TPS: algorithms

ICTP SCHOOL ON MEDICAL PHYSICS
Radiation Therapy:
Dosimetry and Treatment Planning
for Basic and Advanced Applications
ICTP, Trieste 2019

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CENTRUM ONKOLOGII – INSTYTUT
IM. MARII SKŁODOWSKIEJ-CURIE

To understand dose deposition
high atomic number (Z) materials

theory and practice
modeling in TPS

Paweł Kukołowicz, Ryszard Dąbrowski

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Succes or failure of radiotherapy

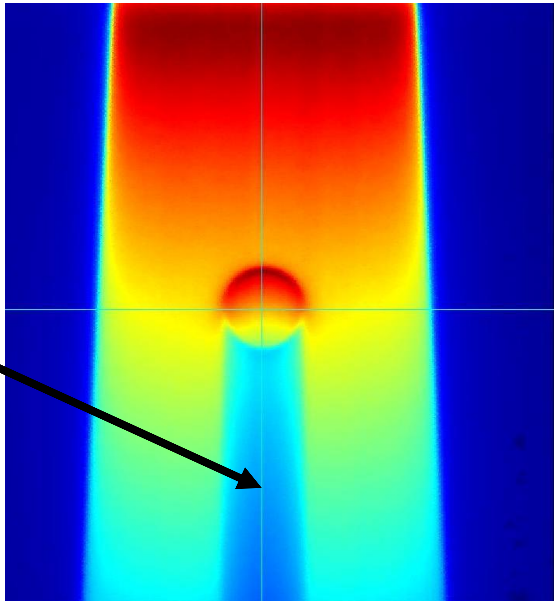
- Depends upon the accuracy with which dose prescription is fulfilled
  - AAPM, Taks Group 63 Report

- Human body consists of many tissues e.g. soft, bone, lung, teeth, and air cavities
  - **high Z materials are also present**
    - **hip prostheses**

Hip prosthesis influence

dose distribution measured with Gafchromic film
X 6MV, 10x10 cm, SSD=90 cm, 200 MU
brass cylinder, diameter 25mm

- decreased tumour dose
- increased dose near the tissue-metal interface



courtesy of Ryszard Dąbrowski

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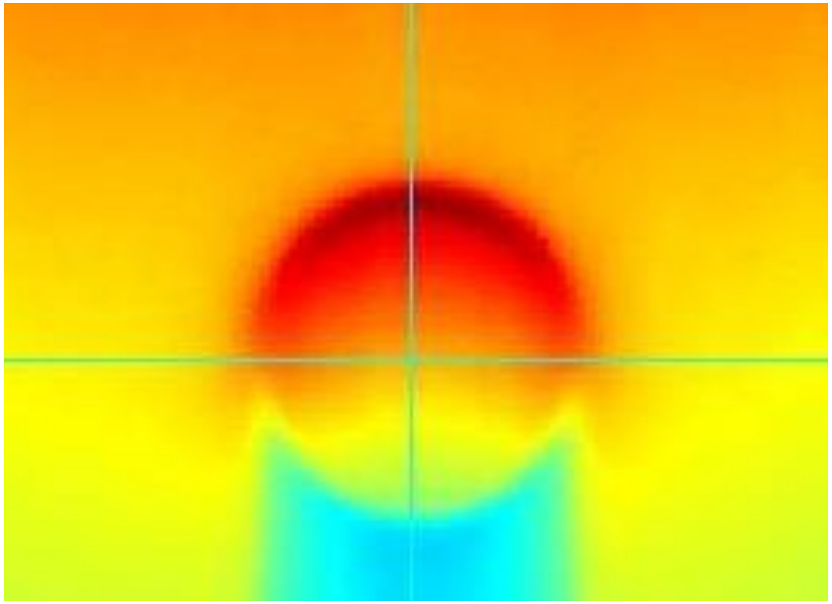
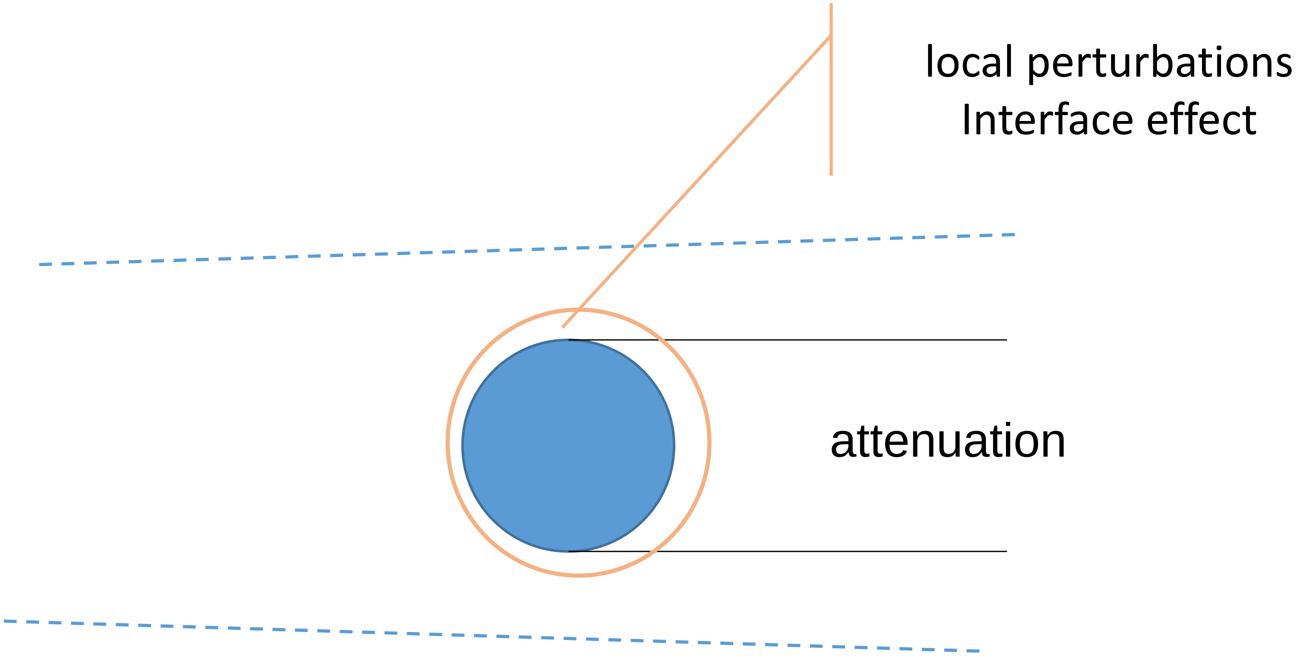


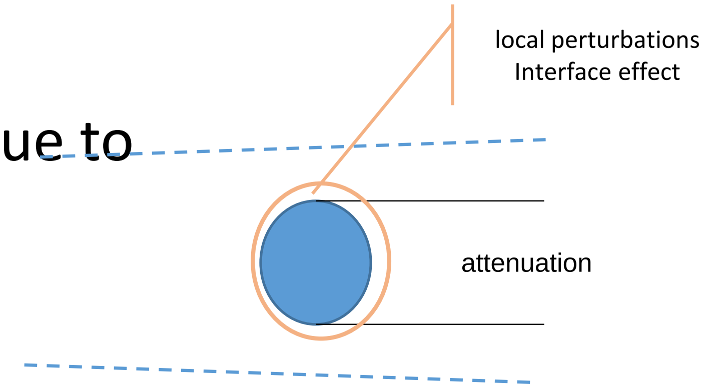
courtesy of Ryszard Dąbrowski

Influence of High Z material on dose distribution



Influence of High Z material on dose distribution

- Attenuation
  - energy photon fluence is smaller due to attenuation of photons
    - dose is smaller



- Local perturbations – interface effects
  - energy electron fluences is changed by local perturbations

What we are talking about?
Comaparison of what?

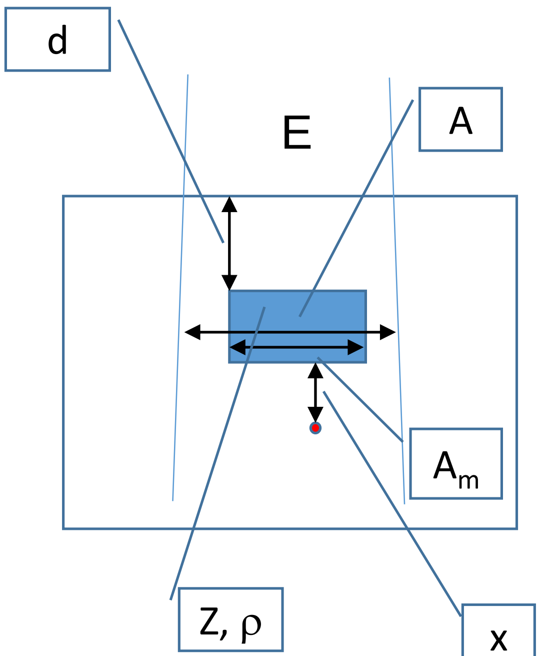
- dose distribution with H – Z material
    - and
- dose distribution without H – Z material

- Correction factor is the ratio of doses with and without the presence of H – Z material

$$CF(E, A, A_m, d, t, x, Z, \rho, \theta) = D_m / D_{H_2O}$$

$$CF\left(E, A, A_m, d, t, x, Z, \rho, \theta\right) = D_m / D_{H_2O}$$

- E – photon Energy (spectrum)
- A, Am – field size, size of H-Z material
- d – depth of interface with the soft tissue
- t – thickness of H – Z material
- x – distance from the material to point where the dose is estimated
- Z, ρ – Z and density of material
- θ – the beam angle relative to material (position with respect to material)



Fluence Correction Factor

- To comapare homogenous and actual situations

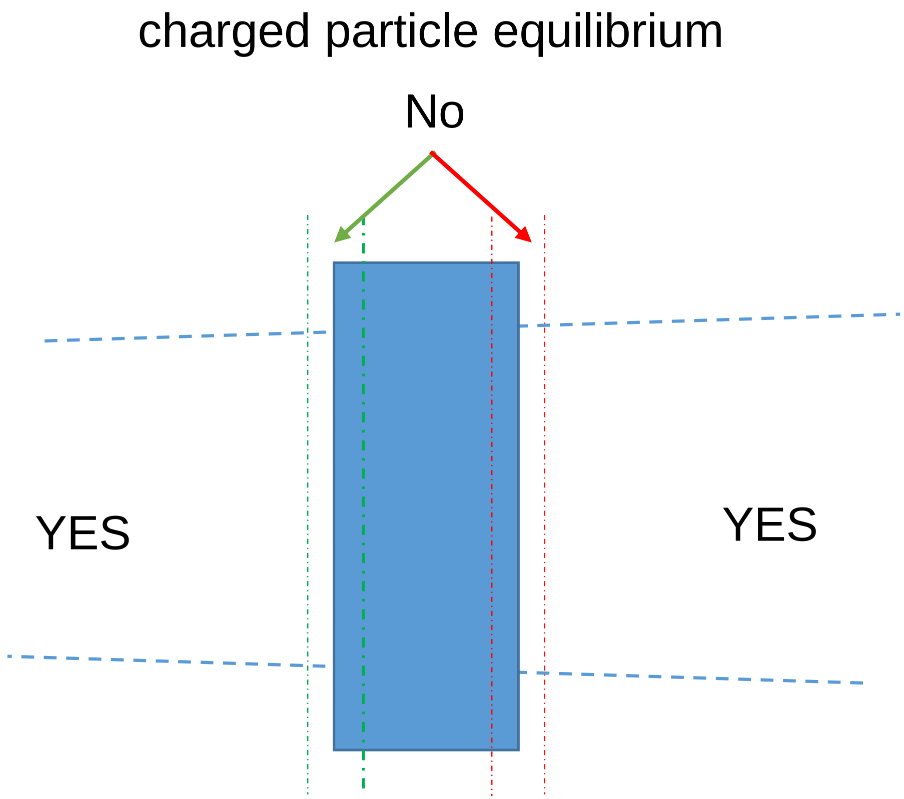
but

- neglecting photon fluence changes
  - CF_{FC}
  - CF is corrected for photon fluence

$$CF_{FC} = CF \cdot \frac{\Phi_{water}}{\Phi_m} = CF \cdot \exp((\mu_{water} - \mu_m) \cdot t_m)$$

t_m – physical thickness of the inhomegeneities (prothesis)

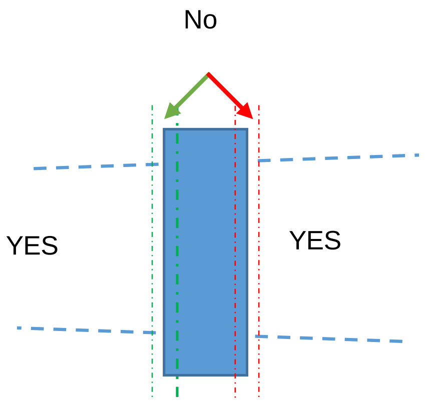
Slab geometry
to make it more simple



Slab geometry

to make it more simple

- Charged particle equilibrium
- YES
  - dose ≈ kerma
    - photon energy fluence
- No
  - dose ≠ kerma
    - transport of secondary electrons and their spectrum is important



Slab geometry
to make it more simple

- Charged particle equilibrium
- YES
  - dose ≈ kerma
    - photon energy fluence

$$D \cong K = \Phi_{h\nu} \cdot \frac{\mu}{\rho} \cdot \overline{E_{e,tr}}$$

- No -
  - dose ≠ kerma
    - transport of secondary electrons and their spectrum is important

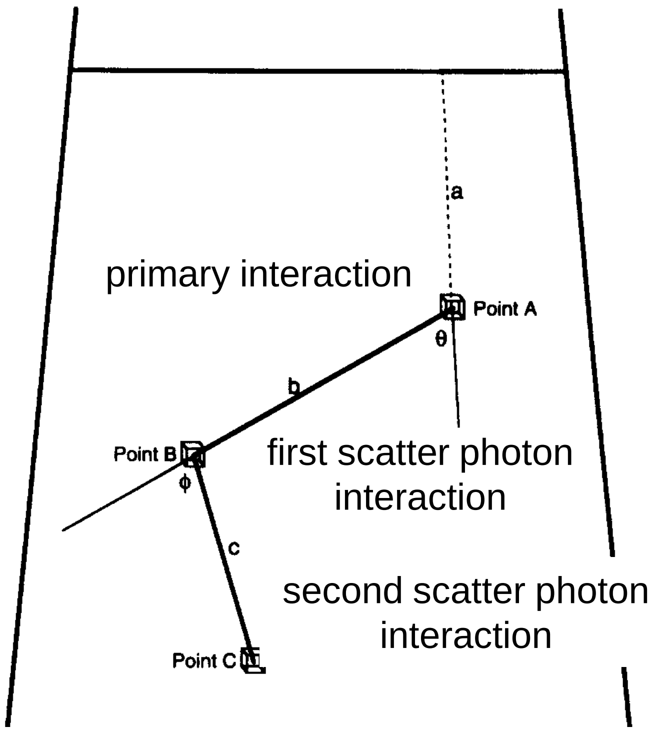
$$D \cong \Phi_e \cdot \frac{S_{col}}{\rho}$$

No Charged Particle Equilibrium

- Energy is transfered from photons to electrons
  - next: electrons transport energy
    - transfer from photons to electrons depends on photons energy
      - spectrum of electrons
      - angular distribution of electrons
- Photons
  - primary photons
  - first scatter photons
  - second and higher order scattered photons

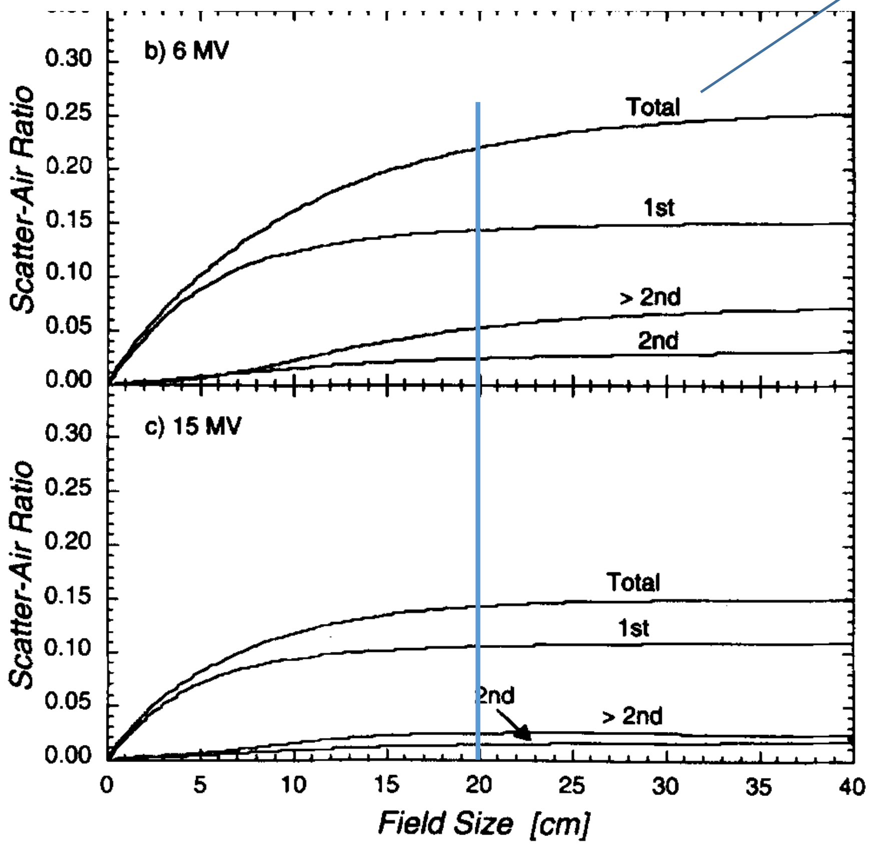
Primary and scattered photons

- Photons
  - primary photons
  - first scatter photons
  - second and higher order scatter photons



Dose components

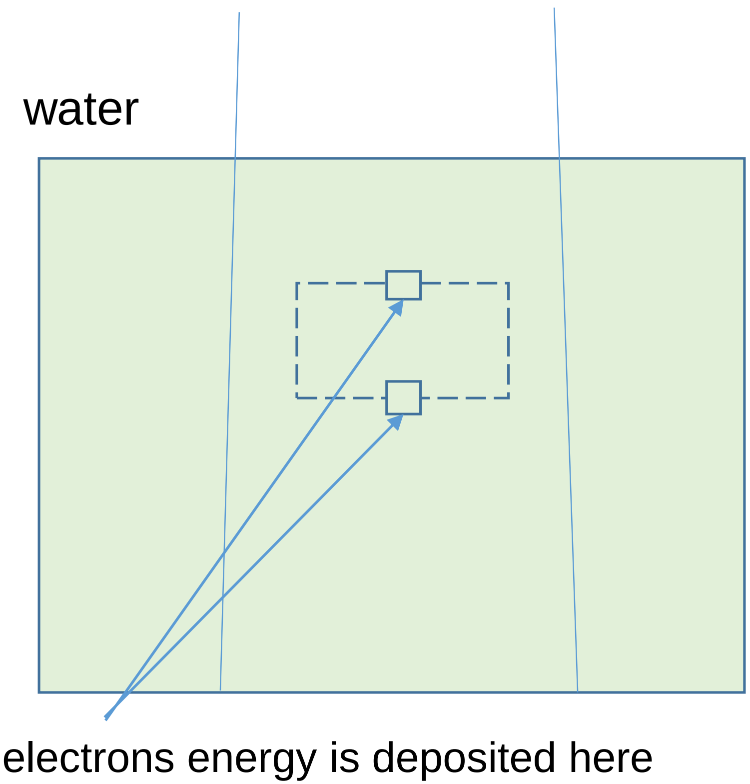
scattered



Sontag, Med. Phys. 1995, 22 (6)

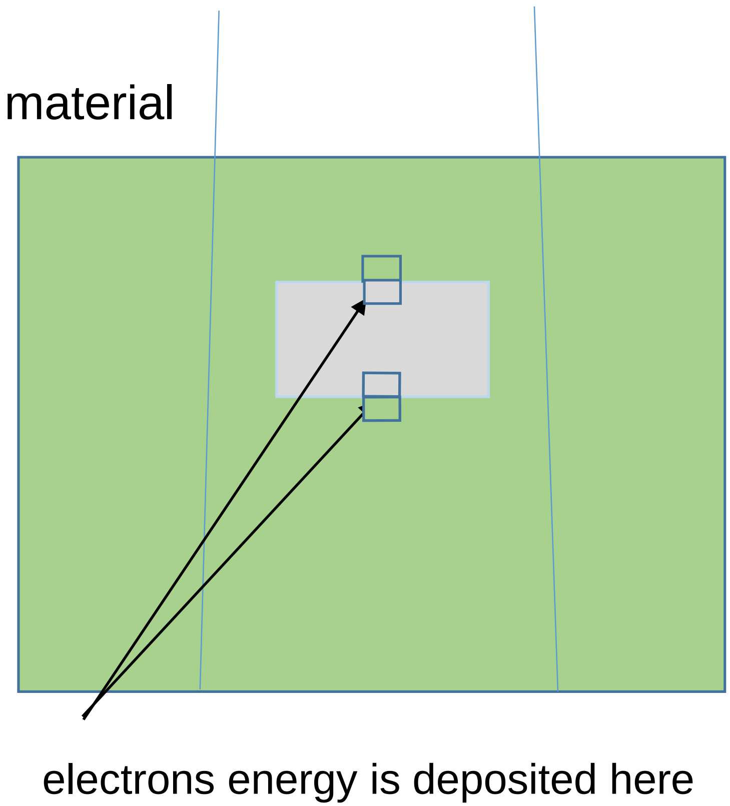
primary dose > 80% of total dose
1st scattered > 60% of total scattered

Energy deposition homogeneous equilibrium state



$$D \cong K_{water} = \Phi_{water} \cdot \left(\frac{\mu}{\rho}\right)_{water} \cdot \overline{E}_{water,tr}$$

Energy deposition understanding



$$D \neq K = \Phi_{h\nu} \cdot \frac{\mu}{\rho} \cdot \overline{E_{e,tr}}$$

Radiological properties

part of energy transfered is emmited as breamstrahlung radiation

	Muscle		Lead	
photon energy	$\left(\frac{\mu}{\rho}\right)$ (cm2/g)	$\overline{E}_{tr}$ (MeV)	$\left(\frac{\mu}{\rho}\right)$ (cm2/g)	$\overline{E}_{tr}$ (MeV)
1 MeV	0.0701	0.440	0.0701	0.550
2 MeV	0.0490	1.060	0.0453	1.130
3 MeV	0.0393	1.740	0.0417	1.860
5 MeV	0.0300	3.210	0.0423	3.600
8 MeV	0.0239	5.610	0.0454	6.470
10 MeV	0.0220	7.320	0.0488	8.45

Larger energy is transfered from photons to electrons for H – Z materials than for soft tissue

Radiological properties

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=

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Larger energy is transfered from photons to electrons for H – Z materials than for soft tissue

Energy that will be transfered to tissue (yellow) from small red box

	Muscle	Lead
photon energy	$\left\{\left(\frac{\mu}{\rho}\right)\cdot\overline{E}_{ab}\right\}_{muscle}\Big/\left\{\left(\frac{\mu}{\rho}\right)\cdot\overline{E}_{ab}\right\}_{lead}$	
1 MeV	0,860	
2 MeV	1,106	←
3 MeV	0,986	
5 MeV	0,736	
8 MeV	0,560	
10 MeV	0,498	

$$\left\{\left(\frac{\mu}{\rho}\right)\cdot\overline{E}_{ab}\right\}_{muscle}\Big/\left\{\left(\frac{\mu}{\rho}\right)\cdot\overline{E}_{ab}\right\}_{lead}$$

H – Z versus muscle

- Primary dose is the most important
  - effective energy transfered to electrons
    - is not (very) much different for 6 MV
    - is higher for 15 MV
- What is very much different
  - Upper - back
    - direction of electrons tracks
  - Lower - forward
    - photon fluence
    - direction of electrons tracks

	Muscle		Ratio
photon energy	$\left\{\left(\frac{\mu}{\rho}\right)\cdot\overline{E}_{ab}\right\}_{muscle} \Big/ \left\{\left(\frac{\mu}{\rho}\right)\cdot\overline{E}_{ab}\right\}_{lead}$		
1 MeV		0,860	
2 MeV		1,106	
3 MeV		0,986	
5 MeV		0,736	
8 MeV		0,560	
10 MeV		0,498	

Back scatter

Upper - back

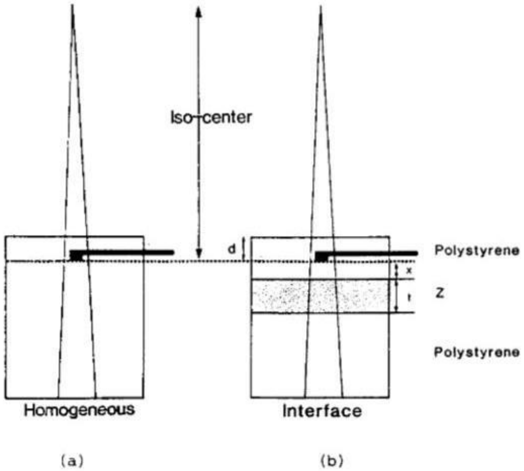


FIG. 2. Experimental setup for the measurement of the backscatter dose factor (BSDF). The ratio of readings in two setups (interface and homogeneous) give the BSDF defined in Eq. (1).

Med. Phys. Das 1989, 16 (3)

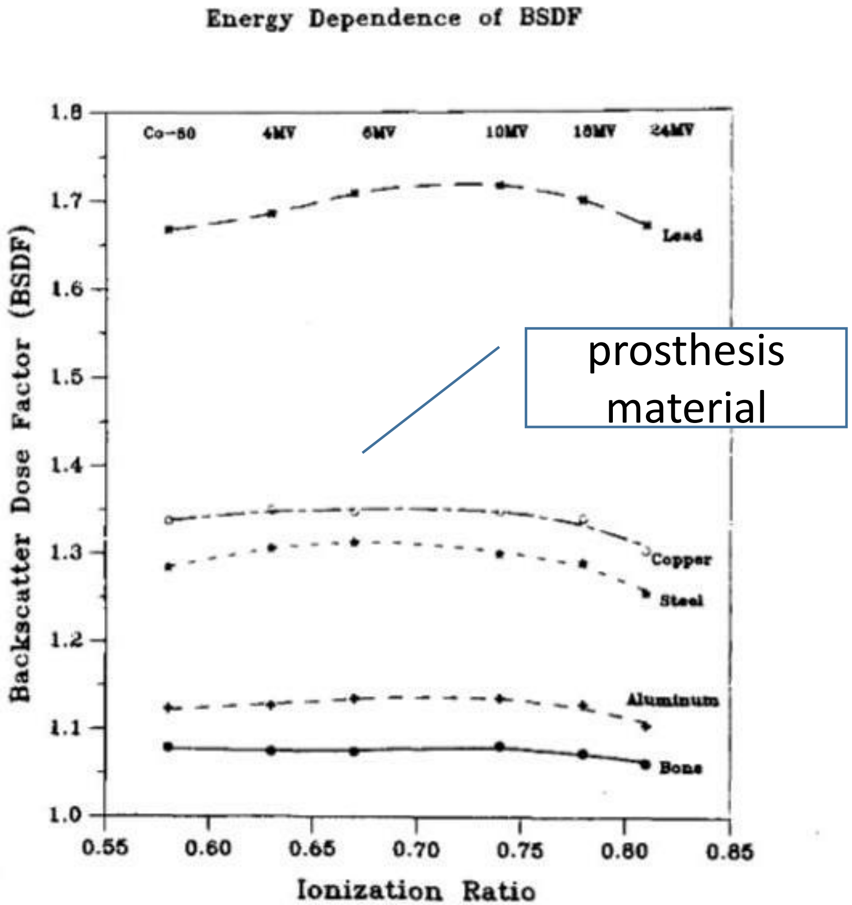
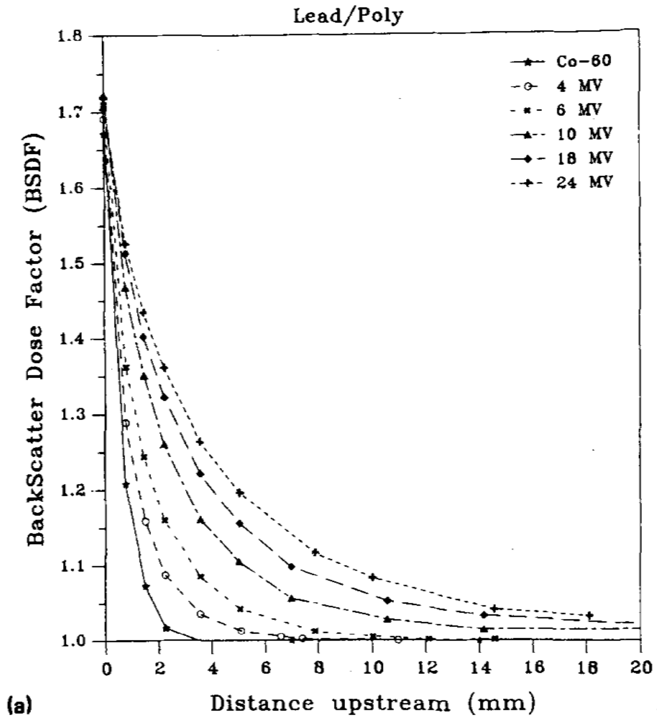
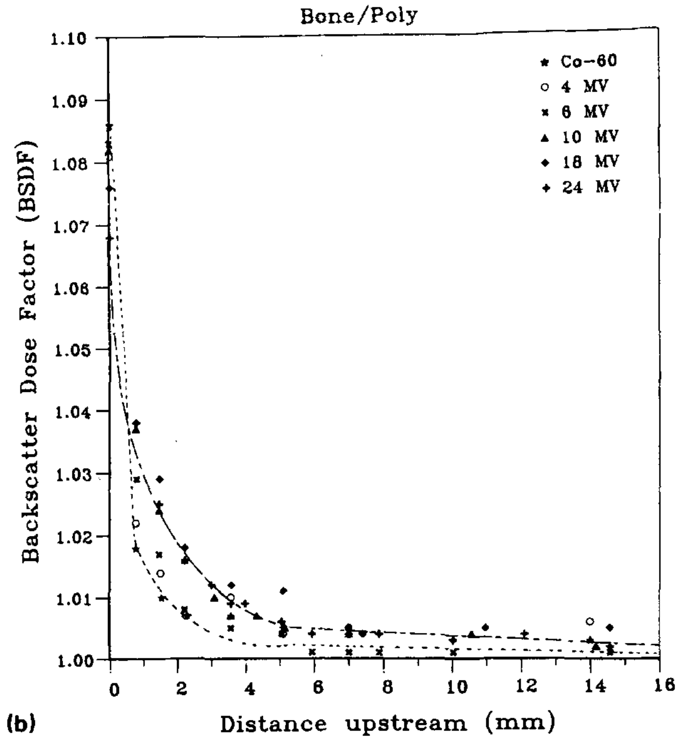


FIG. 5. Backscatter dose factor (BSDF) vs energy of the photon beams plotted as the ionization ratio defined in AAPM Protocol TG-21, for various media.

Back scatter

Upper - back

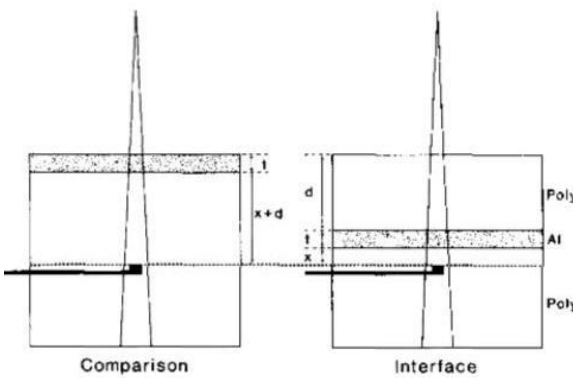




Med. Phys. Das 1989, 16 (3)

Forward scattered
corrected for fluence

$$\beta' = \frac{(\text{dose at interface} - \text{comparison dose})}{\text{comparison dose}}, \qquad (2($$



Aluminium

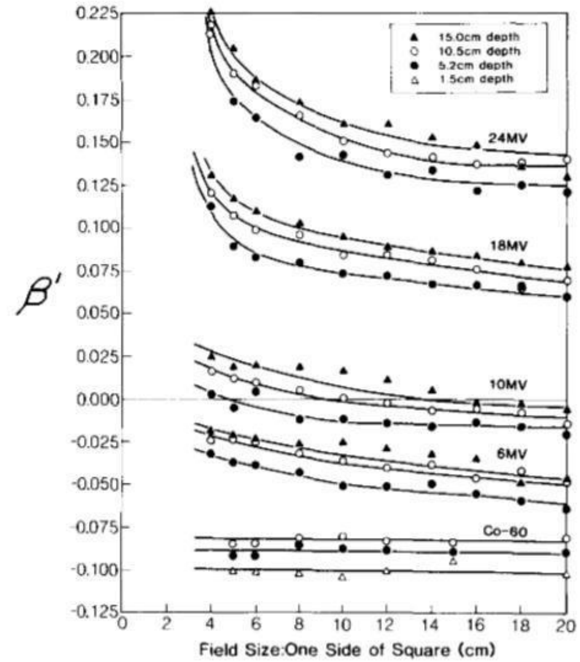


FIG. 5. Measured dose perturbation in polystyrene downstream from a thick aluminum sheet, for photon beams of energies from ^{60}Co to 24 MV, as a function of field size and depth in phantom. The phantom configuration is shown in Fig. 4(a) with $x = 0$, $t = 1.2$ cm for ^{60}Co and 4.0 cm for all other energies, d = variable. The symbols are keyed to the values of d. The vertical axis represents the dose perturbation β' defined by Eq. (20). The error in the measurement of β' is less than $\pm .01$.

Dose changes at interface

- Electron fluence is the same

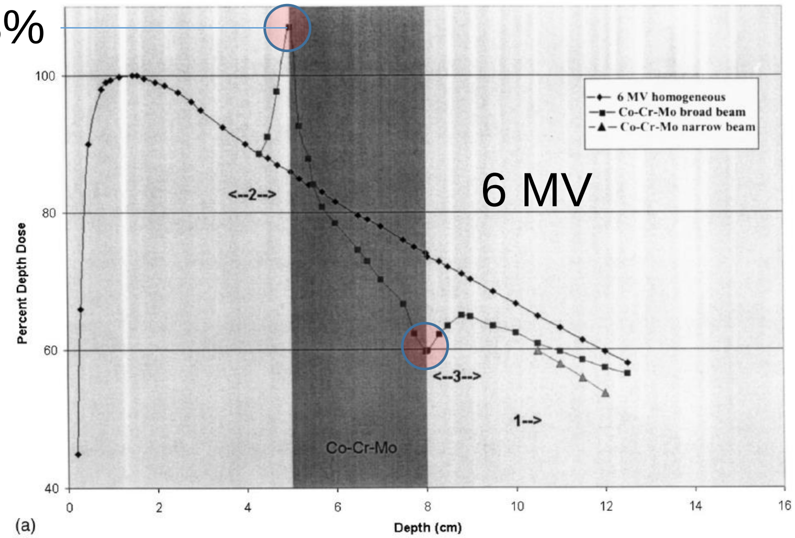
$$\frac{D_{insert}}{D_{water}} \cong \left(\frac{\mathrm{S}_{\mathrm{col}}}{\rho}\right)_{\mathrm{water}}^{\mathrm{insert}}$$

Lower - forward

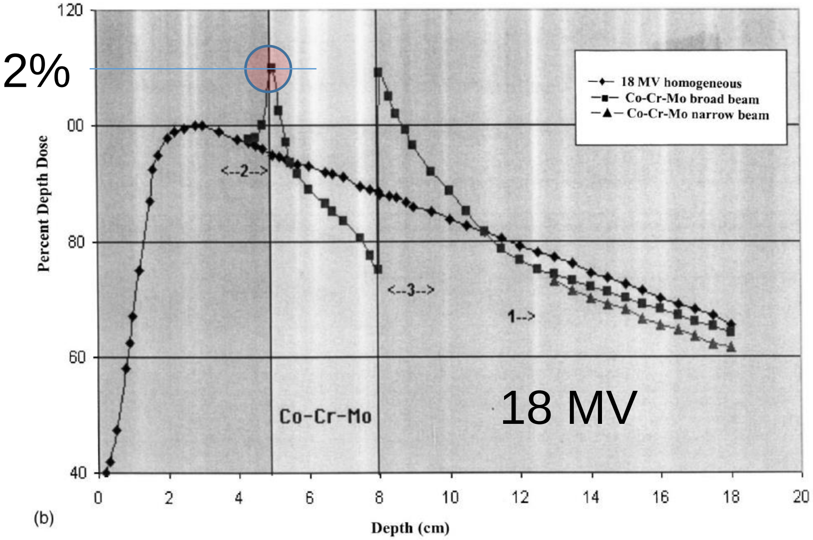
Error at interface – dose jump/drop

$$\left(\frac{S_{col}}{\rho}\right)_{water}^{insert}$$

108%



112%



AAPM TG 63

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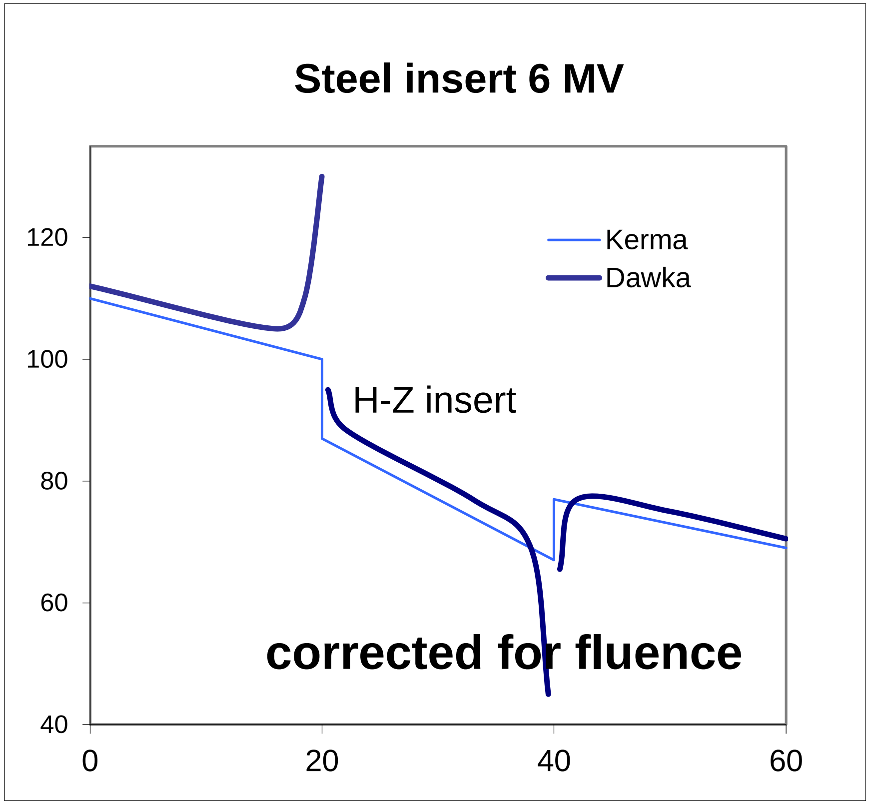
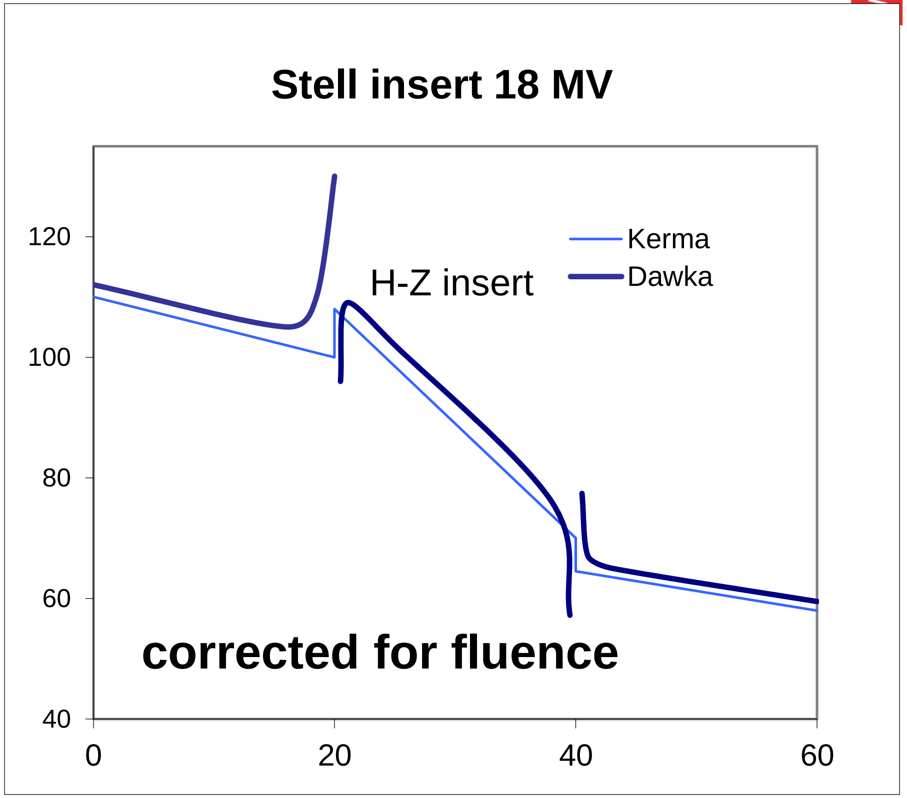
Dawka = Dose

Kerma – Dose at interface

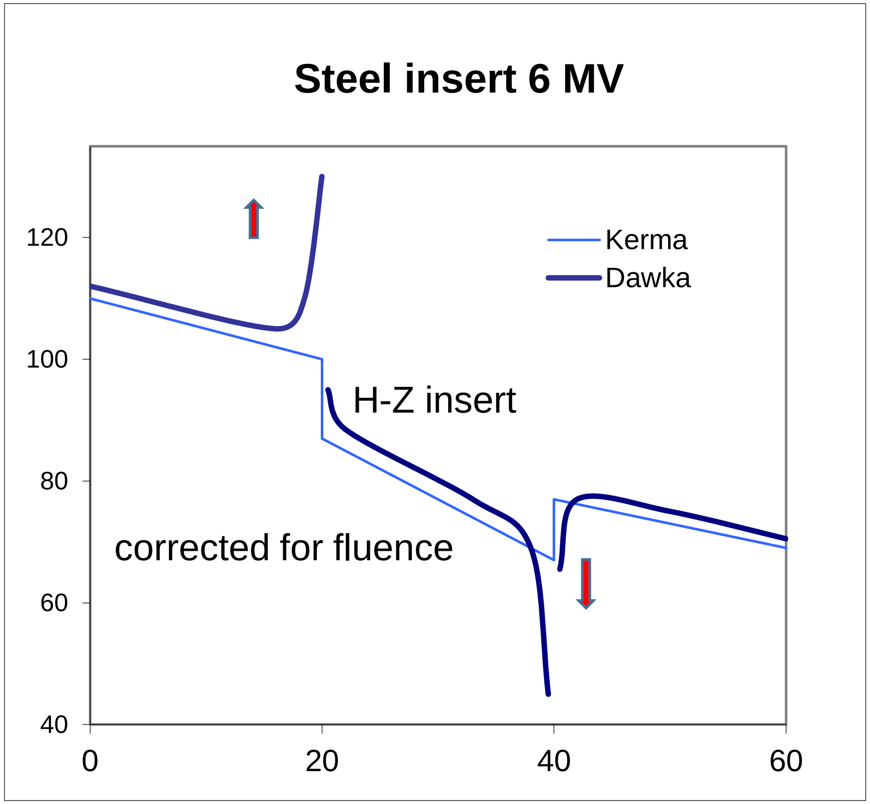


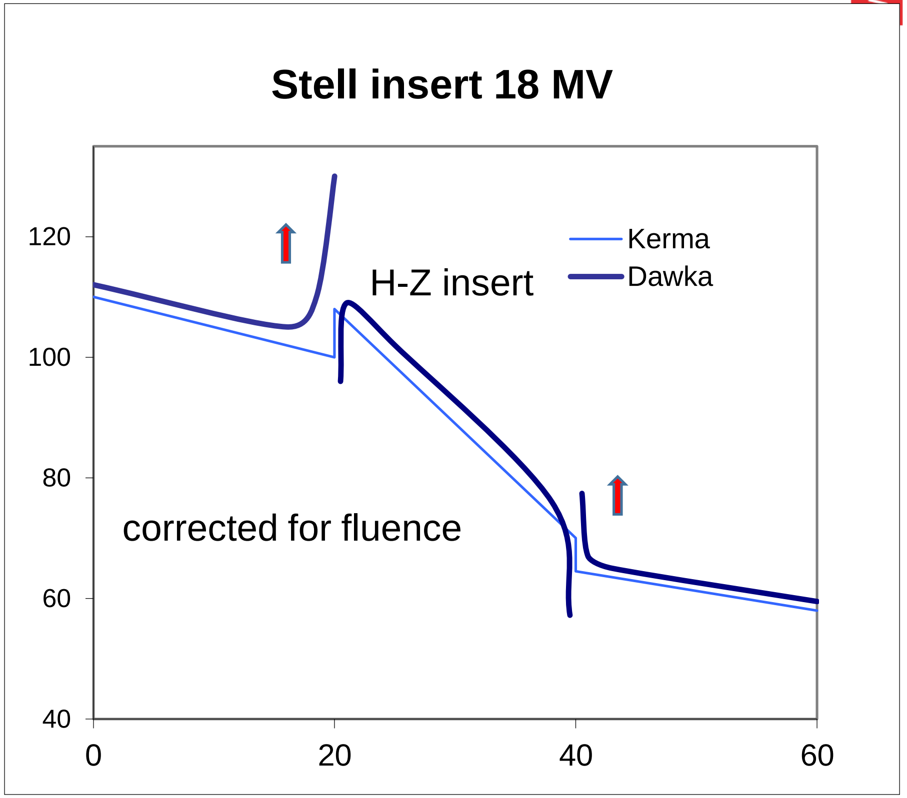


At interface there is jump/drop of dose.

Dawka = Dose

Kerma – Dose at interface





At interface there is jump/drop of dose.

Practice

How to recognize that medical physicist is real expert?

Be able to critically look at the results obtained.

How to cope with H – Z material in daily practice?

- Don’t relay to much on TPS calculations
  - be acquinted with the calculation algorithm
    - limitations
  - relay on your knowledge!
- Use the right HU – electron density curve
  - measured yourself
  - or overlay the electron density obtained from HU curve with the real one
- Use (if possible) CT obtained with metal artifacts reduction protocol (MAR protocol)

Calculation algorithm

- In general
  - superposition-convolution algorithms give good results in CPE region,
  - Monte-Carlo – the only one may accuratly calculate the dose in regin where there is no CPE (Monaco!)
  - Acuros gives quite good results

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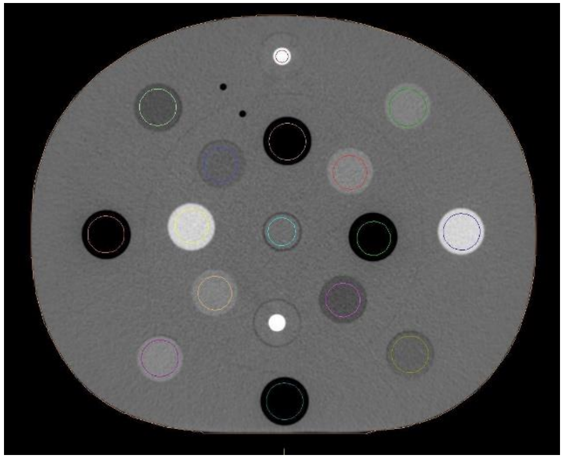
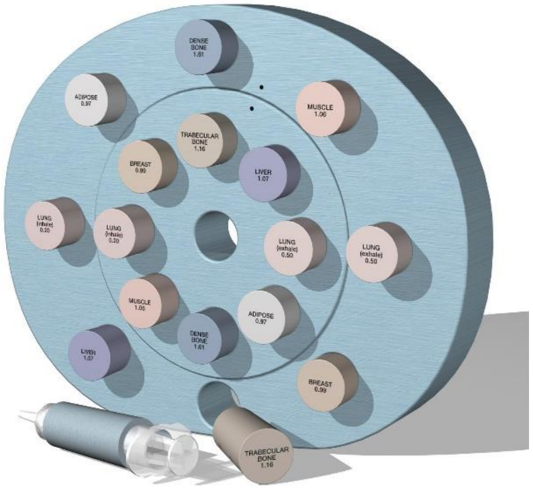
HU – electron density curve measurement

- e.g. CIRS Phantom
  - special H-Z inserts
    - aluminium, brass, steel

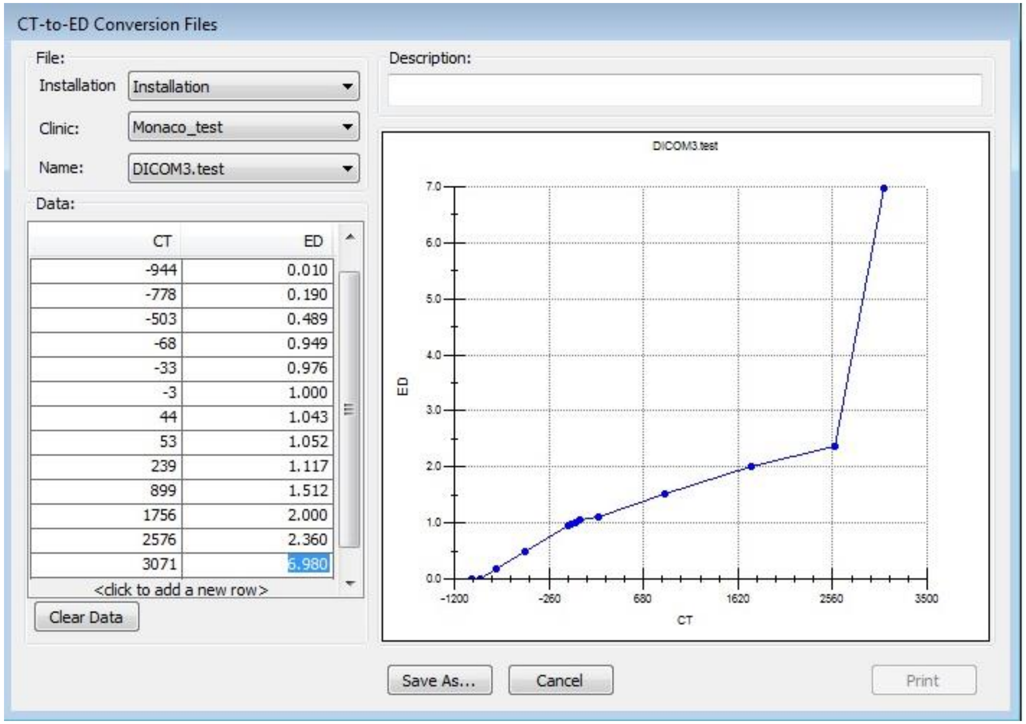




What we should remember of?

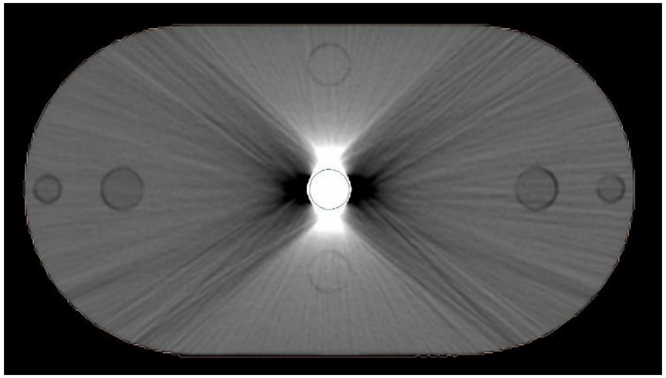
- Standard mode
  - 12 bits up to 2^{12}; 4096 HU: -1204 - +3071 (aluminium)
- Extended mode
  - 16 bits up to 2^{16}; 65536 HU (any material)

HU – electron density conversion curve

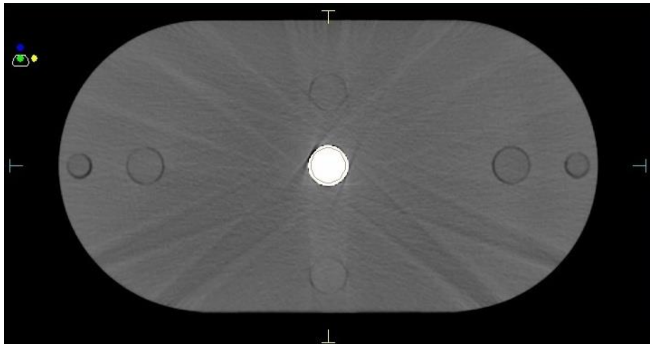


Metal Artifacts Reduction algorithm

without MAR



artifacts
difficuly to draw the external contour



less artifacts
much easier to draw the external contour

with MAR

Med. Phys. 42 (3), March 2015

Clinical evaluation of the iterative metal artifact reduction algorithm for CT simulation in radiotherapy

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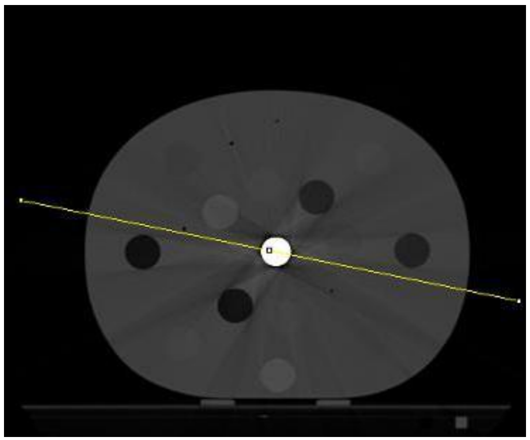
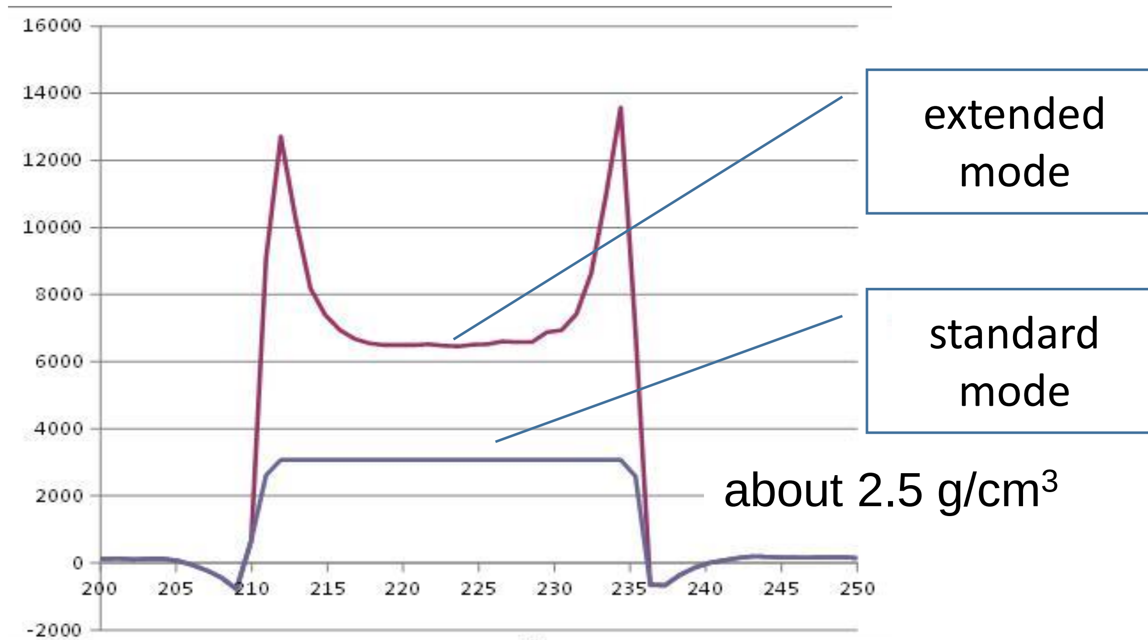
Ajay Paidi
Computed Tomography and Radiation Oncology Department, Siemens Medical Solutions USA, 757A Arnold Drive, Martinez, California 94553

Brass cylinder imaged in standard and extended mode



extended mode



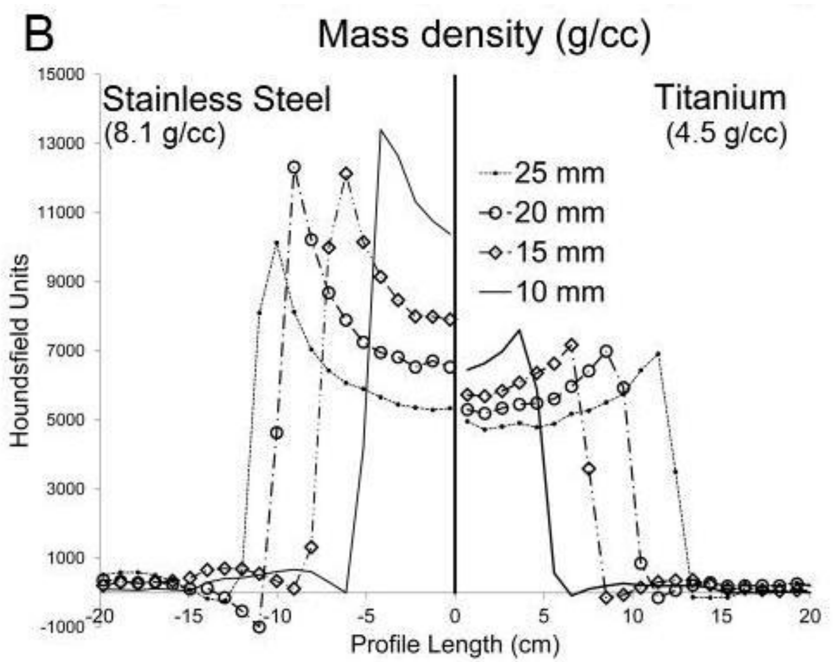
Another approach

- Knowing the prosthesis design
  - manually defined electron density of the prostheis

	Co-Cr-Mo alloy	titanium	steel
atomic composition	Co 60% Cr 30% Mo 5%	Ti 90% Al 6% Va 4%	Fe 65% Cr 18% Ni 12 Mo 3
ρ [g/cm^3]	7.9	4.3	8.1
relative electron density	6.8	3.6	6.7

How to know the design of the prosthesis and its size?

- From patient and manufacturer
  - usually impossible
- From CT made in extended mode
  - very uncertain

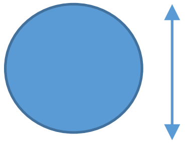


Med. Phys. 2015, 43 (3), Axente at al.

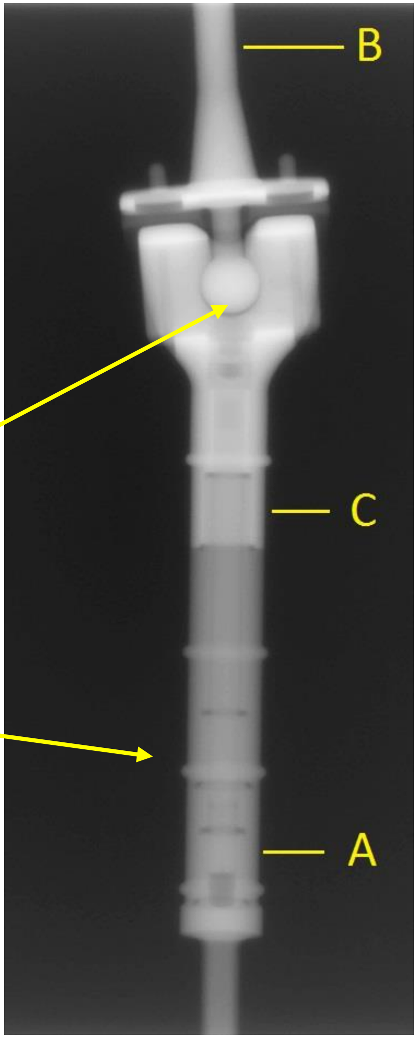
Megavoltage image

- Comparison of calculated and measured attenuation.
  - measured with portal

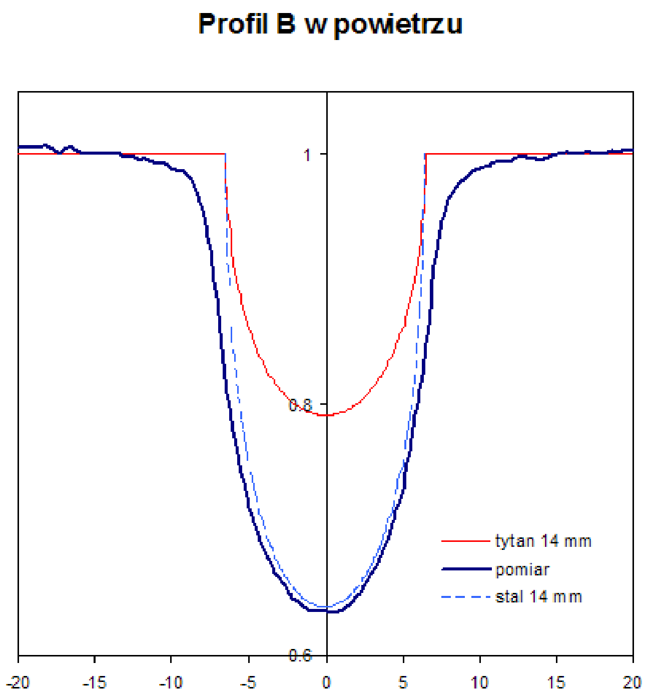
$$\exp(-(\mu_{ins} - \mu_{wody}) \cdot d)$$



close to edge of prosthesis

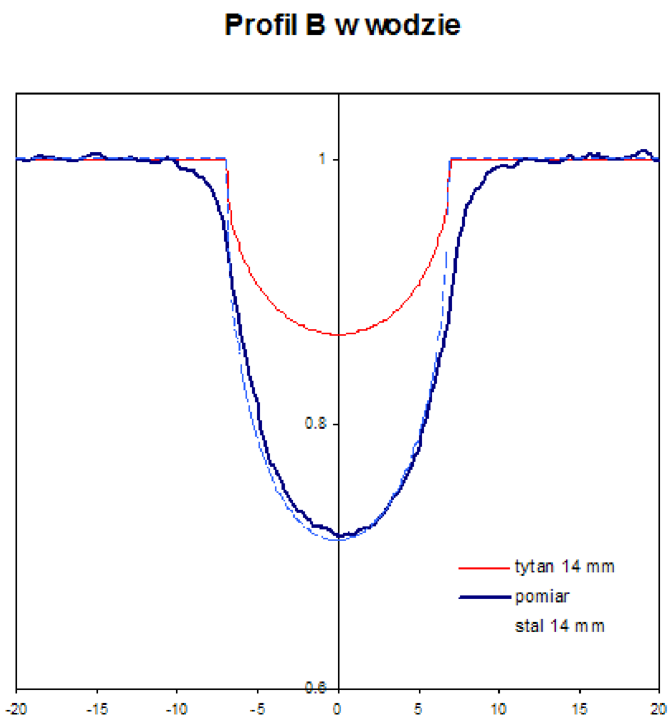


Attenuation calculation



Air

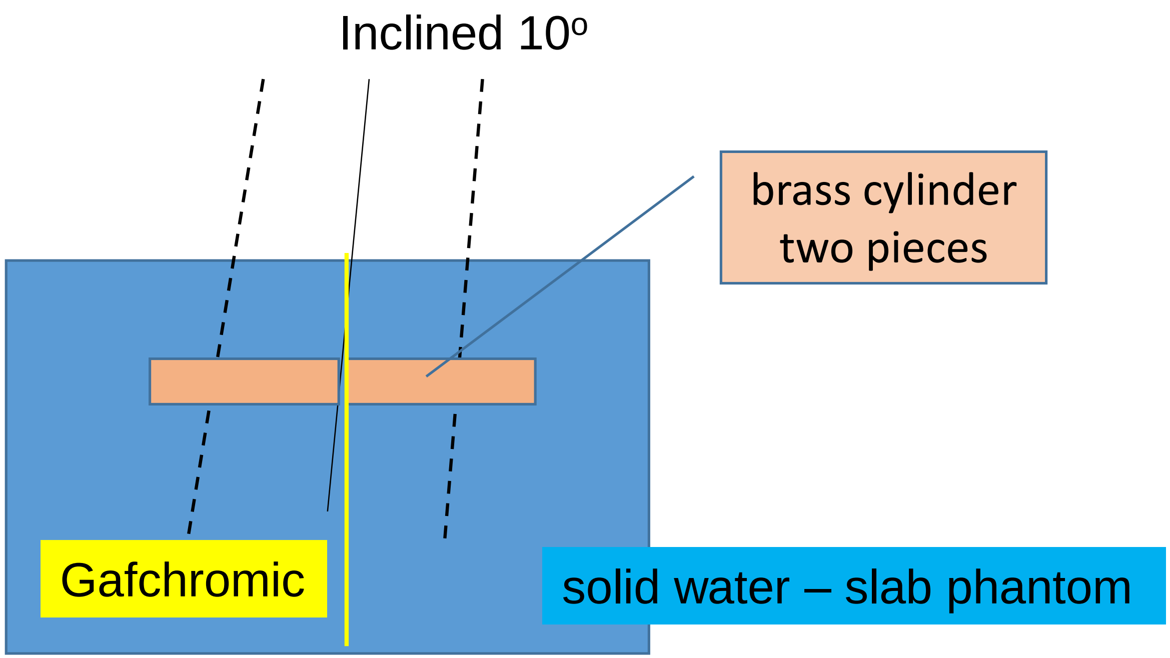
Water



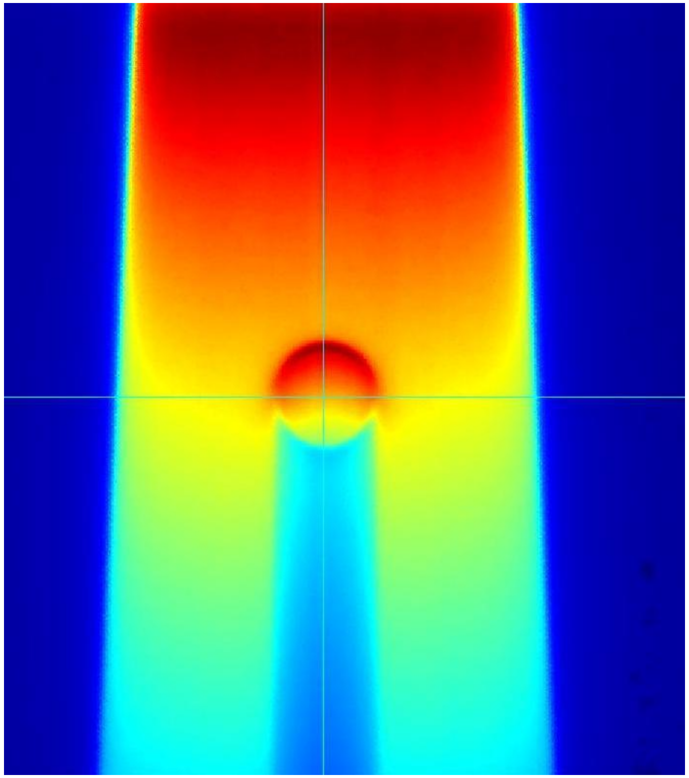
Attenuation for different materials

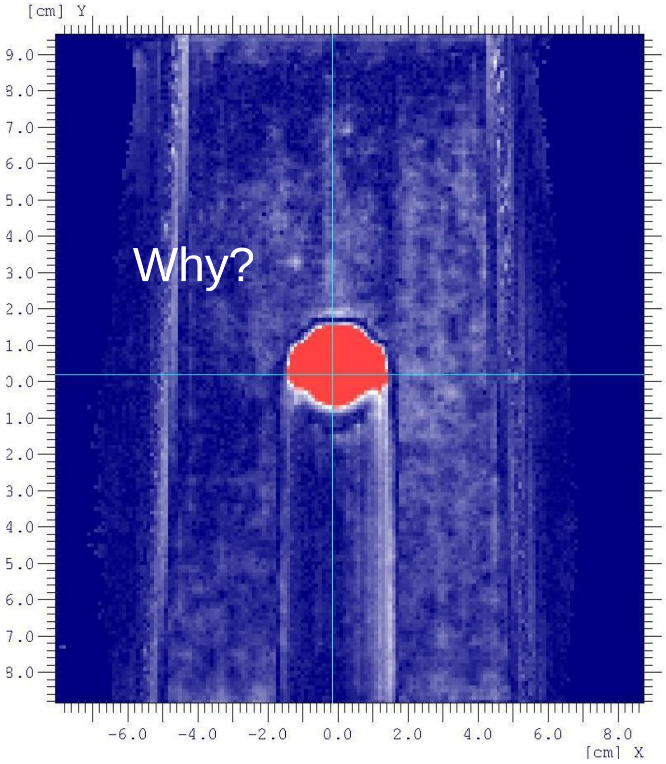
	woda	Titanium	Steel
μ/ρ [cm²/g]	0.0397	0.0351	0.0362
ρ [g/cm³]	1.0	4.3	8.1
attenuation for 1cm [%]	3.9	14.0	25.4

Comparison of measurements and calculations



Measurements results
gamma analysis (versus Monaco)





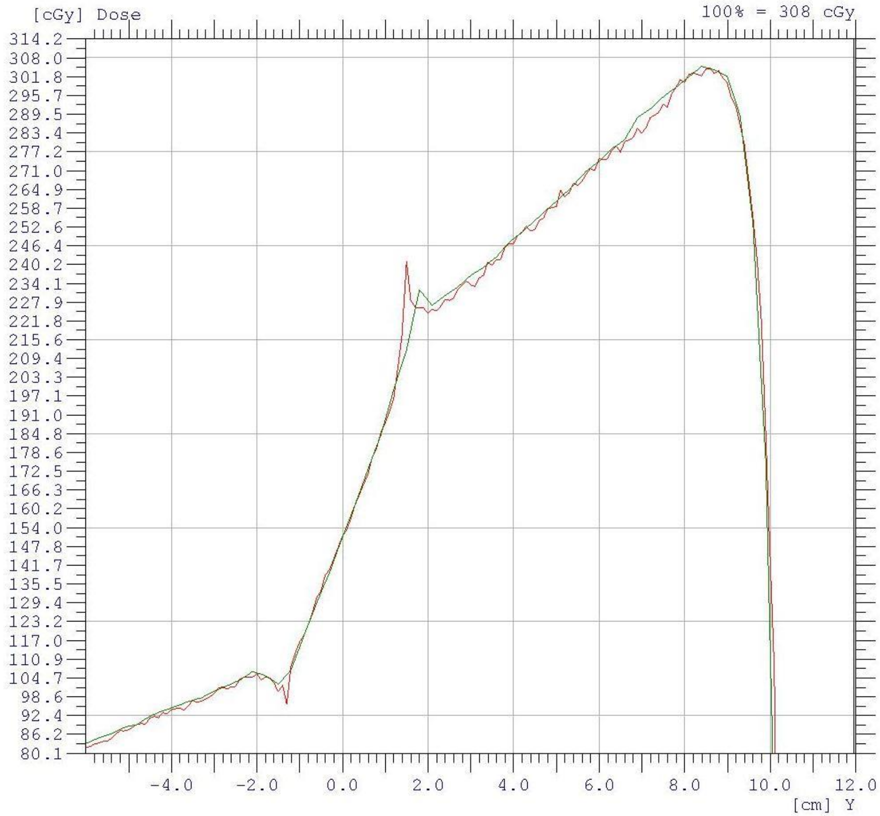
gamma
blue < 1

What we measure with film?
6 MV photons

- We measure the dose delivered by electrons created in brass
  - electron fluence spectrum is brass electron fluence spectrum
  - dose is absorbed in Gafchromic - water

$$\frac{D_{film}}{D_{brass}} = \left(\frac{S_{col}}{\rho}\right)_{brass}^{water} \approx 1.4$$

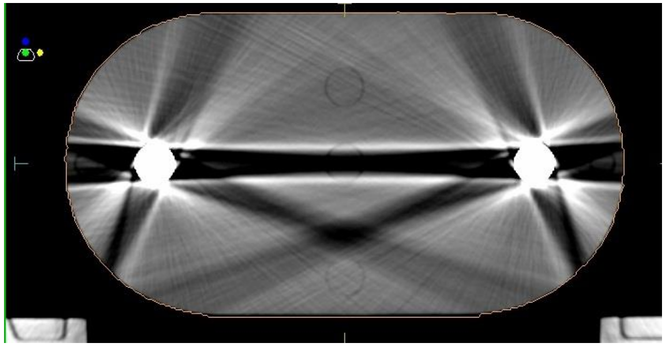
After corrections



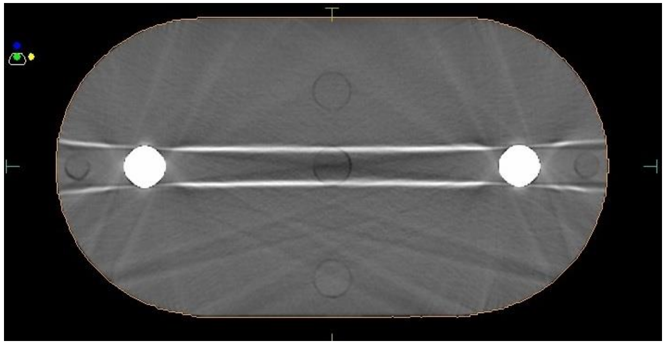
Summary

- CT for planning should be performed with Metal Artifacts Reduction software and in extended mode

without MAR



with MAR



courtesy of Ryszard Dąbrowski

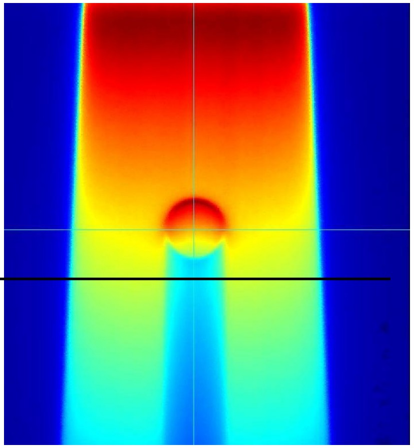
Summary

- Individual HU - electron conversion curve should be used
  - 16 bits mode

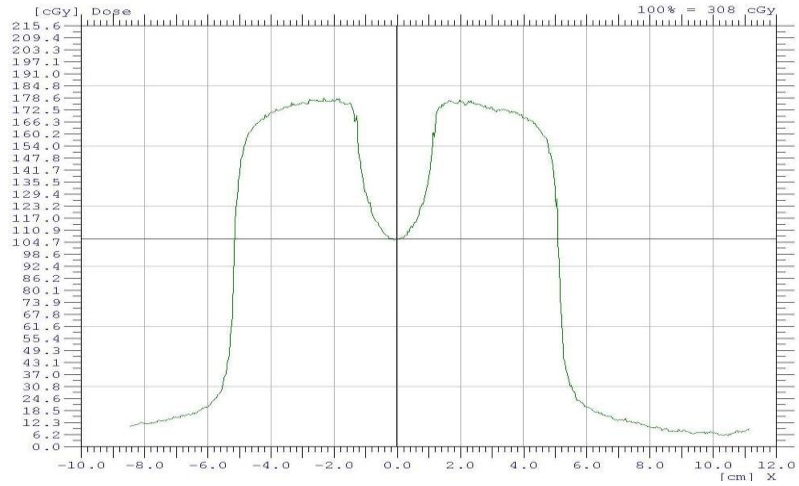
  or

- Actual electron density should be manually overwritten

Summary

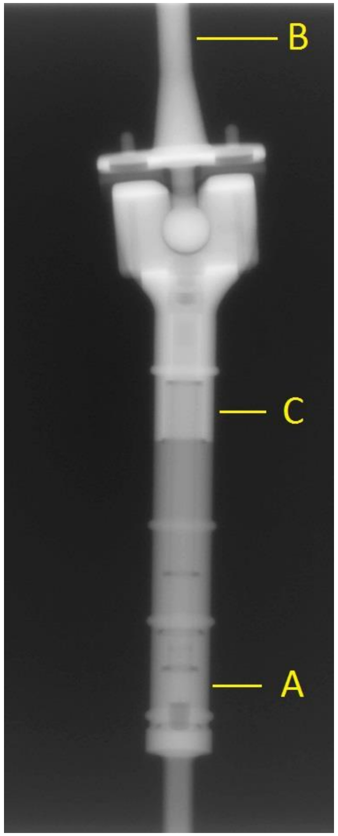


- Influence of high attenuation is the most important



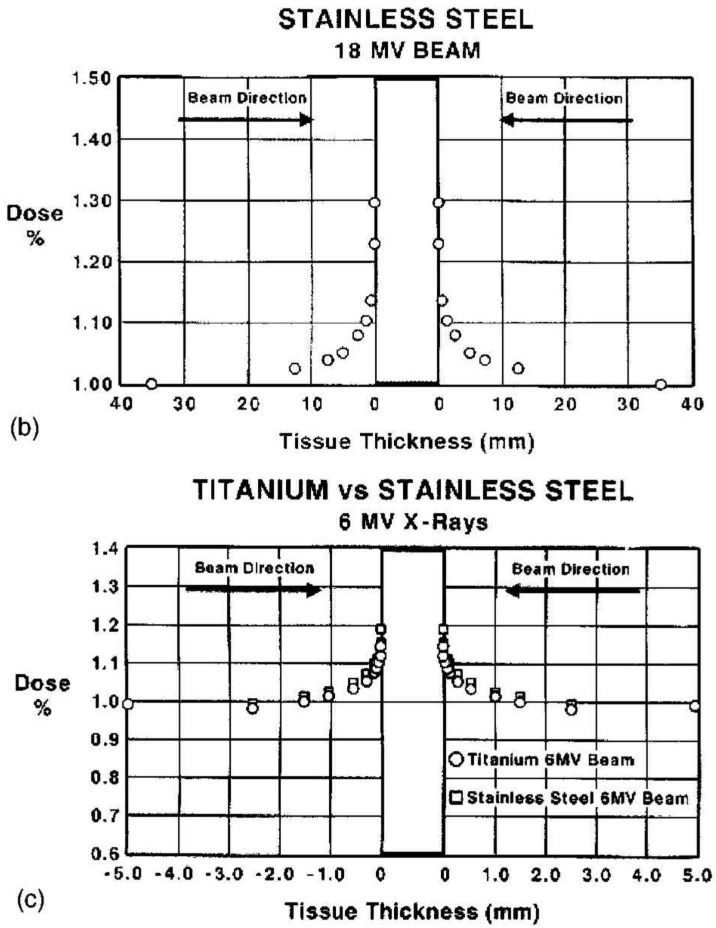
Summary

- To calculate attenuation
  - to know the type of prosthesis
    - it is not homogenous
    - attenuation measurements performed with megavoltage beam is recommended



Summary

- Opposed pairs of beams of 6 MV are preferable
  - perturbance at only 1 mm off



If beams must cross prosthesis!

Thank you
for your attention

Phew!

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