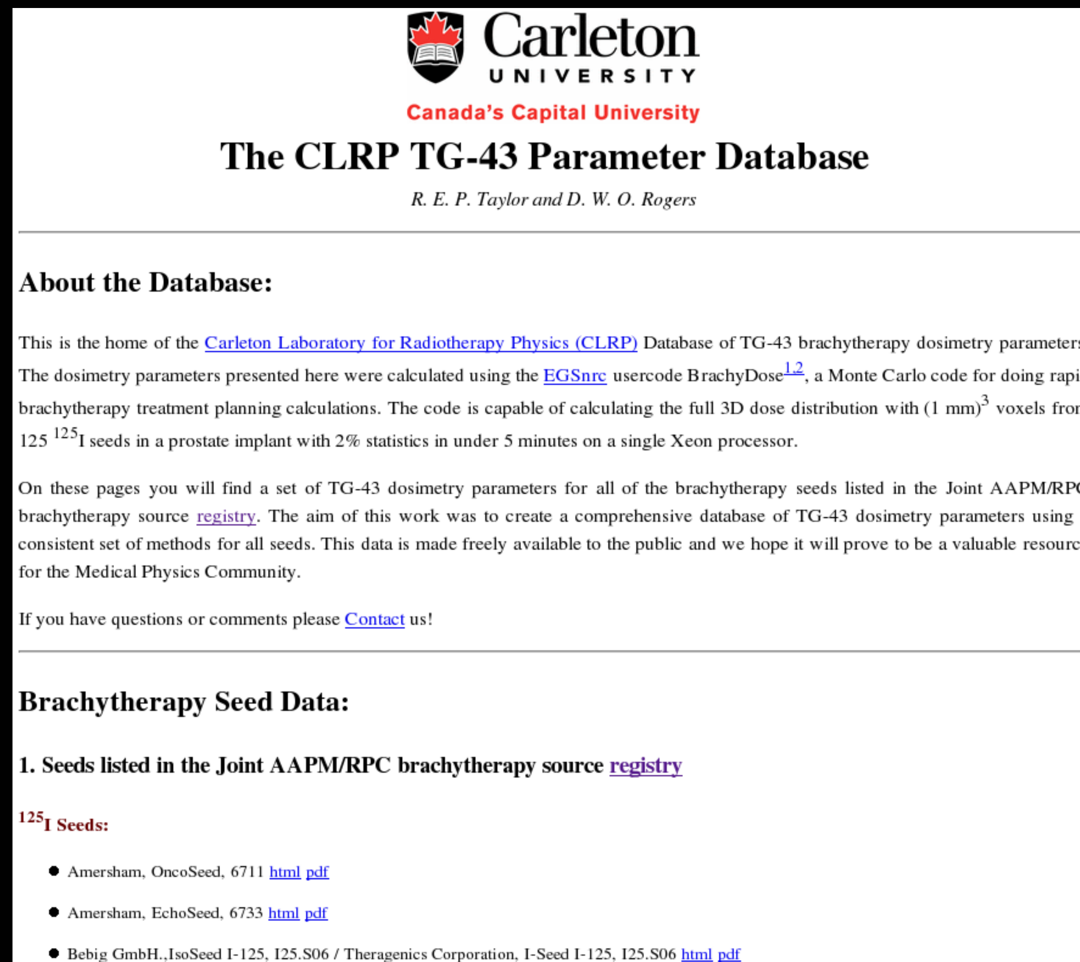
CLRP TG-43 web resource

http://www.physics.carleton.ca/clrp/seed_database

- Full set of tabulated dosimetry data for each source studied
- Description of calculation methods
- Descriptions & scale drawings of sources
- Plots compare values calculated in this study to other results
- Links to relevant papers & websites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The CLRP TG-43 Parameter Database

R. E. P. Taylor and D. W. O. Rogers

About the Database:

This is the home of the Carleton Laboratory for Radiotherapy Physics (CLRP) Database of TG-43 brachytherapy dosimetry parameters. The dosimetry parameters presented here were calculated using the EGSnrc usercode BrachyDose[1,2], a Monte Carlo code for doing rapid brachytherapy treatment planning calculations. The code is capable of calculating the full 3D dose distribution with (1 mm)^3 voxels from 125 ^{125}I seeds in a prostate implant with 2% statistics in under 5 minutes on a single Xeon processor.

On these pages you will find a set of TG-43 dosimetry parameters for all of the brachytherapy seeds listed in the Joint AAPM/RPC brachytherapy source registry. The aim of this work was to create a comprehensive database of TG-43 dosimetry parameters using a consistent set of methods for all seeds. This data is made freely available to the public and we hope it will prove to be a valuable resource for the Medical Physics Community.

If you have questions or comments please Contact us!

Brachytherapy Seed Data:

1. Seeds listed in the Joint AAPM/RPC brachytherapy source registry

^{125}I Seeds:

- Amersham, OncoSeed, 6711 html pdf
- Amersham, EchoSeed, 6733 html pdf
- Bebig GmbH.,IsoSeed I-125, I25.S06 / Theragenics Corporation, I-Seed I-125, I25.S06 html pdf

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CLRP TG-43 web resource

Amersham OncoSeed 6711 ^{125}I Source TG-43 data

Source Description:

The 6711 source consists of radioactive AgI and AgBr coated on a 2.8 mm long cy
the silver rod are conical sections beveled at 45° and the end faces of the rod hav
coating is assumed to have a uniform thickness of 1.75 µm on the cylindrical surf
composition as given in ref. 1. The silver rod is encapsulated in a titanium tube w
0.375 mm thick end welds. The inside of the capsule is filled with air. Overall sou
mm.

Dose Rate Constant - Λ :

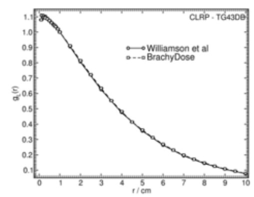
Dose rate constants, Λ , are calculated by dividing the air kerma strength per history
(0.1~mm)^3 voxel centered on the reference position, (1 cm,π/2), in the 30x30x30
constants are provided for air kerma strenth calculated using voxels of 2.7x2.7x0.0
source. The larger voxel size averages the air kerma per history over a region co
primary collimator of the WAFAC[b,c]. The small voxel serves to estimate the air ker

Author	Λ (cG
this study - 0.1x0.1x0.05 cm^3 voxel at 10 cm	
this study 2.66x2.66x0.05 cm^3 voxel at 10 cm	
Williamson[1] (DLC 146)	
Williamson[1] TLD	

Radial dose function - g(r):

The radial dose function, g(r), is calculated using both line and
less than 1 cm from the source and 0.5 cm intervals from 1 cm

Click image for higher res version



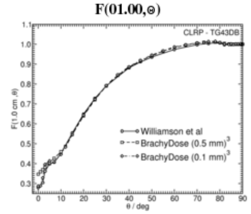
Tabulated g(r) data: html Excel

Anisotropy function - F(r,Θ):

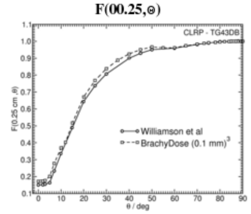
Anisotropy functions are calculated using the line source appro
and 32 unique polar angles with a minimum resolution of 5°. The anisotropy factor, φ_{an}(r), was calculated by integ
weighted dose rate over 0° ≤ θ ≤ 90°.

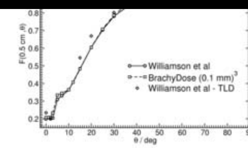
Click images for higher res versions

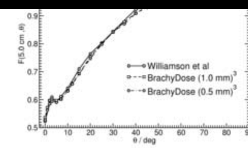
F(01.00,Θ)



F(00.25,Θ)







Tabulated F(r,Θ) data: html Excel

References:

Seed Specific References

1. J. Dolan, Z. Li, and J.F. Williamson, Monte Carlo and experimental dosimtery of an ^{125}I brachytherapy seed, Med. Phys **33** 4675 (2006)

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c. S. M Seltzer *et al*, New National Air-Kerma-Strength Standards for ^{125}I and ^{103}Pd Brachytherapy Seeds, J. Res. Natl. Inst. Stand. Technol., **108**, 337 (2003)

d. R. E. P. Taylor, D.W.O. Rogers, An EGSnrc Monte Carlo calculated TG-43 parameter database, *in preparation*

Back to seed index

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March 30 2007.

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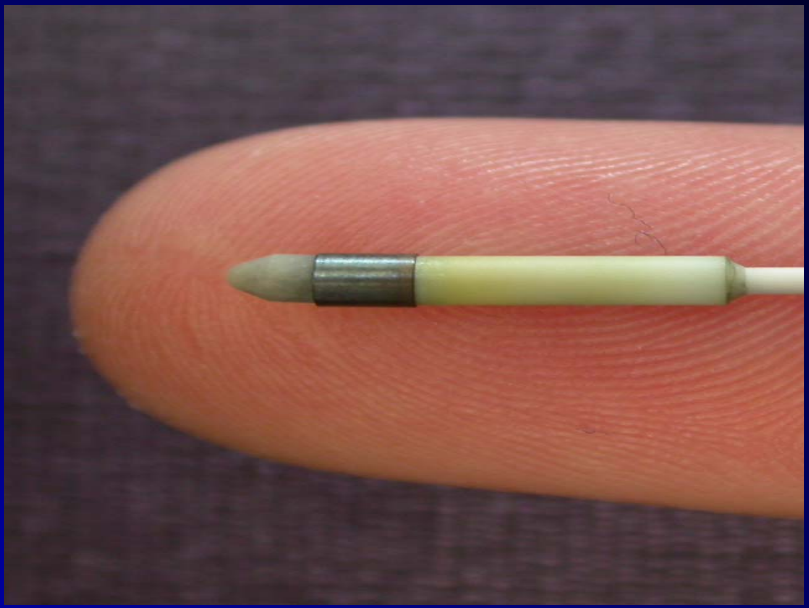
Xoft Axxent X-ray source

- Miniature X-Ray Source
  - 25-50 kV e^- on W target.
  - Lifetime of 5h w/ beam on
- "Tunable" dose rates
- Reduced shielding requirements
- Source can be turned on/off
- FDA Approved – Jan 2006

•EGSnrc can handle this unlike other brachytherapy codes



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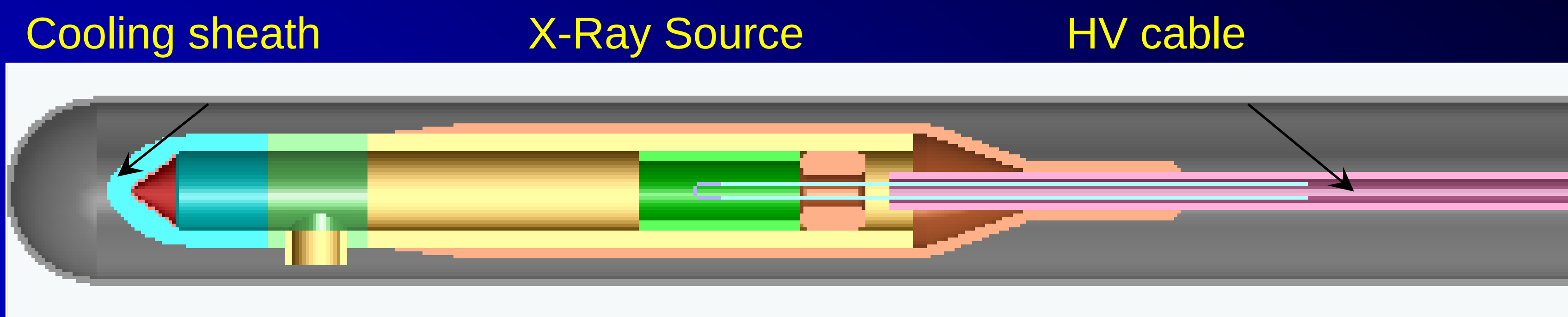
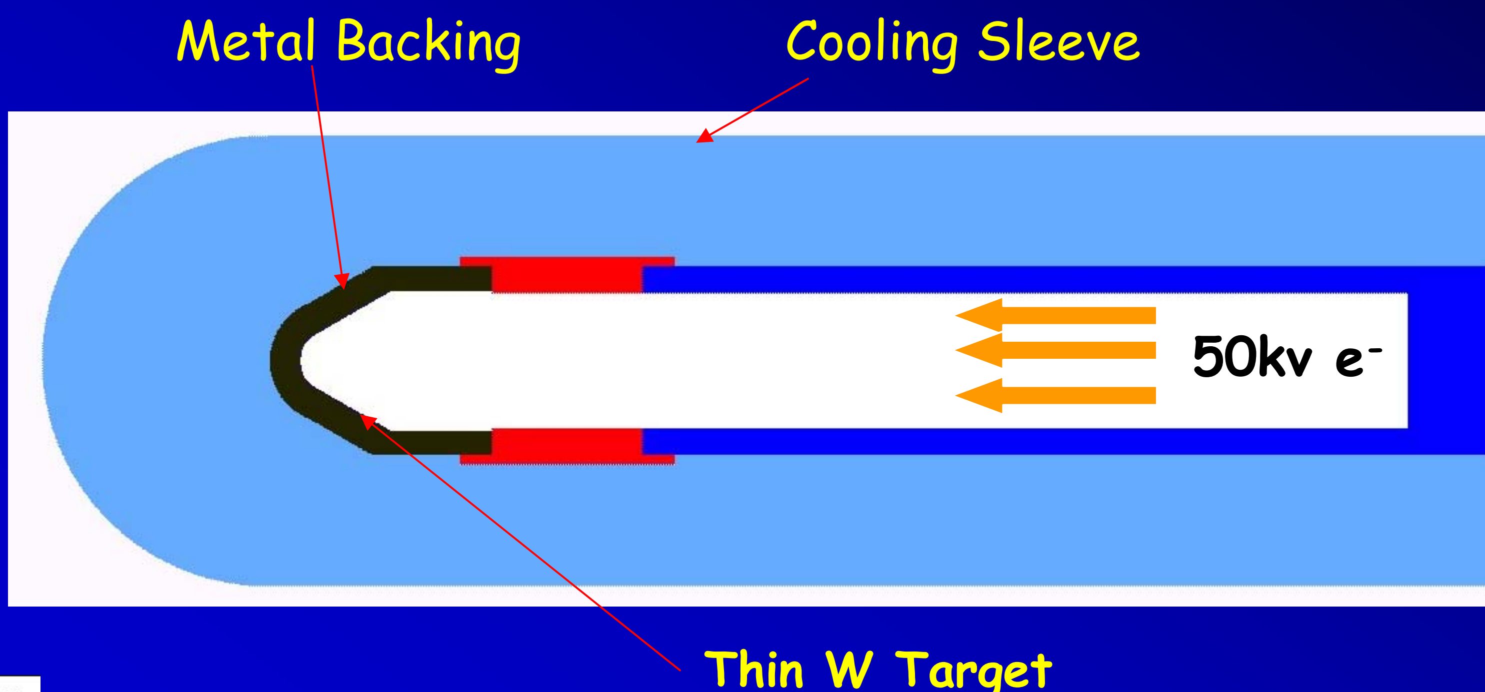
Model for Monte Carlo simulation





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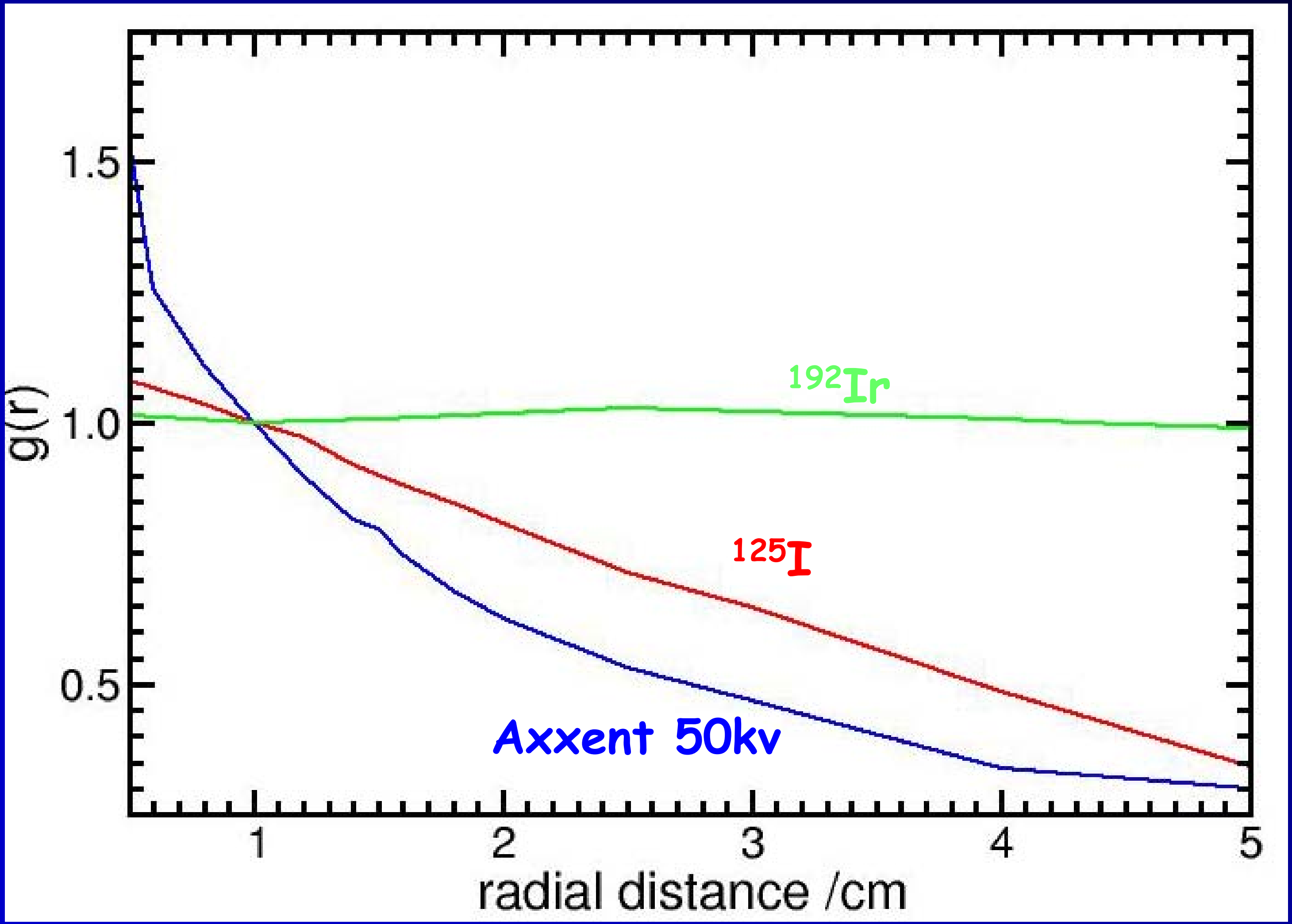
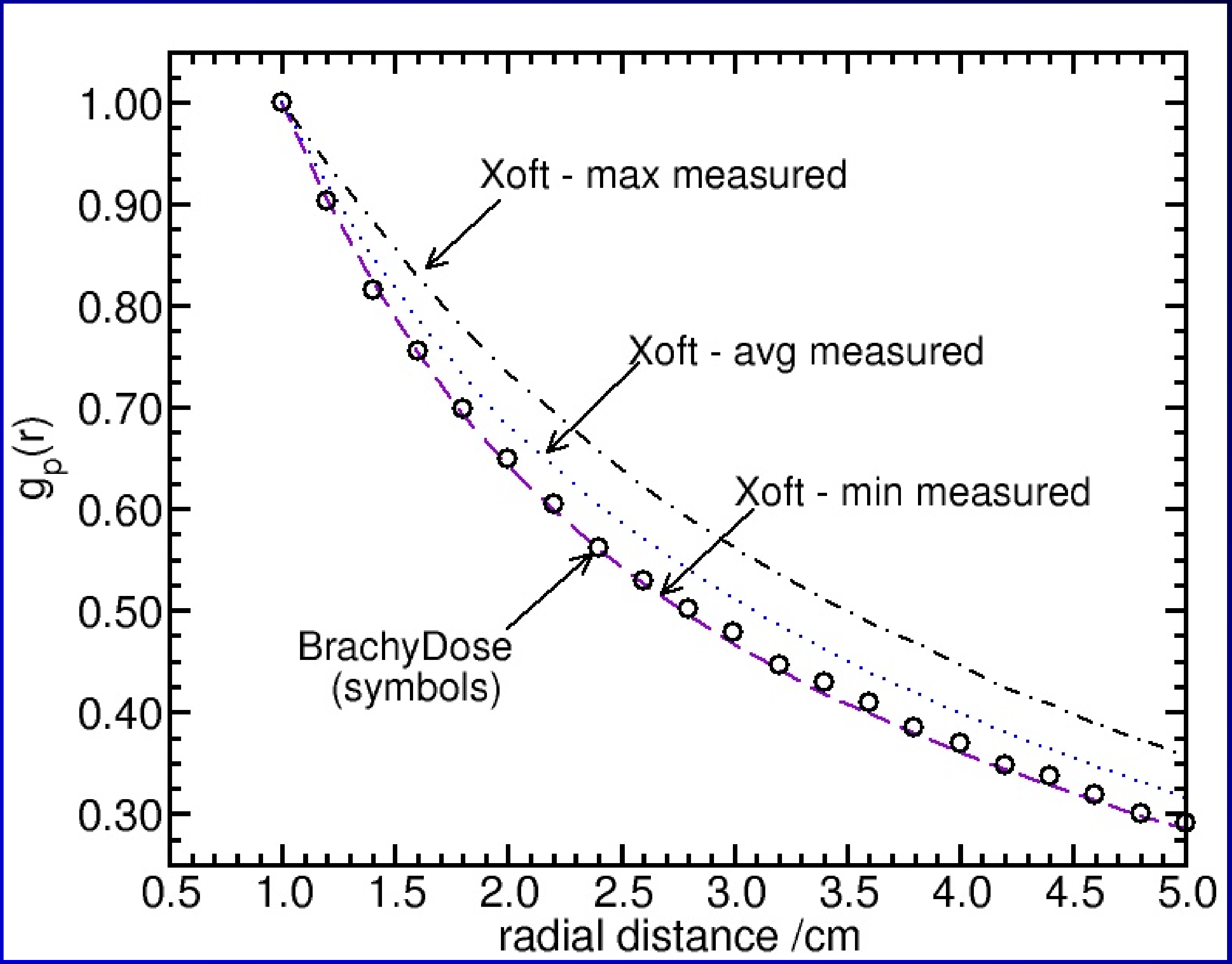
Radial dose function comparison



g(r) – radial dose function



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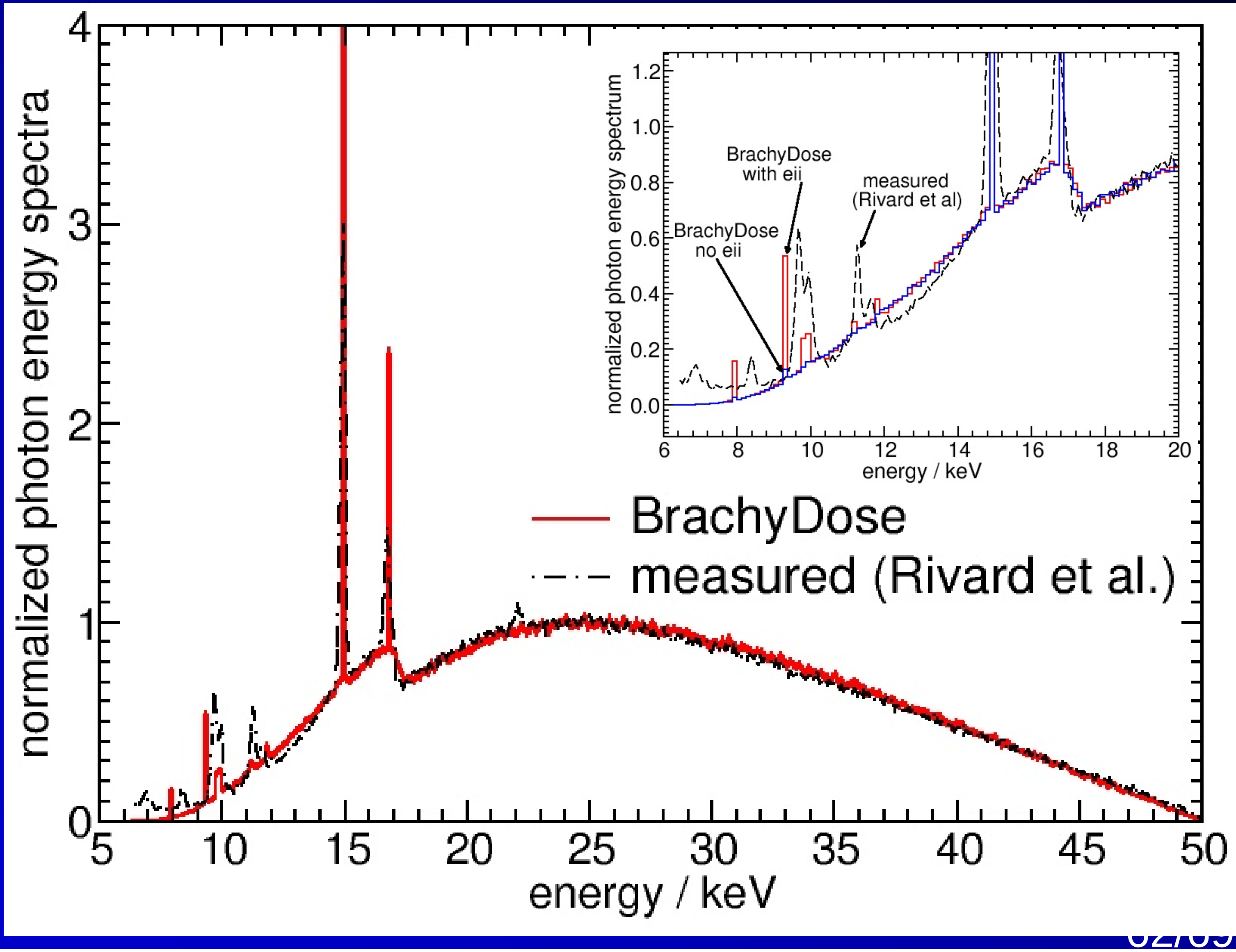
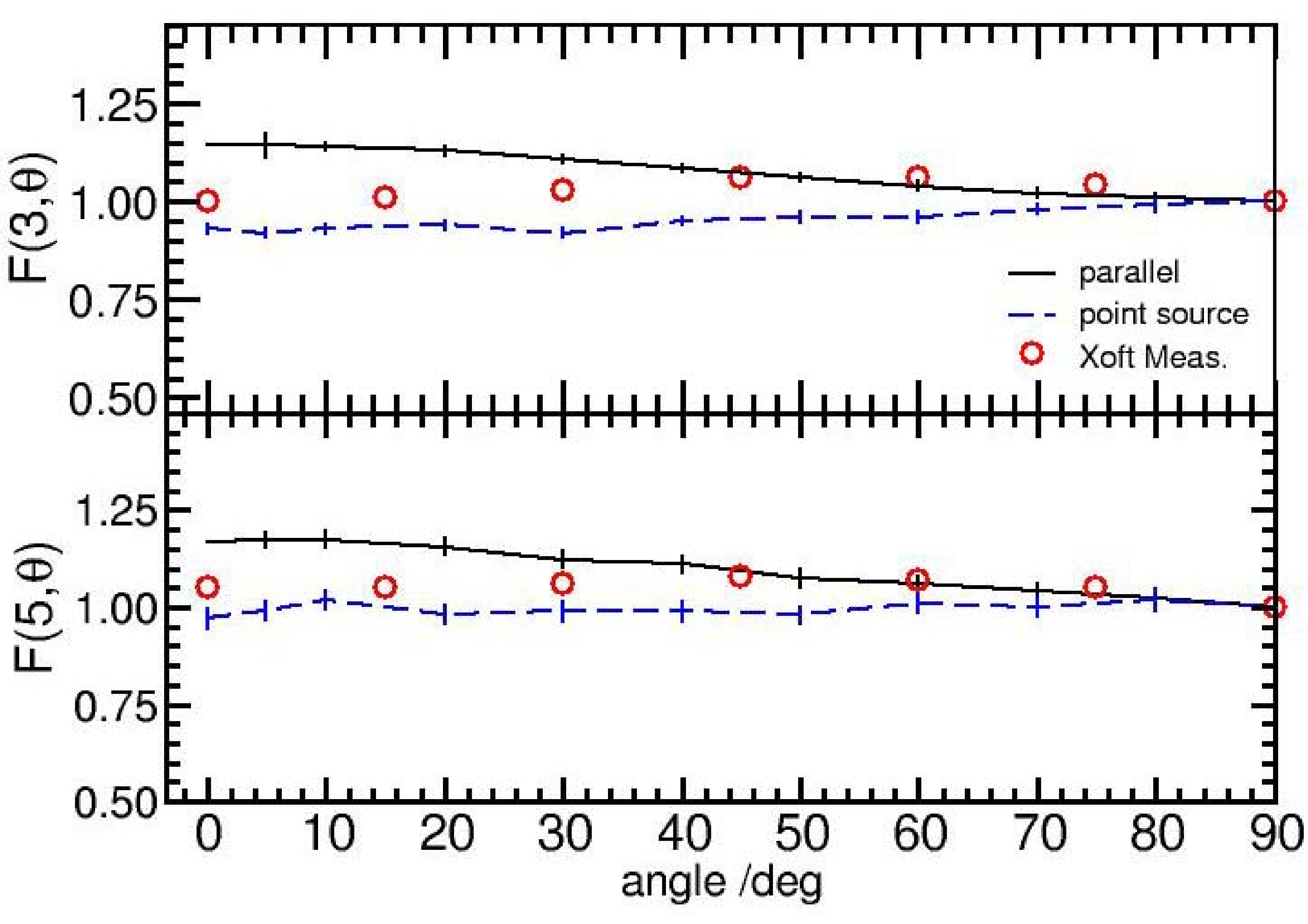
Energy spectrum with EII

spectrum calculated in air

including detector response explains 7 keV "peak"



F(r,θ) – anisotropy function



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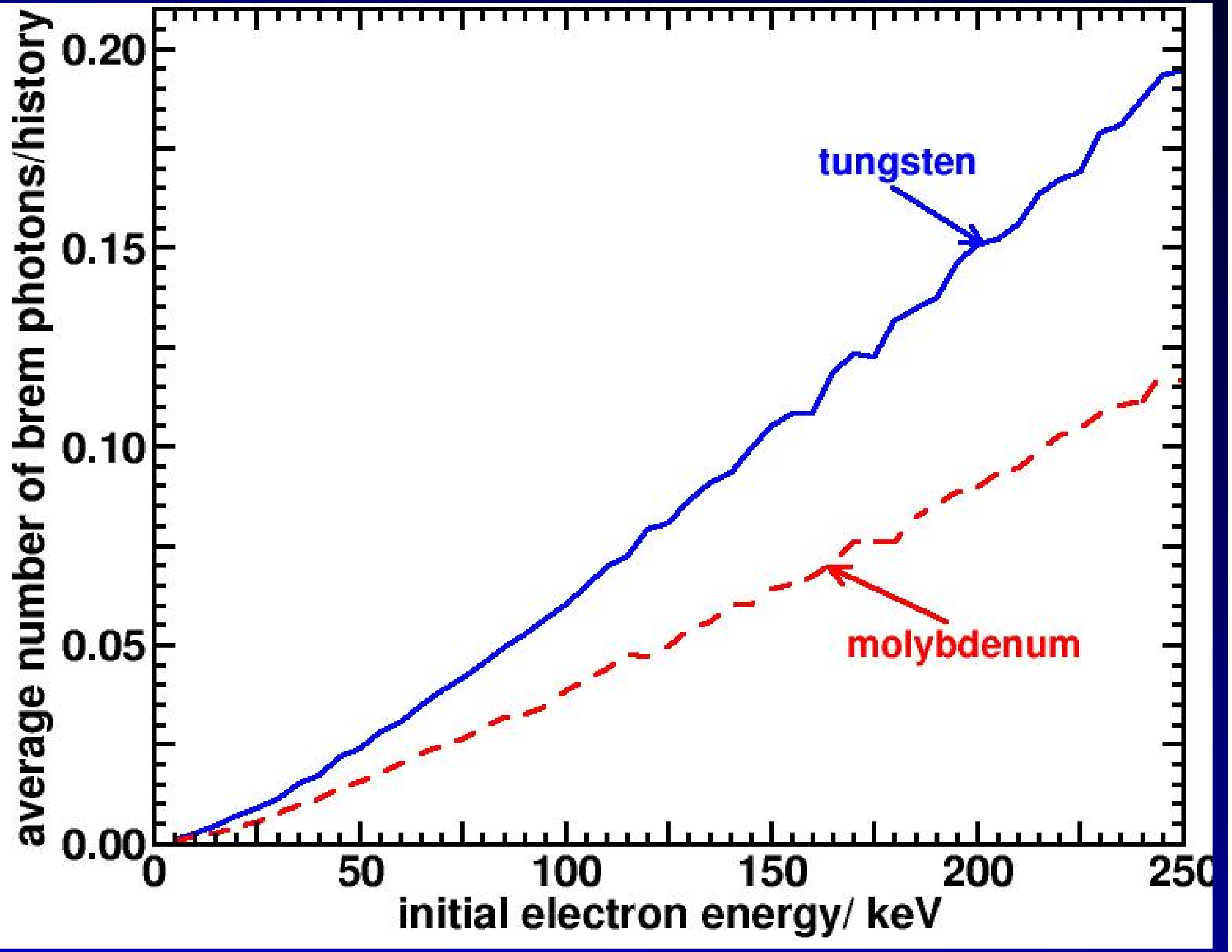
BCSE
brem cross section enhancement

low-energy electrons produce very few brem photons

=> waste time tracking electrons with no effect

Solution: enhance the cross section for brem



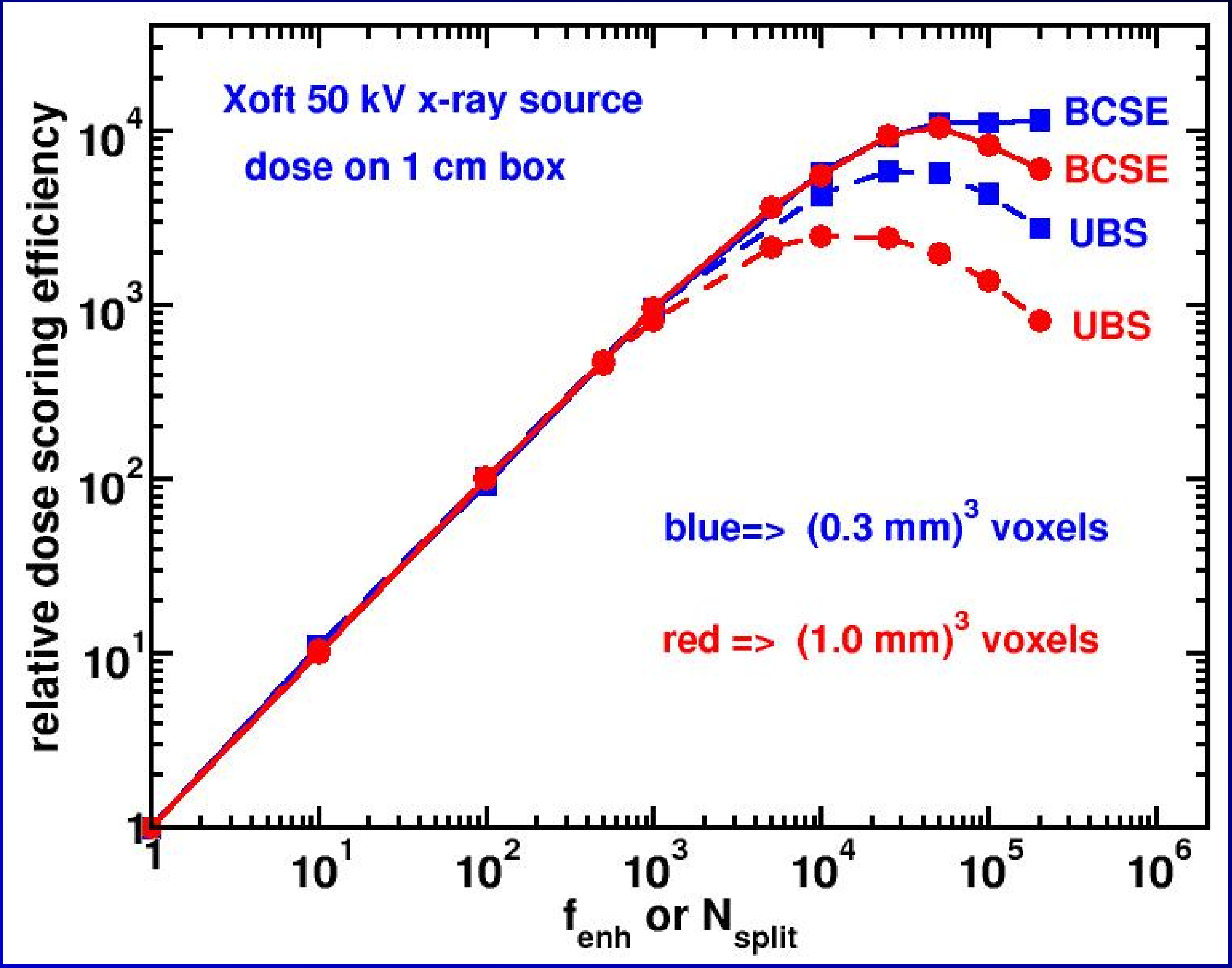
Ali & Rogers, Med Phys 34 (2007) 2143-2154

BCSE

UBS = uniform brem splitting

UBS "saturates" sooner because many photons in the same history.

Optimal approach is hybrid(500,100) 1 mm^3 ε=15,000



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Ali & Rogers, Med Phys 34 (2007) 2143-2154

Phase-space source

- electrons take much longer to transport than photons
- in the patient we only care about photons
- score the phase space data outside the source and inside the "balloon" and re-use
- saves a factor of 4 in the calculation
- will be able to recycle as in BEAMnrc
- not needed for seeds since already reuse each photon with every seed

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Summary

- Monte Carlo has played a central role in brachytherapy dosimetry, especially in calculating TG43 parameters
- Monte Carlo dose calculations are needed in brachytherapy
  - interseed attenuation -realistic materials -lack of full backscatter
- BrachyDose does a 2% cal'n in 1 mm voxels in 4 min.
  - extensive benchmarking for different seeds
  - EGSnrc inherently can model the x-ray sources

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Elsayed Ali

Gultekin Yegin

Randy Taylor

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Thank you

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Med Phys 34 (2007) 2187-2205