BrachyNext
Working Together to Shape the Future of Brachytherapy

UNIVERSITÉ LAVAL
CHU de Québec
Centre de recherche sur le cancer

Session C1:
Physics - Adding Certainty to Safety

Physics - Adding Certainty to Safety

- State-of-the-art in brachytherapy dose calculation
  - Dr. Beaulieu
- Clinical uncertainties: what is the magnitude?
  - Dr. Kari Tanderup
- Advances in real-time imaging for brachytherapy (e.g. real-time MRI and advanced US imaging)
  - Dr. Frank-André Siebert
- In-vivo dosimetry in brachytherapy: feasible and needed?
  - Dr .Annette Haworth
- Panel discussion

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State-of-the-art in brachytherapy dose calculation

Prof. Luc Beaulieu, Ph.D.

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2- Département de radio-oncologie et Centre de recherche du CHU de Québec, CHU de Québec, Canada

Disclosures

- My institution is an Elekta's Center of Excellence in Brachytherapy
- I was the Chair of TG-186 and I am the Chair of the AAPM/ESTRO/ABG Working Group on Model-based Dose Calculation Algorithms.
  - Our WG is working with all brachytherapy TPS vendors.

Acknowledgements

TG-186

- Luc Beaulieu (Chair)
- Å. Carlsson-Tedgren
- Jean-François Carrier
- Steve Davis
- Firas Mourtada
- Mark Rivard
- Rowan Thomson
- Frank Verhaegen
- Todd Wareing
- Jeff Williamson

AAPM/ESTRO/ABG WG

- Luc Beaulieu, CHUQ (Chair)
- Å. Carlsson Tedgren
- A. Haworth
- J. Lief
- Y. Ma
- F. Mourtada
- P. Papagianni
- M.J. Rivard
- F.A. Siebert (Vice-chair)
- R. Smith
- R. S. Sloboda
- R.M. Thomson
- J. Vijande
- F. Verhaegen

Brachytherapy is state-of-the-art

- Exquisite dose distribution and intensity modulation
- Dose deposition “kernel” better than proton
- Real-time image guidance and dose painting
- …

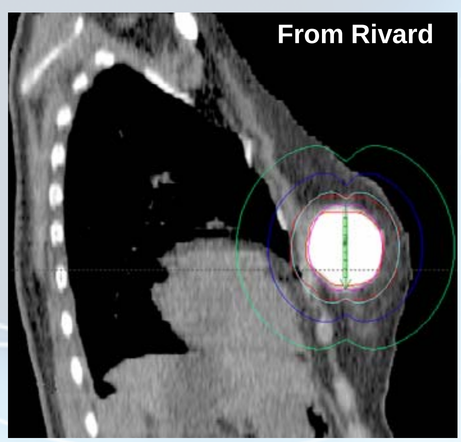
…but dose calculation is not

≥ 10% or more relative to TG-43

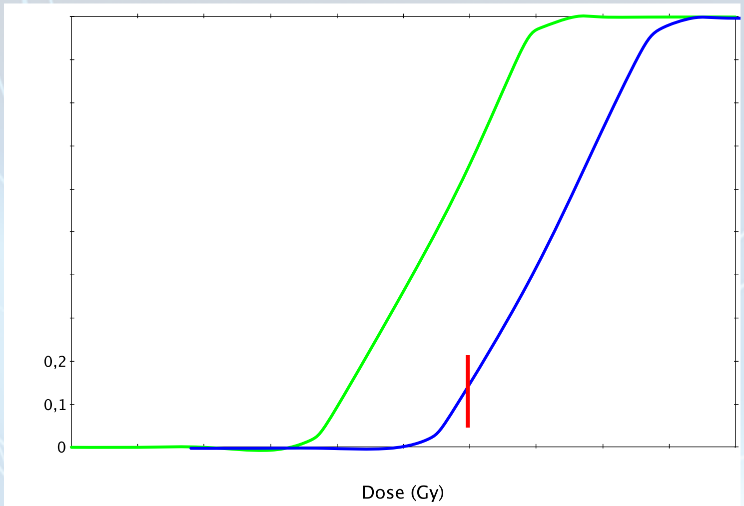
Dose is the fundamental quantity in RT

TG-43 Dose Calculations

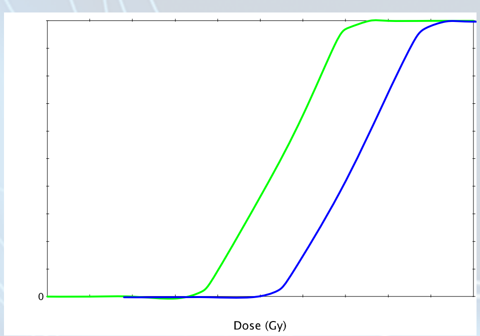
≠



Dose is the foundation of RT/BT



Dose is the foundation of RT/BT

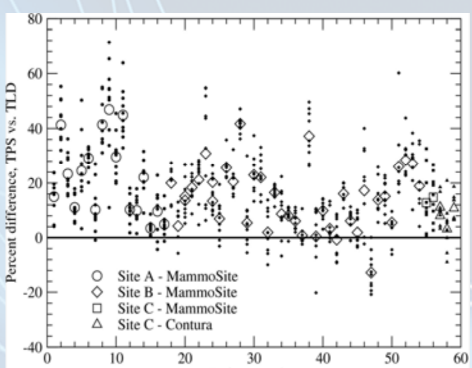


- TCP/NTCP change by the same amount:
  - ➢ Rescaling
- TCP/NTCP change by different amount or in opposite direction:
  - ➢ Differential effect

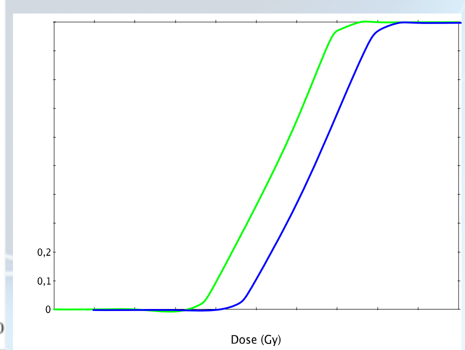
Of all uncertainties, dose is the parameters for which we should have the best handle on

- Already the case for EBRT
- Advanced dose algorithms are now available

“Recalibration” for Breast ^{192}Ir BT

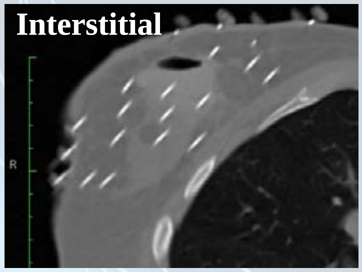


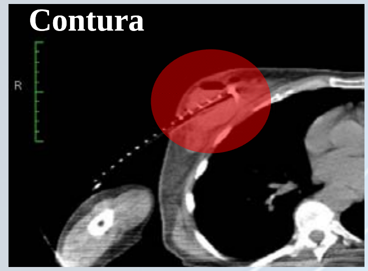
Raffi JA et al, Med. Phys. 37 (2010).

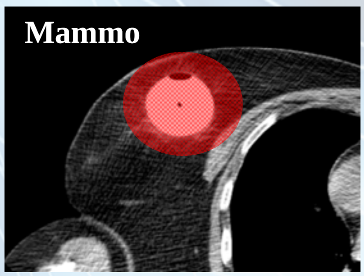


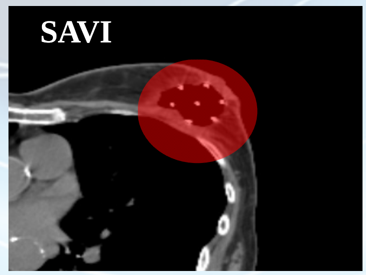
Differential effect: Large for OARs

One size does not fit all!

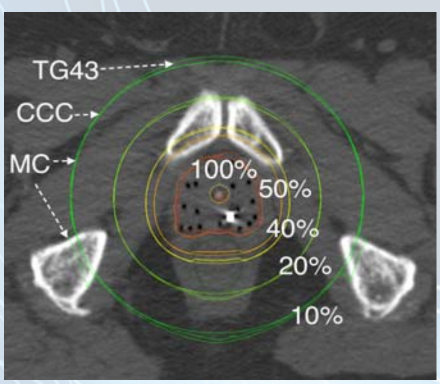






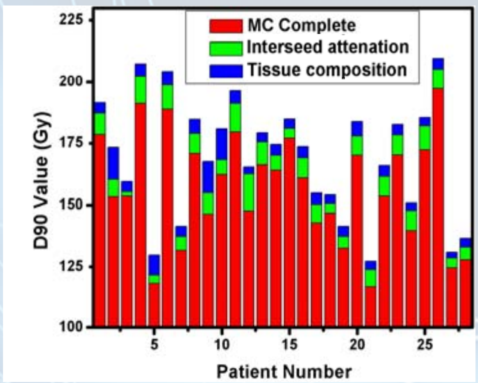


No effect: ^{192}Ir Prostate HDR

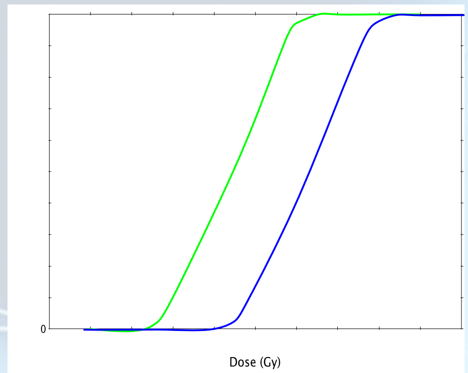


Y. Ma et al., In preparation for Med. Phys.

"Recalibration" for Prostate Seed Implants

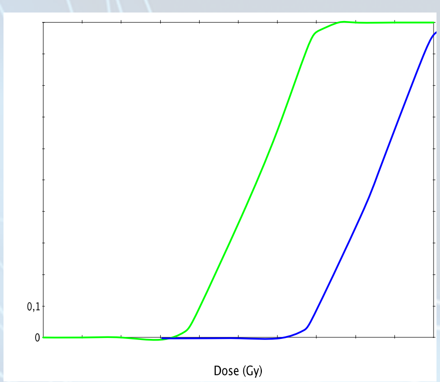


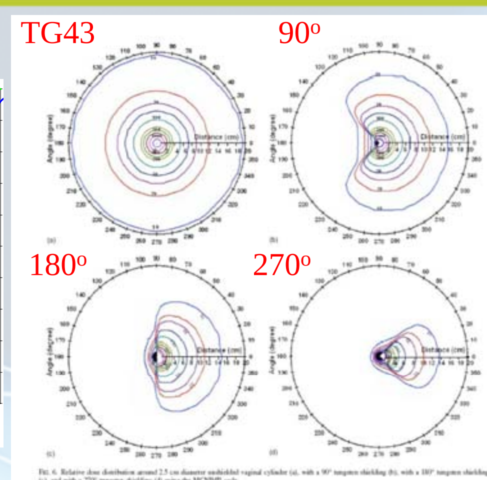
JF Carrier et al., IJROBP 2007



Differential effect: Large for CTV/PTV

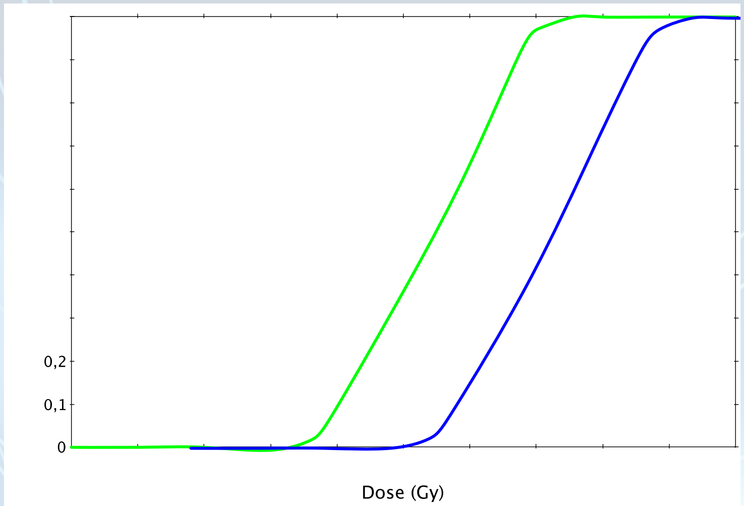
Potentially Large Differential Effect



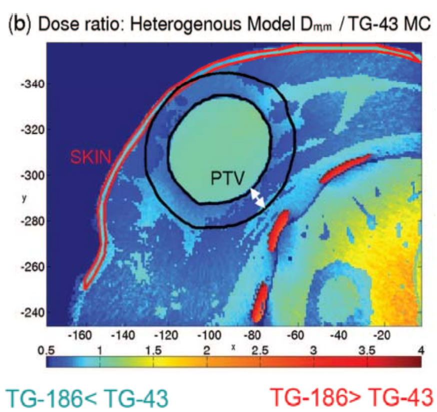


6 : Sureka C S, Aruna P, Ganesan S, « Computation of relative dose distribution and effective transmission around a shielded vaginal cylinder with Ir-192 HDR source using MCNP4B », Med. Phys., 44(6), 2006

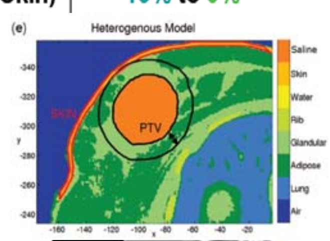
Unknown impact



TG-186 Heterogeneous Model ($D_{m,m}$)



DVH	% differences range
D_{90}	-36% to -33%
V_{100}	- 54% to – 29%
V_{200}	- 97% to - 25%
$D_{0.2cc}$ (Skin)	- 19% to 0%



- Large DVH decreases in $D_{m,m}$ compared to TG-43
- Higher calculated rib dose

Shane White *et al* : Provided by Frank Verhaegen

Sensitivity of Anatomic Sites to Dosimetric Limitations of Current Planning Systems

anatomic site	photon energy	absorbed dose	attenuation	shielding	scattering	beta/kerma dose
prostate	high					
	low	XXX	XXX	XXX		
breast	high				XXX	
	low	XXX	XXX	XXX		
GYN	high			XXX		
	low	XXX	XXX			
skin	high			XXX	XXX	
	low	XXX		XXX	XXX	
lung	high				XXX	XXX
	low	XXX	XXX		XXX	
penis	high				XXX	
	low	XXX			XXX	
eye	high			XXX	XXX	XXX
	low	XXX	XXX	XXX	XXX	

Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)

How Important in the clinic?

Site / Application	Importance
Shielded Applicators	Very large
Eye plaque	-10 to -30% (TG129)
Breast Brachy	-5% (^{192}Ir) to -40% (eBx/^{103}Pd)
Prostate Brachy	< -2% (^{192}Ir) to -15% on D90
GYN	Depends on applicators

- **Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)**
- **Beaulieu *et al* (TG-186), *Med Phys* 39, 2012**

Rule of thumb

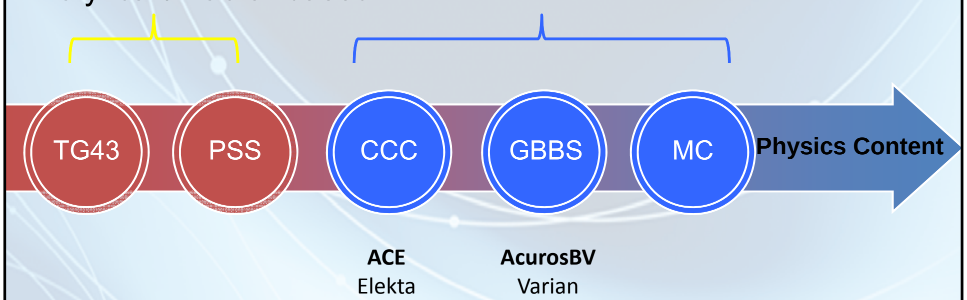
Energy Range	Effect
^{192}Ir	Scatter condition
	Shielding (applicator related)
^{103}Pd/^{125}I/eBx	Absorbed dose (μ_{en}/ρ)
	Attenuation (μ/ρ)
	Shielding (applicator, source)

Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)
Beaulieu *et al* (TG-186), Med Phys 39, 2012

Brachytherapy Dose Calculation Methods

Model-Based Dose Calculation : MBDCA

Analytical / Factor-based



Rivard, Beaulieu and Mourtada, Vision 20/20, Med Phys 2010

The two commercial alternative to TG43

- Collapsed-Cone (CC):
  - Used for a long-time in EBRT
- Grid-Based Boltzmann Solvers (GBBS):
  - Used for a long time in the nuclear industry
  - Released for brachy first (2009)
- Monte Carlo:
  - Not commercially available
  - Considered the gold std: thoroughly validated

Dose for Photon Brachytherapy sources

- Range of secondary electrons small relative to photon mean free path
  - In practice small relative to calculation voxels
- Photon fluence attenuation is small within that range
  - CPE exists
- No radiative energy loss
  - < 1% for water and tissues < 1 MeV)

Dose from Kerma

$$\dot{D}(\vec{r}) = \dot{K}(\vec{r}) = \int \Phi(E,\vec{r},t)E\left(\mu_{en}(E)\Big/\rho\right)dE$$

- If the fluence rate and energy distribution is known at all points in the geometry, the dose rate distribution is also known.
- Trivial for a perfect point source in a perfectly homogeneous medium considering only the primary photon spectrum.
  - Can still be easily done for real-sources in heterogeneous medium (primary only!)

Advanced Algorithms Basics

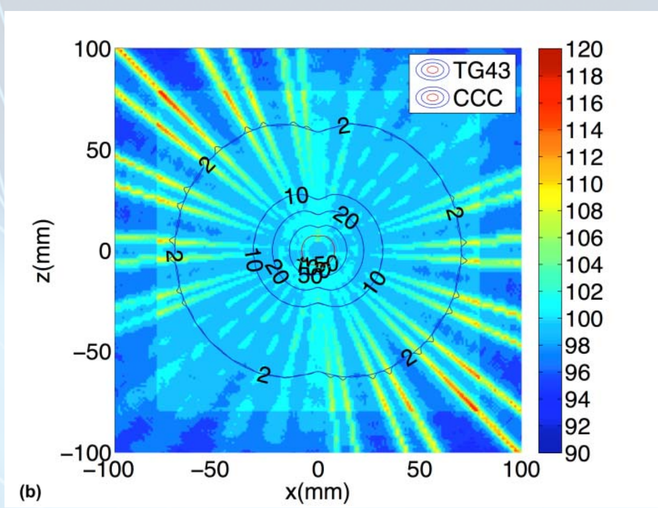
- Both ACE and Acuros calculate from first principals the primary dose
  - Ray tracing with scaling
- Both ACE and Acuros calculate the 1st scatter dose from Scerma:
  - $$S(r) = \left(\frac{\mu - \mu_{en}}{\mu_{en}}\right) D_{prim}(r)$$

BUT different approaches to treat the scatter dose

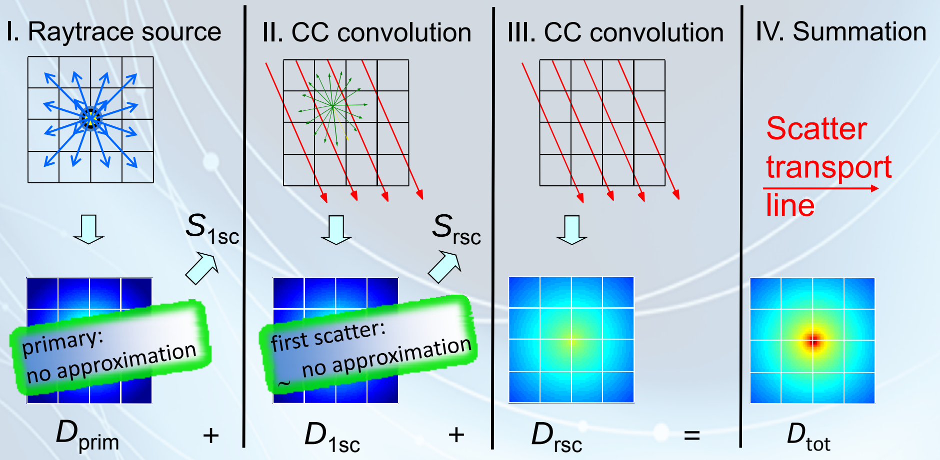
Advanced Algorithms Basics

- Collapsed-cone
  - Pre-calculated Monte Carlo kernels for 1st and multiple scatter components
    - Fitted by bi-exponential functions
    - Change in spectral composition (scatter vs primary) not exactly taken into account
  - Transport through the volume of interest using the collapsed-cone method
    - Angle discretization critical in high dose gradient regions
    - Similar for Acuros

Angle Discretization Effect



Outline of the brachy-CC MBDCA



(Åsa K. Carlsson, Anders Ahnesjö, 2000)

Grid-Based Boltzmann Solver (GBBS)

$$\hat{\Omega}\cdot\vec{\nabla}\Psi(\vec{r},E,\hat{\Omega})+\sigma_t(\vec{r},E)\Psi(\vec{r},E,\hat{\Omega})=Q^{scat}(\vec{r},E,\hat{\Omega})+Q^{ex}(\vec{r},E,\hat{\Omega})$$

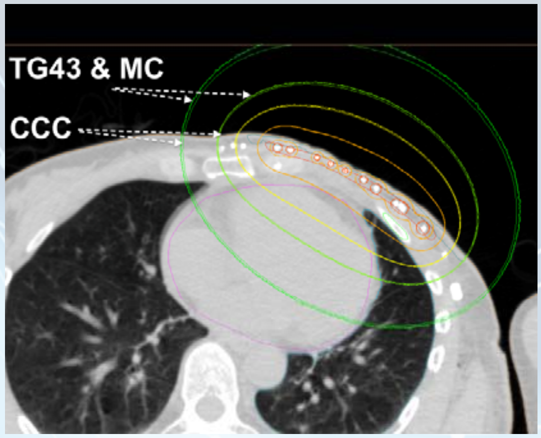
Solving the linear Boltzmann transport equation:

- Position: $\vec{r}=(x,y,z)$ — mesh position discretization (finite elements)
- Energy: *E* — *Energy bins (cross section)*
- Direction: $\hat{\Omega}=(\theta,\phi)$ — Angular discretization

« multi-group discrete ordinates grid-based …»

2D: Daskalov et al (2002), Med Phys 29, p.113-124
3D: Gifford et al (2006), Phys Med Biol vol 53, p 2253-2265

ACE Performance

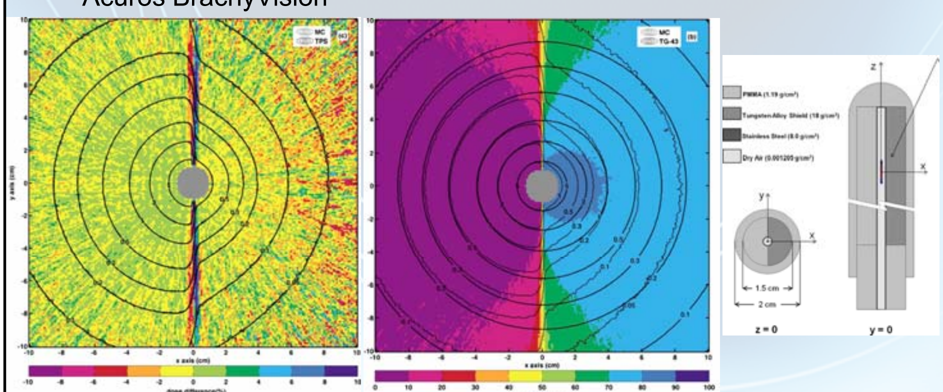


Y. Ma et al., In preparation for Med. Phys.

Acuros Performance

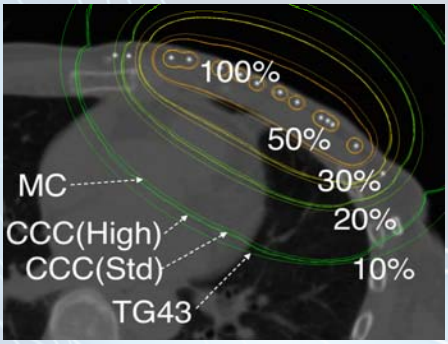
Excellent reference HDR ^{192}Ir benchmarks in *MedPhys*

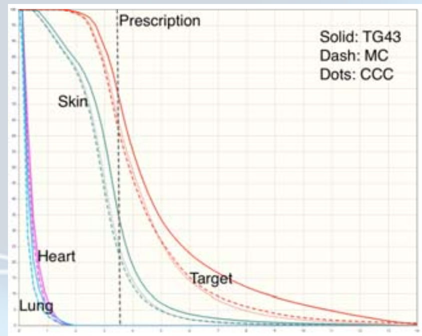
- Acuros BrachyVision



Petrokokkinos *et al.*, MedPhys 38, 1981-1992 (2011)

ACE Performance



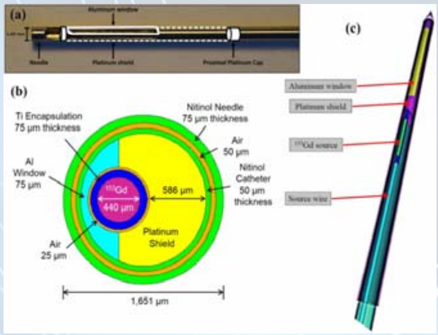


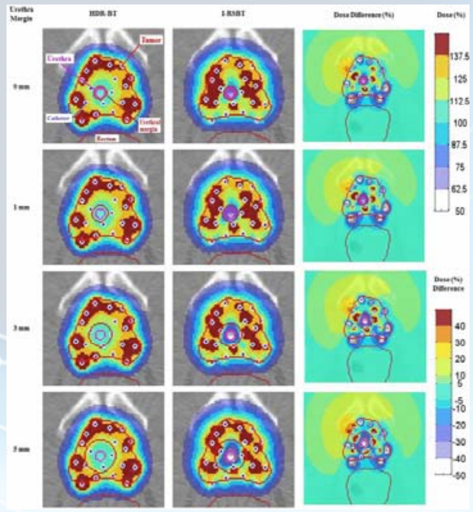
Y. Ma et al., In preparation for Med. Phys.

Why advanced dose calculation algorithms?

- Correct large dose discrepencies
- Meaningful radiobiology
- Possibility of better tx approaches
  - Shielded applicators
  - Directional sources
  - Different sources (isotopes or eBx)

Moving away from TG43 to enable new techniques, e.g. Interstitial Rotating Shield





- Q.E. Adams et al., Med Phys 41 (2014)

Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation

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The charge of Task Group 186 (TG-186) is to provide guidance for early adopters of model-based dose calculation algorithms (MBDCAs) for brachytherapy (BT) dose calculations to ensure practice uniformity. Contrary to external beam radiotherapy, heterogeneity correction algorithms have only recently been made available to the BT community. Yet, BT dose calculation accuracy is highly dependent on scatter conditions and photoelectric effect cross-sections relative to water. In specific situations, differences between the current water-based BT dose calculation formalism (TG-43) and MBDCAs can lead to differences in calculated doses exceeding a factor of 10. MBDCAs raise three major issues that are not addressed by current guidance documents: (1) MBDCA calculated doses are sensitive to the dose specification medium, resulting in energy-dependent differences between dose calculated to water in a homogeneous water geometry (TG-43), dose calculated to the local medium in the heterogeneous medium, and the intermediate scenario of dose calculated to a small volume of water in the heterogeneous medium. (2) MBDCA doses are sensitive to voxel-by-voxel interaction cross sections. Neither conventional single-energy CT nor ICRU/ICRP tissue composition compilations provide useful guidance for the task of assigning interaction cross sections to each voxel. (3) Since each patient-source-applicator combination is unique, having reference data for each possible combination to benchmark MBDCAs is an impractical strategy. Hence, a new commissioning process is required. TG-186 addresses in detail the above issues through the literature review

6208 Med. Phys. 39 (10), October 2012 0094-2405/2012/39(10)/6208/29/$30.00 © 2012 Am. Assoc. Phys. Med. 6208

Read Prior to Usage!

TABLE OF CONTENTS

Conclusion

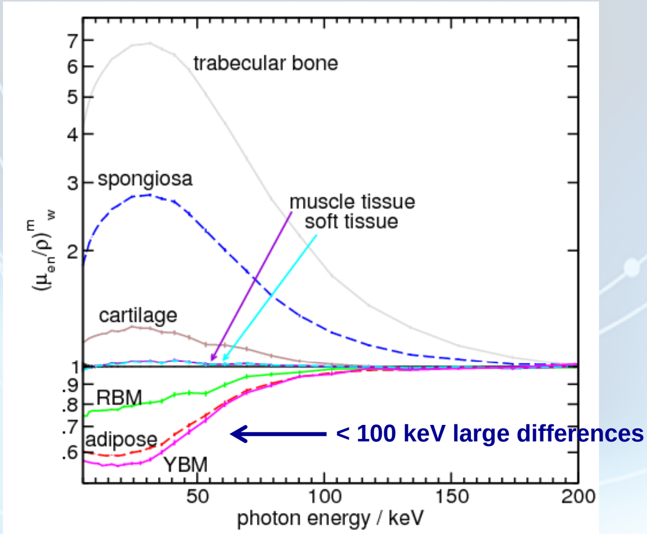
- Advanced dose calculations are available and is a necessary step for better brachytherapy treatments
  - ➢ Accurate dose calculation, new techniques, …
- Dose-outcome/dose-toxicity relationships will be revisited once enough data are available
  - ➢ Large scale dose recalculation and prospective TG43/MBDCA calculations
- For ^{192}Ir BT:
  - Air, applicator and shield (library!), contrast bone: essentials
  - Soft tissues = water!

Merci!

beaulieu@phy.ulaval.ca

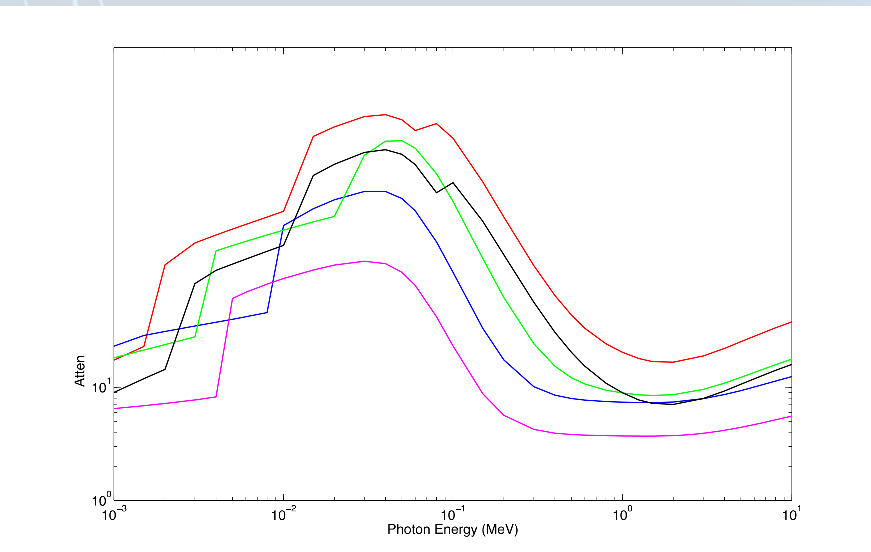
http://physmed.fsg.ulaval.ca

Water vs Tissues: Photon Energy



Beaulieu *et al* (TG-186), Med Phys 39, 2012

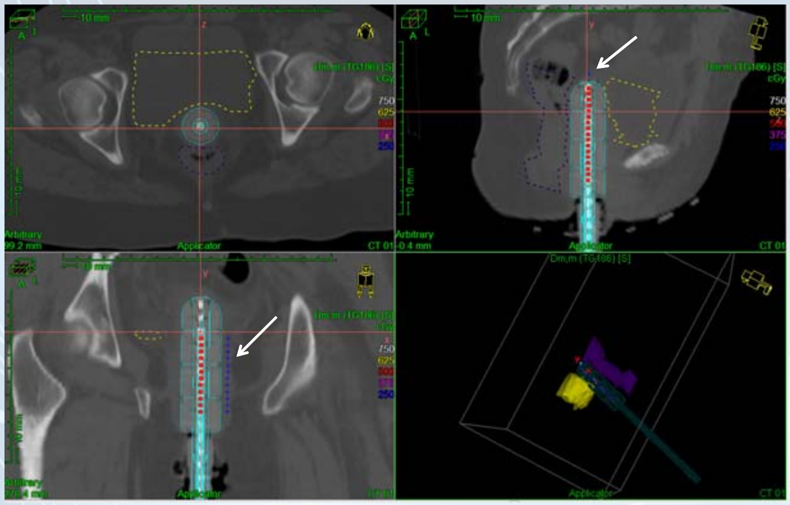
Attenuation by Metals



From NIST website

GYN example

- Simple vaginal cylinder: CT/MR applicator
  - 17 dwell-positions; 500cGy/fx; 100% isodose at 5 mm



GYN example

- The plastic applicator has little effect for ^{192}Ir, but for the **air** inside central channel...
- 5 mm past the apex:
  - TG-43: 490.78 Gy
  - TG-186: 520.23 Gy
  - Difference of:
    - +29.45 Gy or +6% relative to TG-43 expectation
    - +4% above prescription dose

    - <u>Mileage will vary depending on that last dwell-position relative to the applicator end</u>