Background and Rationale for Model Based Dose Calculation in Brachytherapy

A presentation on behalf of "AAPM Working Group on Model-Based Dose Calculation Algorithms in Brachytherapy"

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Strål säkerhets myndigheten

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Rationale

- Individualized treatment plans
- More reliable dose response data
- Safe introduction of new sources and techniques

Learning objectives

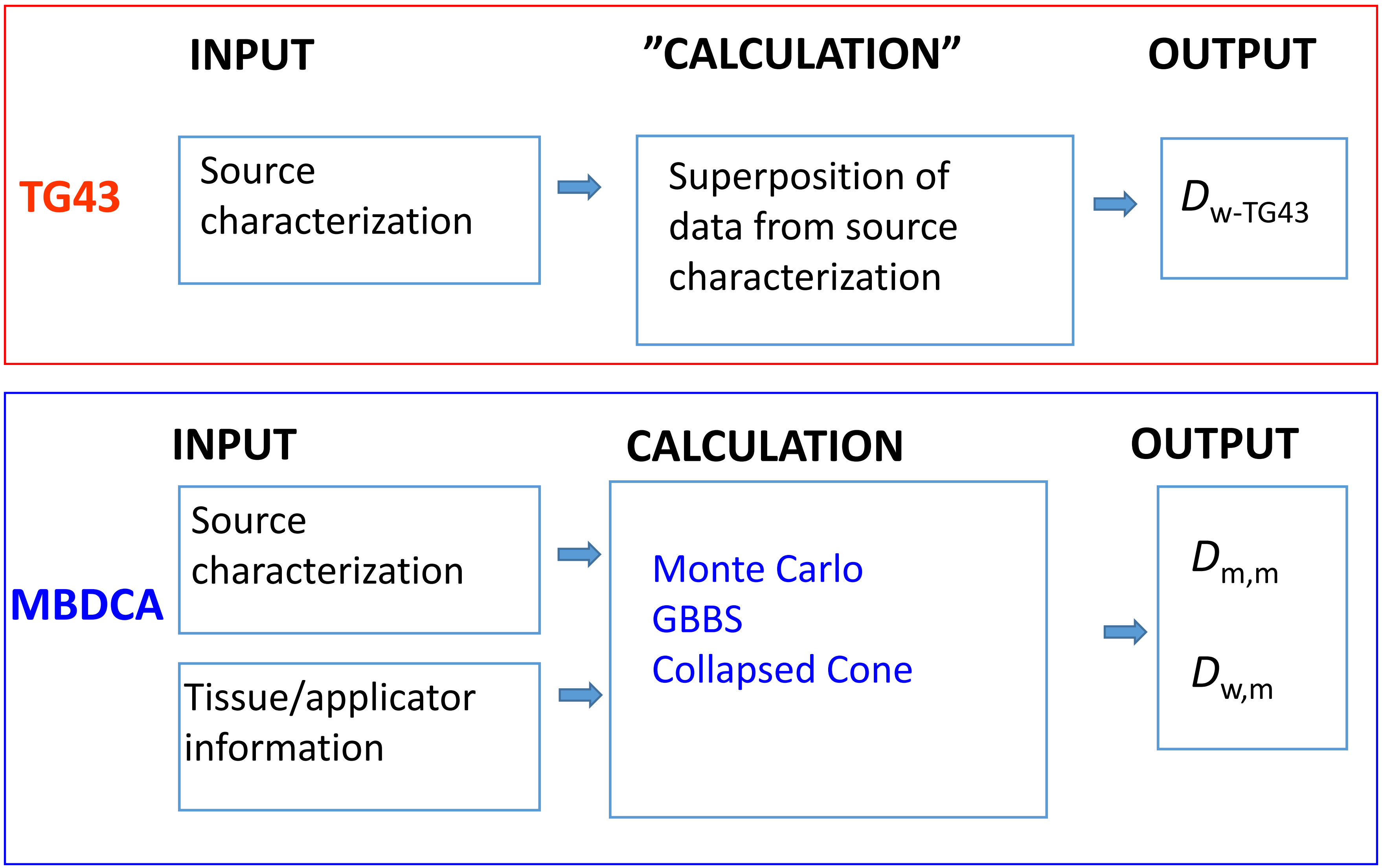
- Insight into limitations of TG43

- Understanding differences TG43- MBDCA at various photon energy

- Insight into the importance of accuracy in dosimetry

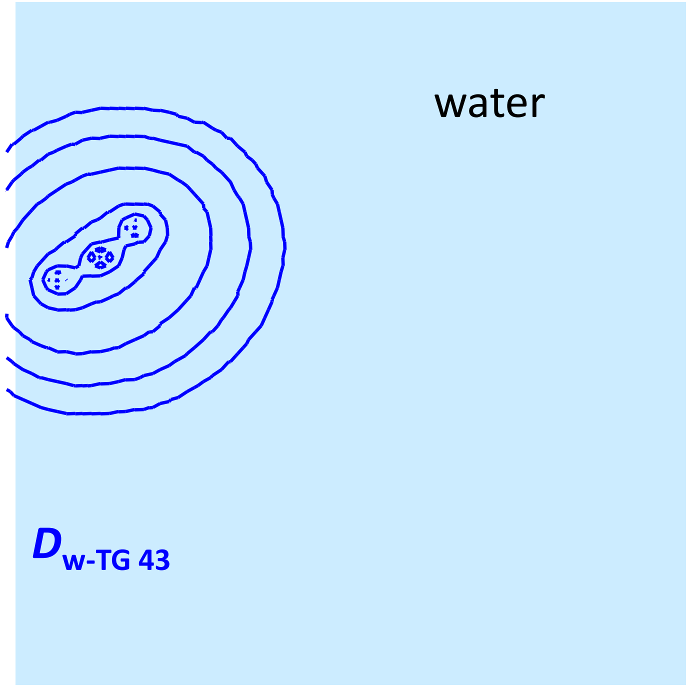
- Awareness of non-MBDCA uncertainties and non-resolved issues affecting output

TG43 versus MBDCA



Dose calculation

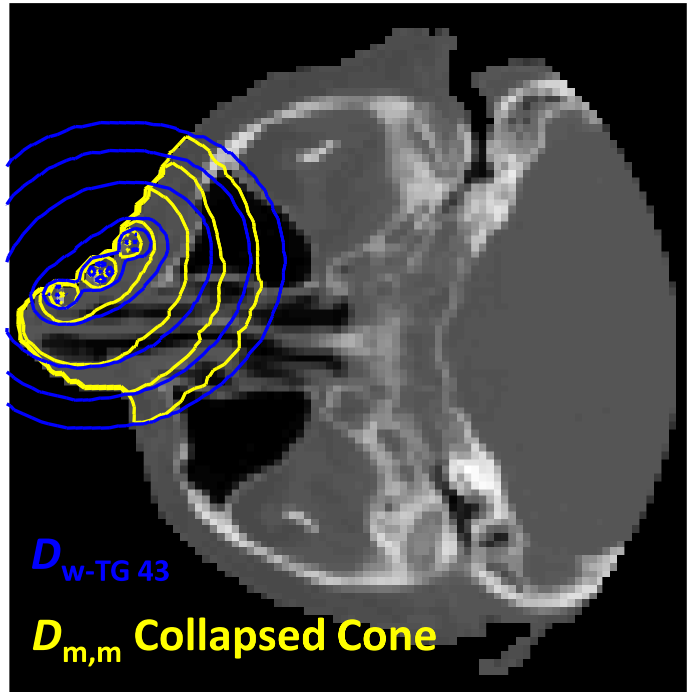
I. TG43



Superposition of single-source water-dose

Imaging : to localise dose -anatomy

II. MBDCA



Dose is *calculated*

- Imaging: for information on tissues

Importance of accuracy in dosimetry

CANCER TREATMENT

Principles of cancer treatment by radiotherapy

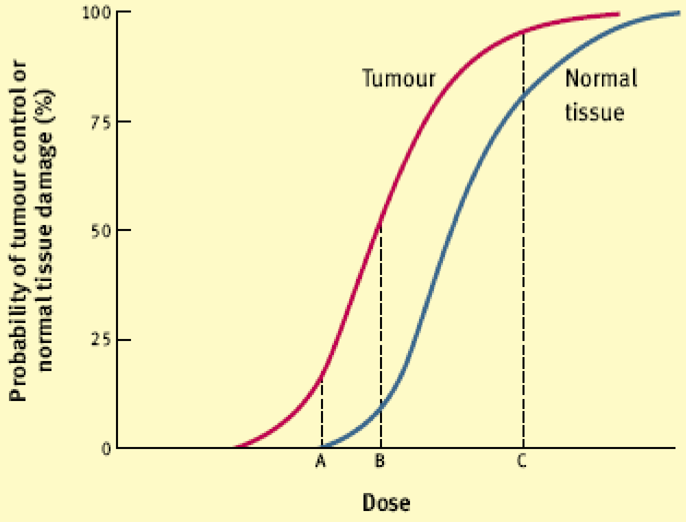
Stephen Falk

Radiotherapy is a very important component of anticancer treatment, with up to half of all patients with cancer receiving radiotherapy at some stage in their disease.

The biological basis of radiotherapy

The effect of radiotherapy in killing cancer cells is largely related to its effects on DNA, with the introduction of single-stranded DNA breaks and, to a lesser extent, double-stranded DNA breaks. DNA damage arises from the absorption of gamma radiation in tissues, which leads to the immediate production of ionized atoms and the

Differential sensitivity to ionizing radiation of normal and malignant tissues



Increasing the radiation dose increases local control, but increases the risk of long-term radiation damage, C versus A. B represents an acceptable balance between control and damage.

From Falk (2009) Surgery vol 27, p 169-172

Brachytherapy is evolving

New sources- ^{131}Cs, ^{169}Yb, ^{170}Th, electronic kV sources

New techniques; APBI, inverse planning

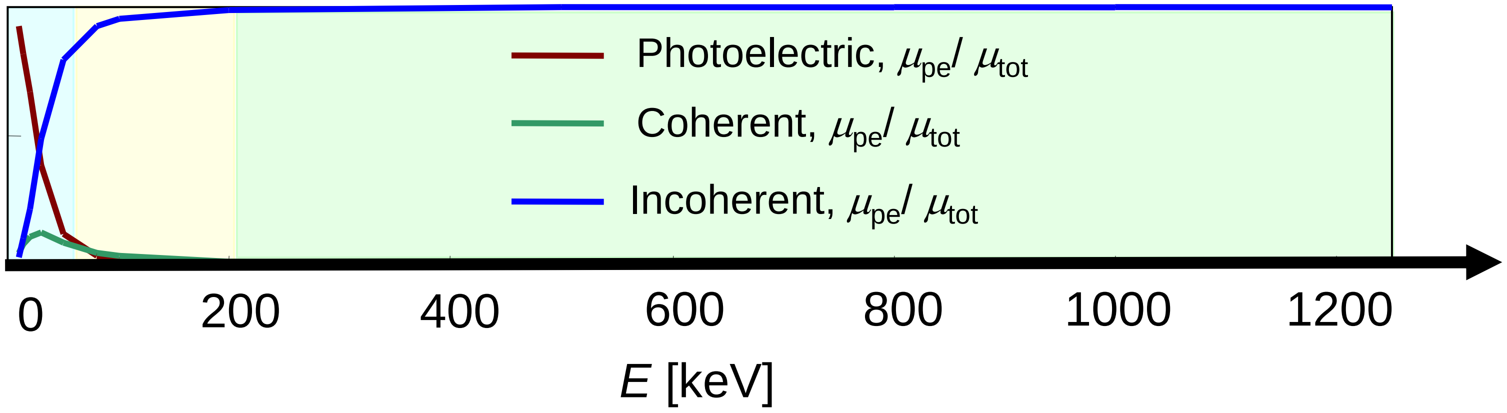
Special Brachytherapy Modalities Working Group

Working Group on Robotic Brachytherapy

Dosimetric accuracy is cruical for safe transfer of clinical knowledge obtained with one technique into new ones!

Energy dependence of effects

Energy region	Isotope	Energy [keV]	~Distance [cm] $D_{scat}=D_{prim}$	~Fraction to scattered photons, $(1-\mu_{en}/\mu)$
low	^{103}Pd	22	1,5	0,5
low	^{125}I	28	1,5	0,6
low	Electronic	30-60 kV	1-2 cm	0,5
intermediate	^{169}Yb	93	2,5	0,85
high	^{192}Ir	370	6	0,7
high	^{137}Cs	662	10	0,5

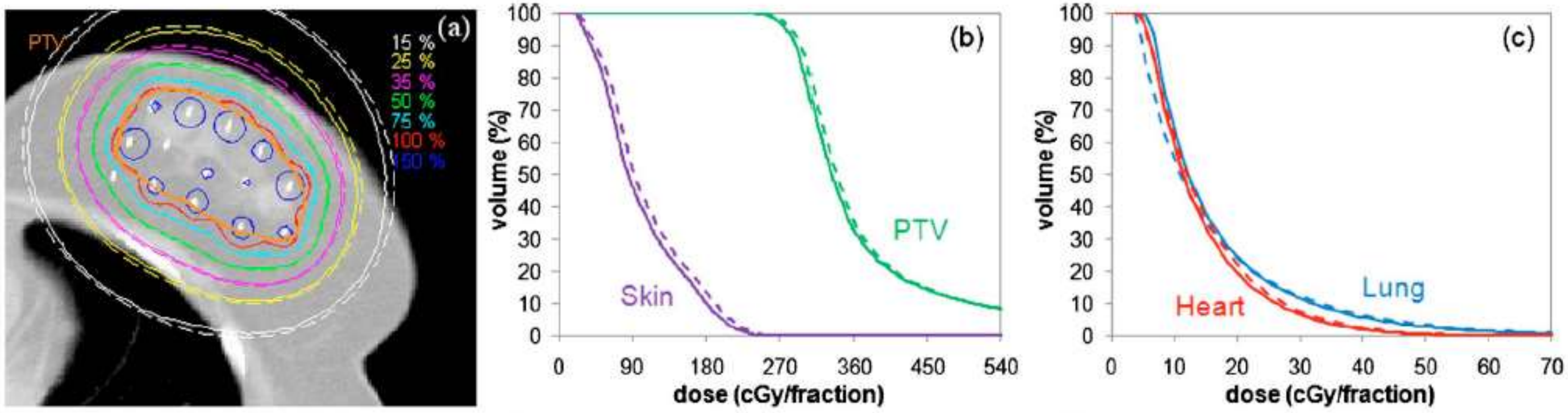


Energy dependence of effects

Isotope	**Soft tissue**	**Finite dims**	**Seed-to-seed shielding**	**Shields**	**MBDC vs TG43**	**Precaution*)**
^{103}Pd	X	-	X	X	large	yes
^{125}I	X	-	X	X	large	yes
Electronic	X	-	-	X	large	yes
^{169}Yb	(X)	X !	-	X !	(large)	(yes)
^{192}Ir	-	X	-	X	moderate	none

*) tissue segmentation and choice of dose scoring medium

^{192}Ir (350 keV) breast implant : effects of finite patient dimensions

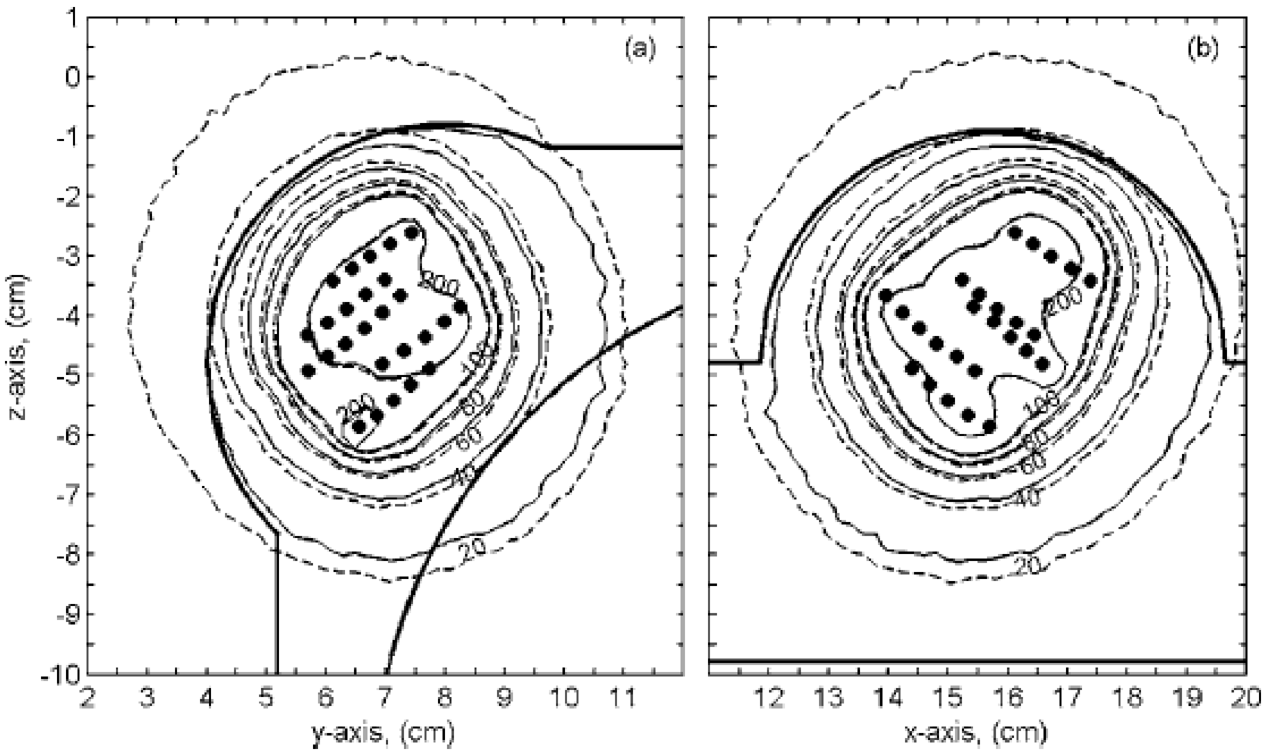


From: Poon and Verhaegen (2009), Med Phys, p 3703-3713

MBDC and TG43 agree in the target

1/20 patients was excluded from APBI due to skin dose overestimated by the TG43 dose calculation.

^{169}Yb (93 keV) breast implant : effects of finite patient dimensions

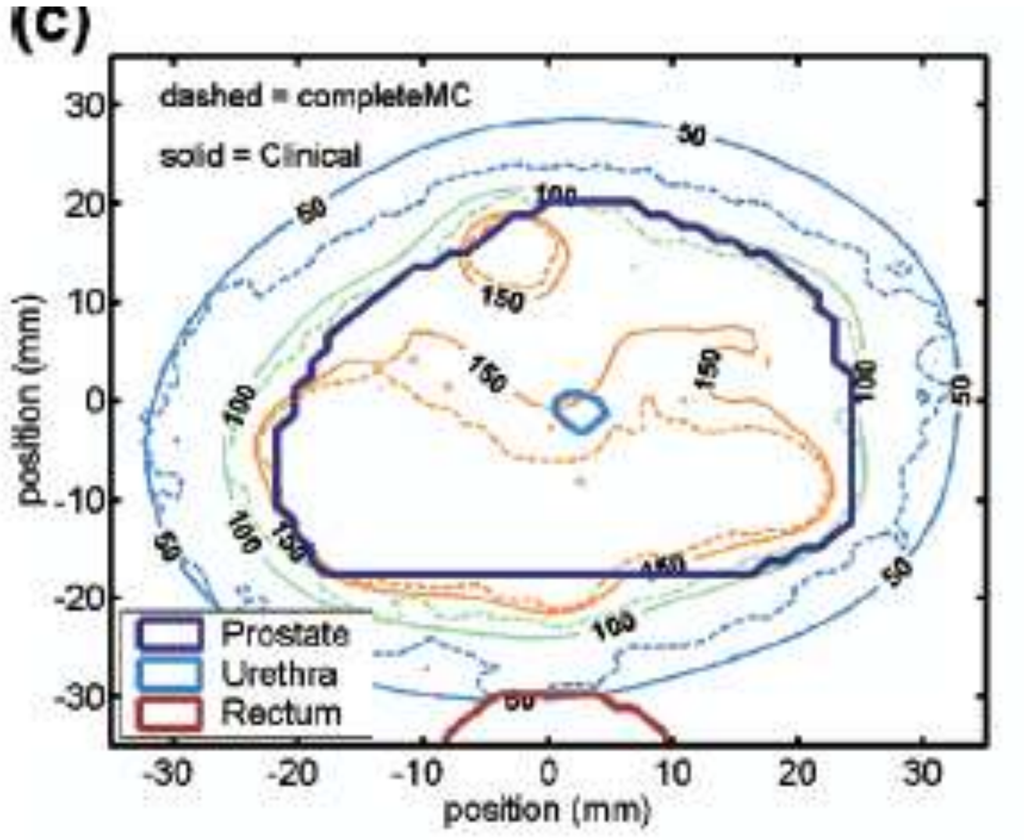


From Lymperopoulou et al 2006, Medical Physics vol 33, p 4583-4589

Contrast media within a Mammosite balloon causes additional differences! see Papagiannis et al 2007, Med Phys, vol 34 p 3614-3619

TG43 vs MC in ^{125}I prostate implants

Prostate tissue, seed-to-seed shielding => 10 Gy reduced D_{90}



Carrier et al, Int. J., Rad, Oncol., Biol. Phys. (2007) vol 68 p 1190-1198

TG43 vs MC for APBI with an electronic source

5290 C Shi *et al*

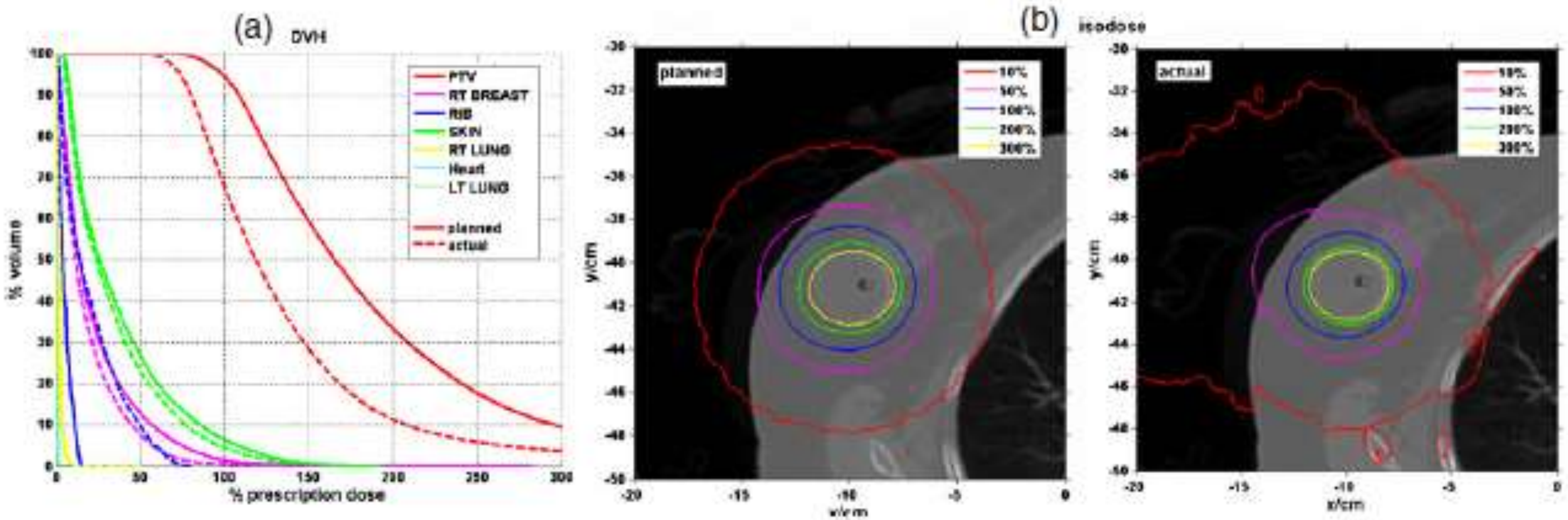
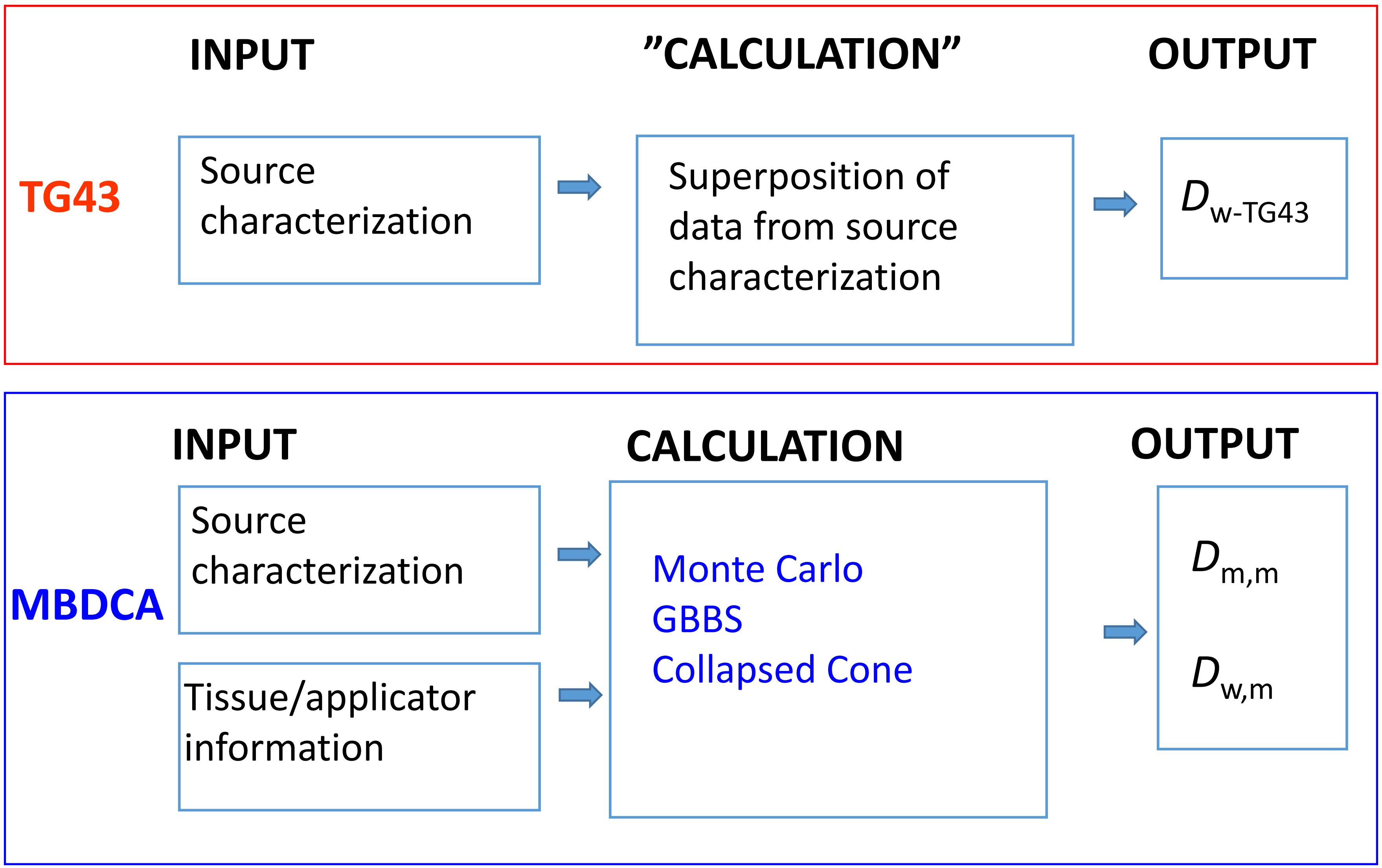


Figure 2. (a) DVH comparison of the planned and actual dose distributions for case #5 and (b) isodose comparison of planned and actual dose distributions for case #5.

Shi et al (2010) Phys Med Biol vol 55 p 5283-5297

TG43 versus MBDCA



Dose calculation algorithms: one link in the chain

Table 2. Determination of accuracy goal in dose calculations. With present delivery and calibration technique 2–3% should be the aim while 1% might be the ultimate accuracy goal.

	Present technique $100 \times \Delta D(1\sigma)/D$	Future development $100 \times \Delta D(1\sigma)/D$
Absorbed dose determination at the calibration point	2.0	1.0
Additional uncertainty for other points	1.1	0.5
Monitor stability	1.0	0.5
Beam flatness	1.5	0.8
Patient data uncertainties	1.5	1.0
Beam and patient set-up	2.5	1.6
Overall excluding dose calculation	**4.1**	**2.4**
Dose calculation	1.0 2.0 3.0 4.0 5.0	0.5 1.0 2.0 3.0 4.0
Resulting overall uncertainty	**4.2 4.6 5.1 5.7 6.5**	**2.4 2.6 3.1 3.8 4.7**

Proposed requirement for EBRT:

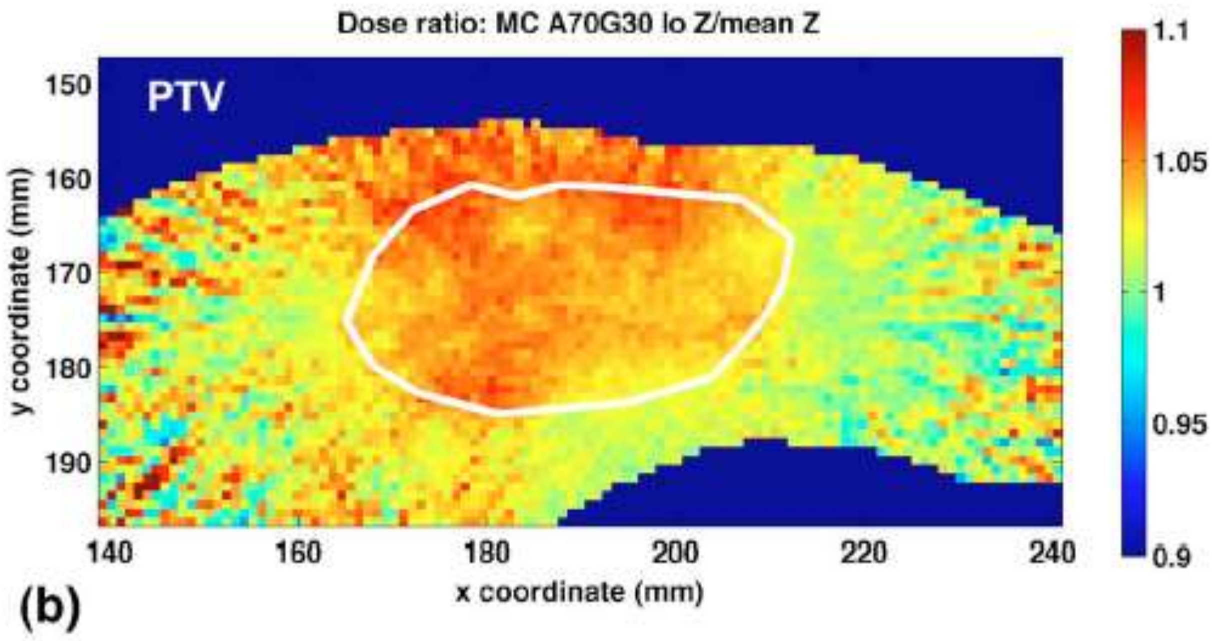
Dose calculation algorithms should be accurate enough to not contribute significantly to the overall uncertainty.

Ahnesjö and Aspradakis (1999) PMB vol 44 p R99-R155

Precaution – CT as input at *E* < 50 keV

Variations in mean tissue composition affect MBDC dosimetry

CT cannot estimate elemental tissue composition precise enough



^{103}Pd in breast

ΔD 5%-10%

From Landry et al (2010) Med Physics vol 37 p 5188-5198

CT and tissue segmentation

TG-186 INTERRIM SOLUTION < 50 keV : tissue segmentation based on contouring and selected datasets for tissue composition

DRAWBACK : Lack of individual information on e.g. calcifications, of importance in prostate and breast implants

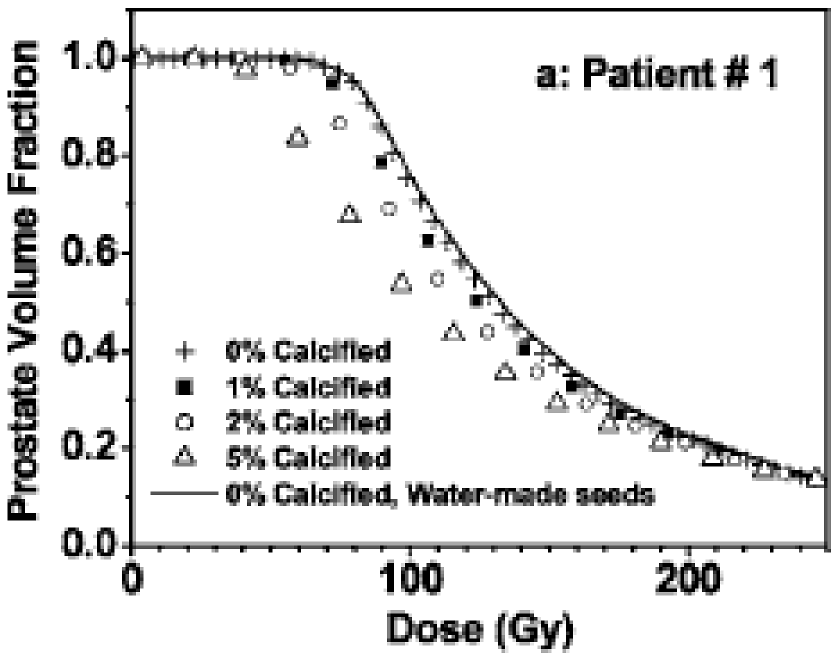


Figure from: Chibani and Williamson Med Phys **32**, 3688-3698 (2005)

Precaution: Report $D_{m,m}$ and/or $D_{w,m}$?

MBDC transport dose in the actual medium and can report :

- $D_{m,m}$ =dose to medium in that medium
- $D_{w,m}$ =dose to a small water cavity in that medium

POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to the Moderator: William R. Hendee, Medical College of Wisconsin, Milwaukee: whendee@mcw.edu. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

D_m rather than D_w should be used in Monte Carlo treatment planning

Liu and Keall, Medical Physics 2002

Conversion method for $D_{w,m}$/ $D_{m,m}$:depends on cavity size and range of secondary electrons

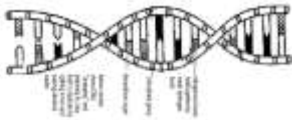
"Small cavity" => $$D_{w,m} / D_{m,m} = \left[{}_{m}\bar{s}_{col} \right]_{m}^{w}$$

"Large cavity" => $$\bar{D}_{w,m} / D_{m,m} = \left[\frac{\bar{\mu}_{en}}{\rho} \right]_{m}^{w}$$

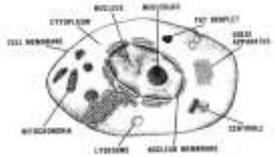
Dimensions of potential ”cavities” for $D_{w,m}$

1.0E-09 1.0E-06 1.0E-03

nm μm mm

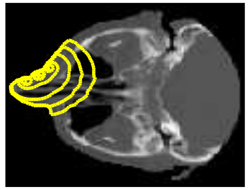


DNA, DNA-bound water



Cell nuclei

Enger et al (2012)
Thomson et al (2013)



Dose calculation grids (CT images)

Rivard et al (2010)
Landry et al (2011)
Acuros system

For BT there is a need to decide how to specify $D_{w,m}$ before discussing which quantity $D_{w,m}$ or $D_{m,m}$ to use!!

TG-186 recommends: report *at the least* Dm,m.

When Dw,m is reported provide information on *how it was defined*!

Dw,m/Dm,m under small and large cavity assumptions

Table 2. The conversion coefficients $D_{\mathrm{w,med}}/D_{\mathrm{med}}$ for bone, adipose and muscle tissue derived using (a) mass-collision-stopping power values averaged over the electron fluence spectra (equation (6)) and (b) mass energy absorption coefficients averaged over the photon energy fluence spectra (equation (7)) for sources emitting monoenergetic photons of energies 20 , 50 and 300 keV and spectra according to isotopes ^{125}I, ^{169}Yb and ^{192}Ir.

Photon energy/isotope	$[_m\bar{S}_{\mathrm{col}}]^{\mathrm{w}}_{\mathrm{adipose}}$	$\left[\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right]^{\mathrm{w}}_{\mathrm{adipose}}$	$[_m\bar{S}_{\mathrm{col}}]^{\mathrm{w}}_{\mathrm{muscle}}$	$\left[\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right]^{\mathrm{w}}_{\mathrm{muscle}}$	$[_m\bar{S}_{\mathrm{col}}]^{\mathrm{w}}_{\mathrm{bone}}$	$\left[\frac{\bar{\mu}_{\mathrm{en}}}{\rho}\right]^{\mathrm{w}}_{\mathrm{bone}}$
20 keV	0.958	1.693	1.011	0.977	1.151	0.155
^{125}I	0.959	1.681	1.011	0.976	1.148	0.150
50 keV	0.959	1.410	1.011	0.970	1.142	0.171
^{169}Yb	0.962	1.033	1.011	1.004	1.142	0.634
300 keV	0.967	1.001	1.011	1.009	1.130	0.989
^{192}Ir	0.968	1.002	1.011	1.009	1.127	1.014

From Carlsson Tedgren and Alm Carlsson PMB (2013) p 2561-2579

Conclusions

- Dosimetric accuracy cruical for safe introduction and useful evaluation of new techniques.

- Differences MBDCA:s –TG43 larger at low (<50 keV) than at high (>50 keV) photon energies.

- Improved tissue segmentation methods important

  < 50 keV. Dual-energy CT ?

- Be aware on the Dm,m - Dw,m issue for BT!

Suggested references

Beaulieu L et al 2012 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 *Med. Phys.* **39** 6208-36

Carlsson Tedgren Å, Verhaegen F and Beaulieu L 2012 Chapter 11: On the introduction of model-based algorithms performing nonwater heterogeneity corrections into brachytherapy treatment planning *In: Comprehensive brachytherapy. Physical and clinical aspects Edited by Venselaar J, Baltas D, Meigooni A S, Hoskin P J CRC Press Taylor and Francis Group Boca Raton London New York (pages 145-160)*

Published after the TG-186 report:

Carlsson Tedgren Å and Alm Carlsson G 2013 Specification of absorbed dose to water using model based dose calculation algorithms for treatment planning in brachytherapy *Phys. Med. Biol.* **58** 2561-2579

Thomson R M, Carlsson Tedgren Å and Williamson J F 2013 On the biological basis for competing macroscopic dose descriptors for kilovoltage dosimetry: cellular dosimetry for brachytherapy and diagnostic radiology *Phys. Med. Biol.* **58** 1123-50

Lindborg L et al 2013 Lineal energy and radiation quality in radiation therapy: model calculations and comparison with experiment *Phys Med Biol*. **58** 3089-3105

Malusek A, Karlsson M, Magnusson M and Alm Carlsson G 2013 The potential of dual-energy computed tomography for quantitative decomposition of soft tissues to water, protein and lipid in brachytherapy, Phys. Med. Biol. 58 771

AAPM Working Group on Model-Based Dose Calculation Algorithms in Brachytherapy

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Ronald Sloboda
Rowan Thomson
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Three follwing slides are extra material to be available just in case discussion goes this direction

Burlin cavity theory

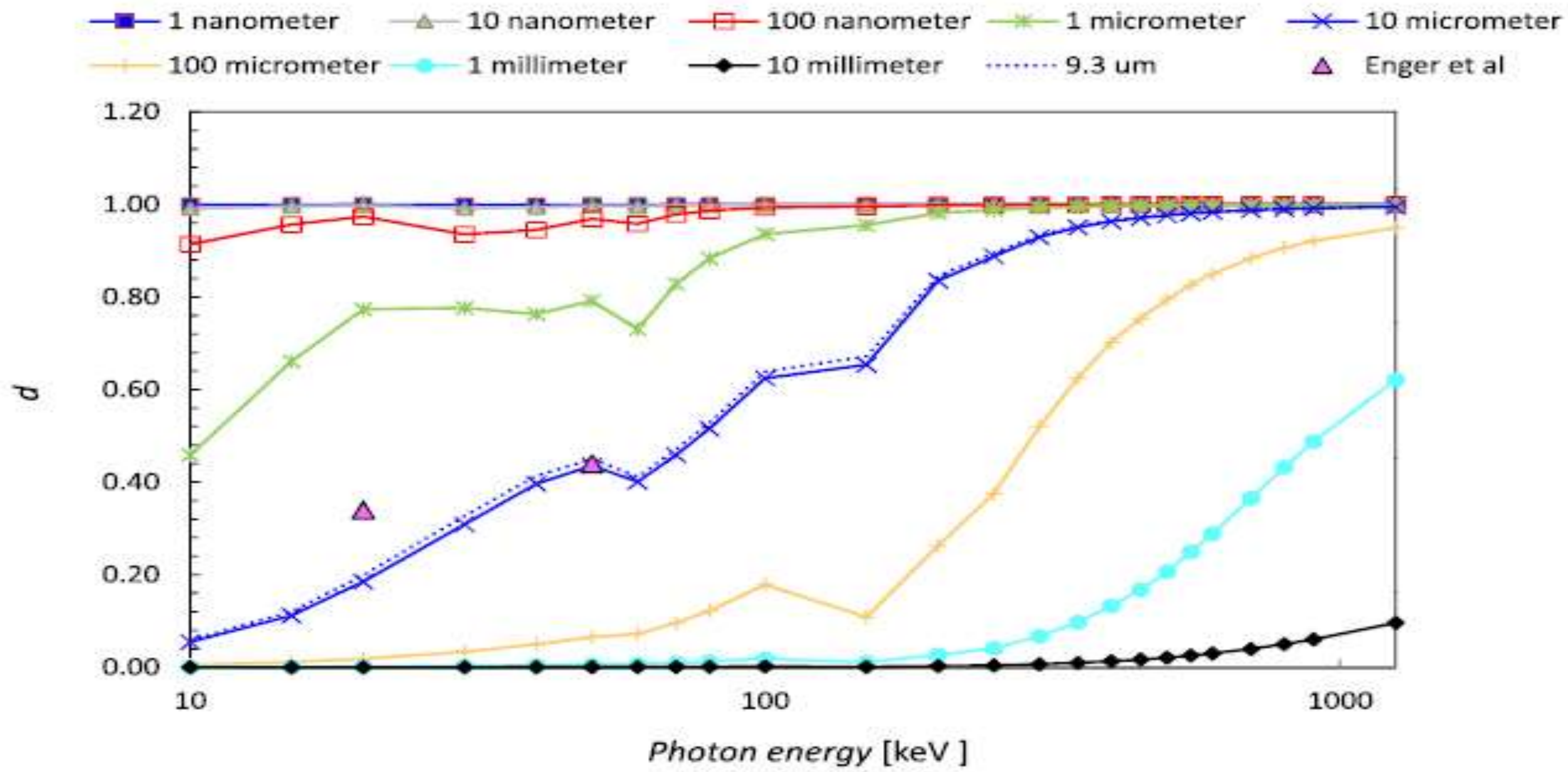
$$\overline{D}_{\mathrm{w,m}} / D_{\mathrm{m,m}} \approx d\left[{}_{\mathrm{m}}\bar{s}_{\mathrm{col}} \right]_{\mathrm{m}}^{\mathrm{w}} + (1-d)\left[\frac{\mu_{\mathrm{en}}}{\rho} \right]_{\mathrm{m}}^{\mathrm{w}}$$

$$d = (1-e^{-\beta g}) / \beta g$$

<u>g mean chord length of the cavity</u>

β mass attenuation of generated secondary electrons

Values of paramater *d* in Burlin theory



From Carlsson Tedgren and Alm Carlsson PMB (2013) p 2561-2579

Correlation between RBE and y_D in 10 nm diameter volumes

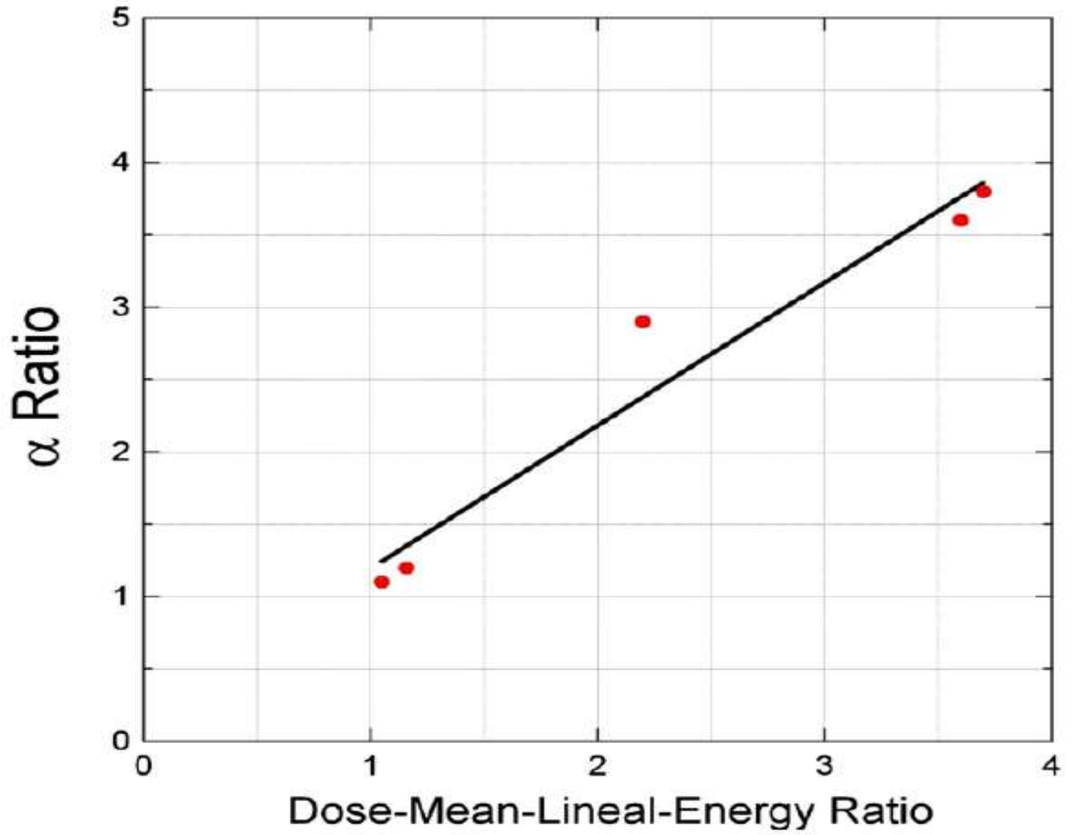


Figure 5. The α-ratio as a function of the $\bar{y}_D$-ratio for square cylinders with diameter of 10 nm. The values at $\bar{y}_D$-ratio of 2.2 represent the carbon ion beam at the centre of the SOBP (12.5 cm). The uncertainty in $\bar{y}_D$ is here larger than in the calculation for the distal part. The α-values are derived from the LQ-relation and are stated in table 1.

From Lindborg *et. al.* PMB (2013) p 3089-3105