BRACHYTHERAPY Physics Part I

Basic dose calculation and applicator reconstruction

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IAEA

3D image guided brachytherapy workflow

Planning and application

Clinical Evaluation
Therapeutic decision making
Patient preparation
Applicator placement

3D imaging (with applicator)

Purpose of imaging
Imaging methodology
Imaging protocols

Contouring

Target and OARs definition

Applicator reconstruction

Defining the source-path
in the individual patient

3D dose planning and reporting

Plan optimisation, evaluation
Final dose prescription
Dose reporting
Plan verification and approval

Dose delivery

Plan Transfer to afterloader
Pre-delivery QC
Dose recording

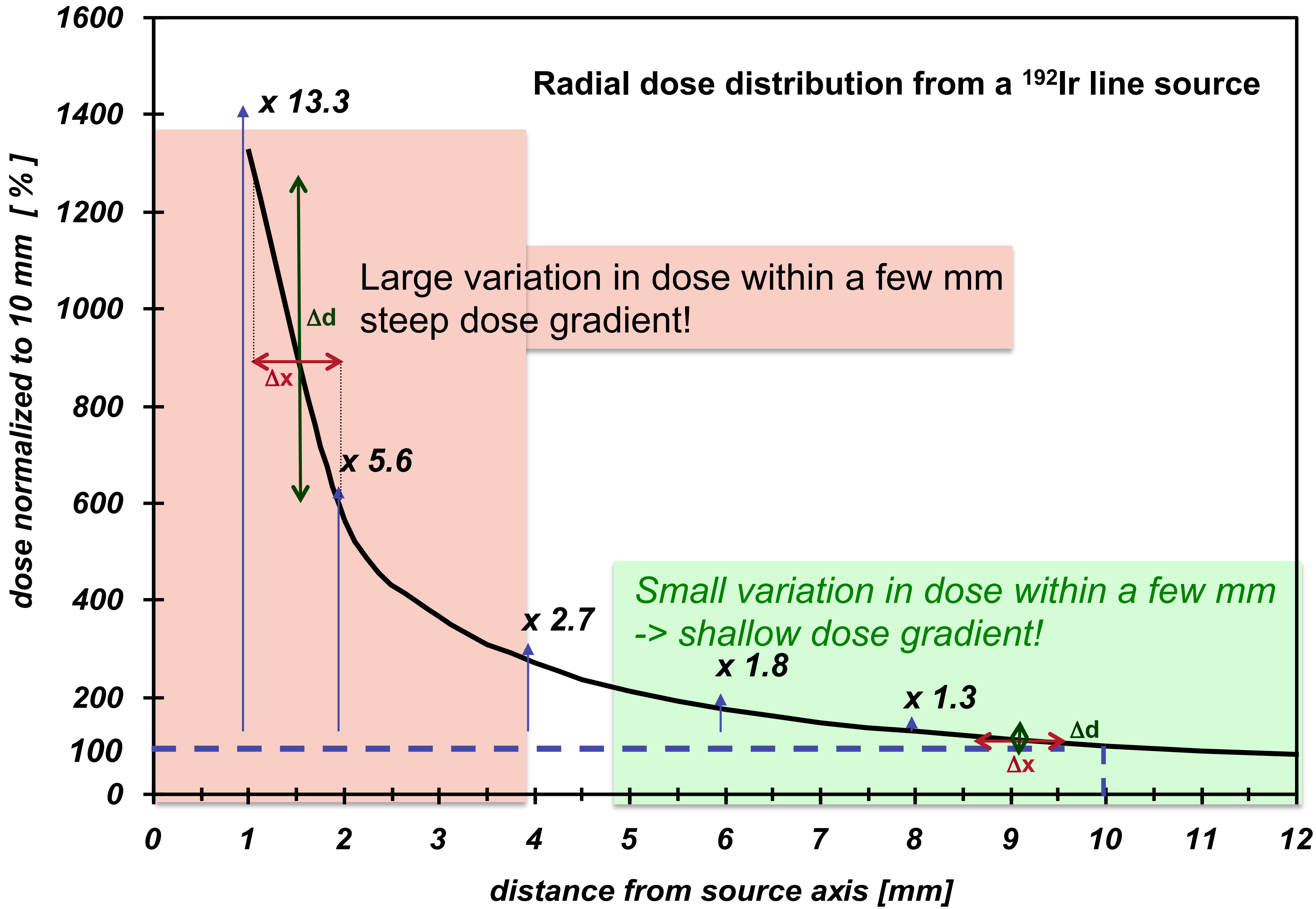
Post-treatment

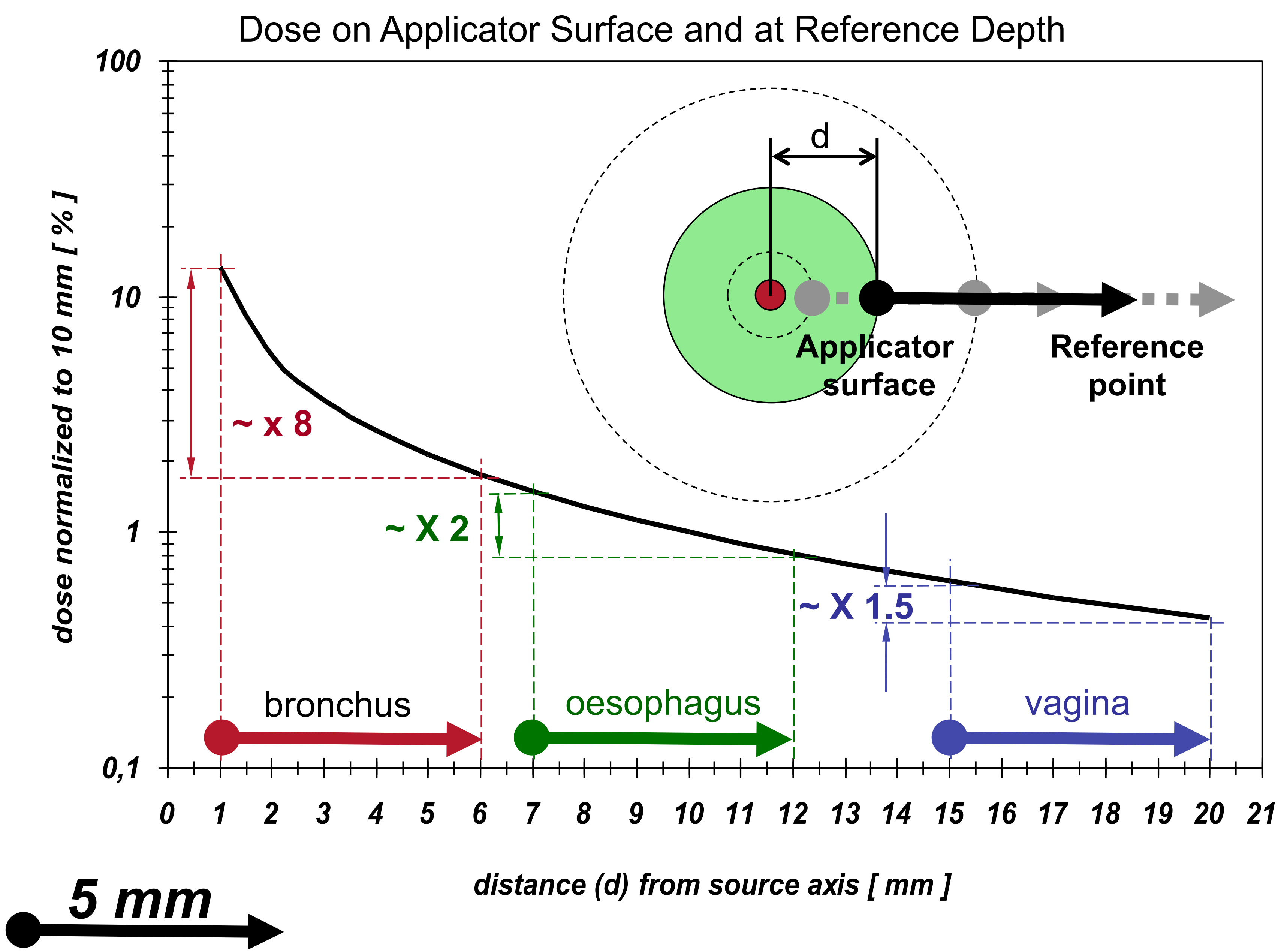
Removal of Applicator
Follow-up

Transport, Organization, Documentation, Nursing

Brachytherapy

- Short distance treatment of cancer with radiation from small, encapsulated radionuclide sources.
- Treatment is given by placing sources directly into or near the volume to be treated.
- High dose can be delivered to the tumor with rapid fall off in the surrounding normal tissue.


Radial dose distribution from a 192Ir line source
x 13.3
x 5.6
x 2.7
x 1.8
x 1.3
Δd
Δx
Large variation in dose within a few mm
steep dose gradient!
Small variation in dose within a few mm
-> shallow dose gradient!
dose normalized to 10 mm [%]
distance from source axis [mm]
1600
1400
1200
1000
800
600
400
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12



Dose on Applicator Surface and at Reference Depth
100
10
1
0,1
dose normalized to 10 mm [%]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
distance (d) from source axis [mm]
d
Applicator surface
Reference point
~ x 8
~ X 2
~ X 1.5
bronchus
oesophagus
vagina
5 mm

Physical properties of some nuclides

Radio Nuclide	Half time $T_{1/2}$	λ (s^{-1})	Average Photon Energy (keV)	Mass for 100 MBq (μg)
^{226}Ra	1600 y	1.37 10^{-11}	830	45
^{137}Cs	30 y	7.27 10^{-10}	662	31
^{60}Co	5.26 y	4.18 10^{-9}	1253	2.4
^{192}Ir	74.2 d	1.08 10^{-7}	380	0.29
^{125}I	60.2 d	1.34 10^{-7}	28	0.16
^{103}Pd	17 d	4.72 10^{-7}	21	0.04

From Baltas et al., The Physics of Modern Brachytherapy 2007
a) NIST Physical reference Data, b) ICRP 21

Interactions of Photons with Matter

❖ **Mechanisms of Energy Loss: Photoelectric Effect**

- In the photoelectric absorption process, a photon undergoes an interaction with an absorber atom in which the **photon completely disappears**.

- In its place, an energetic **photoelectron** is ejected from one of the bound shells of the atom.

- For gamma rays of sufficient energy, the most probable origin of the photoelectron is the most tightly bound or *K* shell of the atom.

- The photoelectron appears with an energy given by $E_{e-} = h\nu - E_b$

(E^b represents the binding energy of the photoelectron in its original shell)

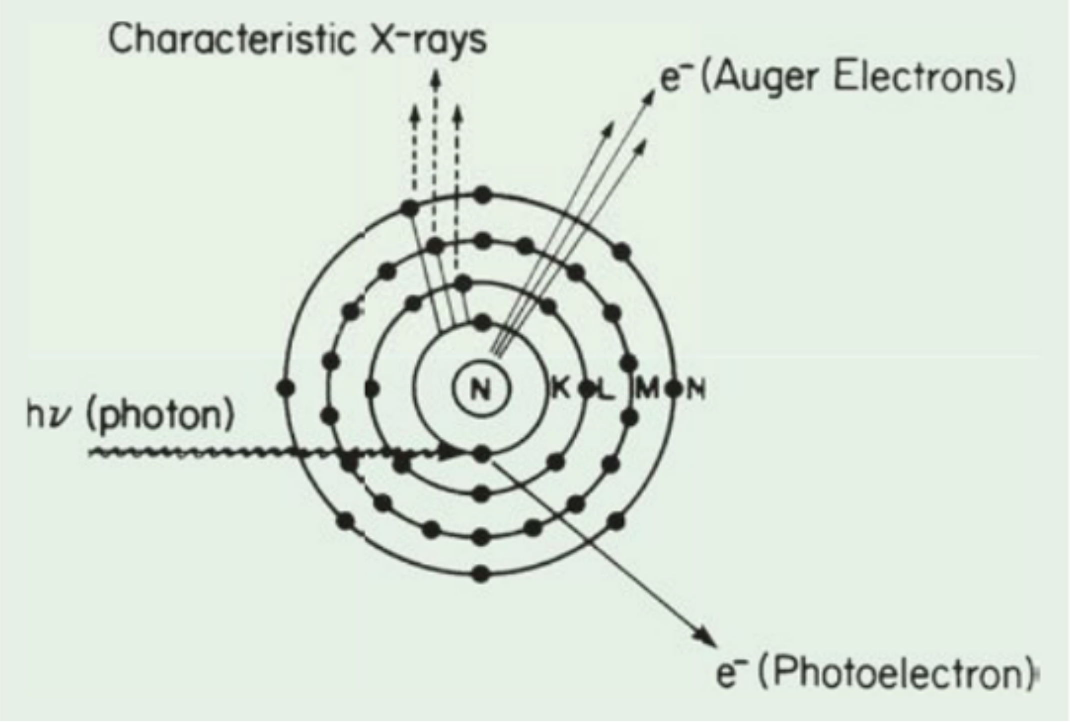
Interactions of Photons with Matter

❖ **Mechanisms of Energy Loss: Photoelectric Effect**

Gamma-ray energies of more than a few hundred keV, the photoelectron carries off the majority of the original photon energy.
Filling of the inner shell vacancy can produce fluorescence radiation, or x ray photon(s).

Probability τ of photoelectric absorption

$$\tau \propto \frac{Z^n}{(h\nu)^3}$$



predominant at **o relatively low photon energies**
o high atomic number Z

Interactions of Photons with Matter

❖ Compton Scattering

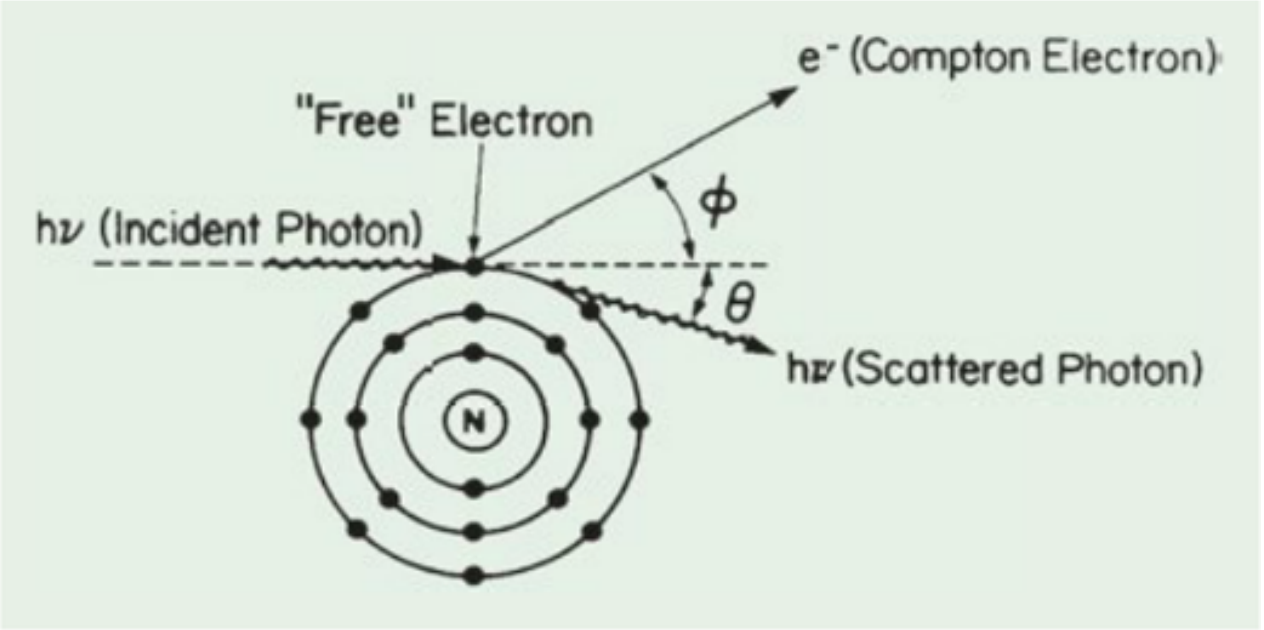
The incoming gamma-ray photon is **deflected** through an angle θ with respect to its original direction.

The photon transfers a portion of its energy to the electron (assumed to be initially at rest), which is then known as a *recoil electron,* or a ***Compton electron***.

All angles of scattering possible.

The energy transferred to the electron can vary from zero to a large fraction of the gamma-ray energy.

The Compton process is **most important** for energy absorption for **soft tissues** in the range from 100 keV to 10MeV



Probability σ: almost ***independent of atomic number Z***;
decreases as the photon energy increases
directly proportional to the number of electrons per gram,

Interactions of Photons with Matter

❖ Compton Scattering ENERGETICS

The energies of the scattered photon $h\nu'$ and the Compton electron E_e, are given by:

[$m_0 c^2$ is the electron rest energy, 0.511 MeV, $h\nu$ is the incoming photon energy]

$$h\nu' = h\nu \frac{1}{1+\alpha(1-\cos\theta)} \qquad E_e = h\nu \frac{\alpha(1-\cos\theta)}{1+\alpha(1-\cos\theta)} \qquad \alpha = \frac{h\nu}{m_0 c^2}$$

Limits of Energy L

Maximum energy transfer to
angle of electron recoil is forwa
scattered photon straight ba
with θ = 180°, cos θ =

$$E_{e(max)} = h\nu \frac{2\alpha}{1+2\alpha}$$

$$h\nu'_{min} = h\nu \frac{1}{1+2\alpha}$$

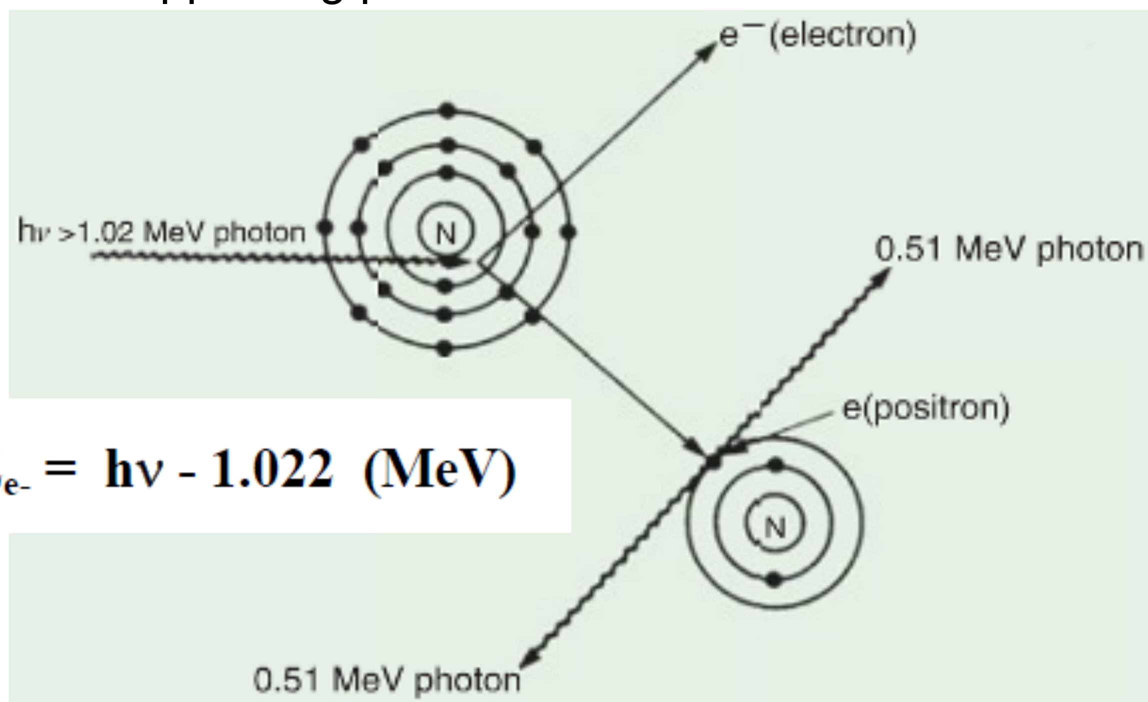
For **low-energy photons**, **little energy is transferred**, regardless of the probability of such an interaction.

As the energy increases, the fractional transfer increases, approaching 1.0 for photons at energies above 10 to 20 MeV.

Interactions of Photons with Matter

Pair Production

If a photon enters matter with an energy in excess of 1.022 MeV, it may interact by pair production. The photon, passing near the nucleus of an atom, is subjected to strong field effects from the nucleus and may disappear as a photon and reappear as a positive and negative electron pair. The two electrons produced, e^- and e^+, are not scattered orbital electrons, but are created, de novo, in the energy/mass conversion of the disappearing photon.

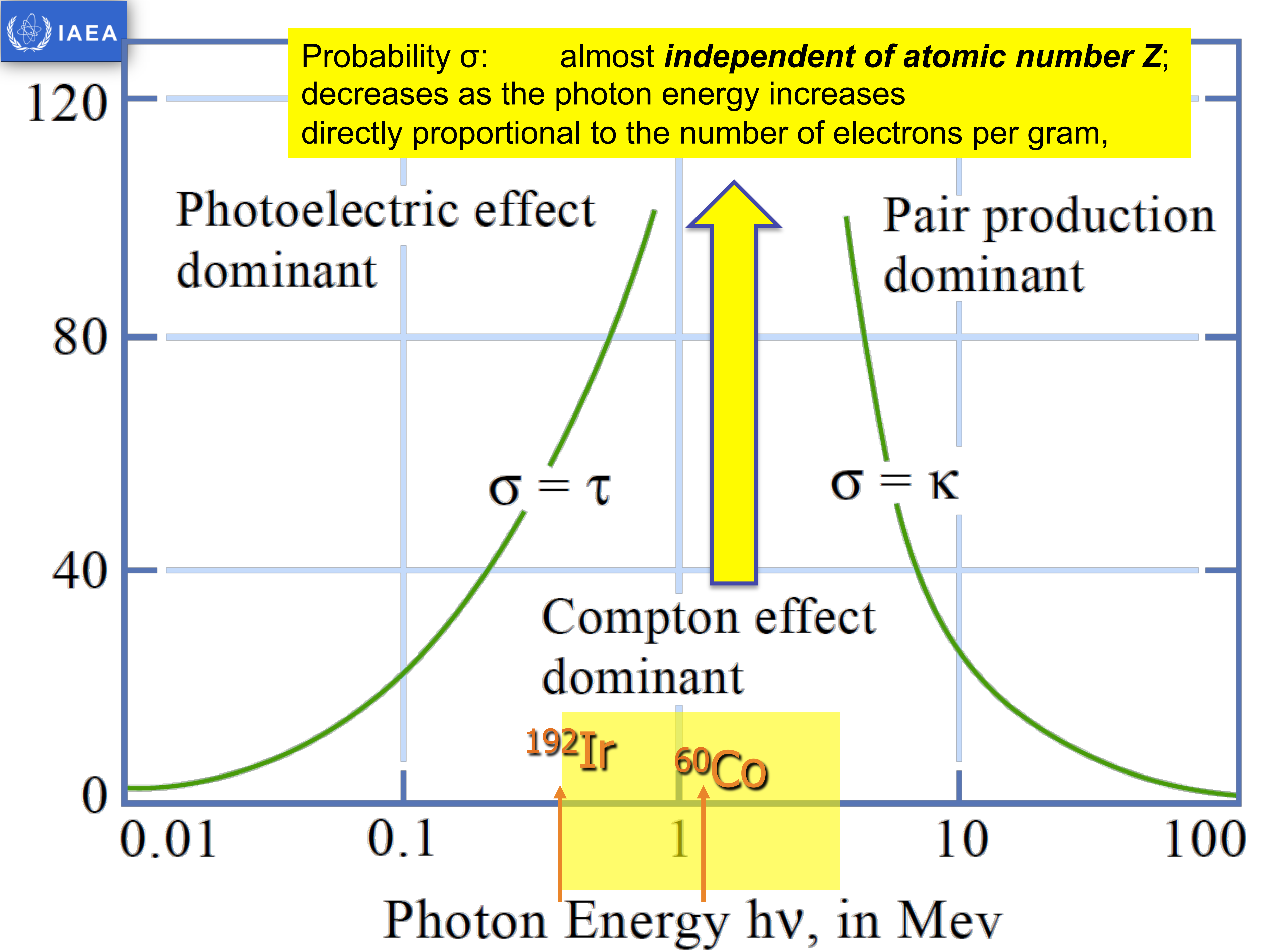


$$E_{e+} + E_{e-} = h\nu - 1.022 \ \text{(MeV)}$$

Pair production probability, symbolized κ (kappa),

Increases with **increasing photon energy**

Increases with atomic number approximately as **Z²**



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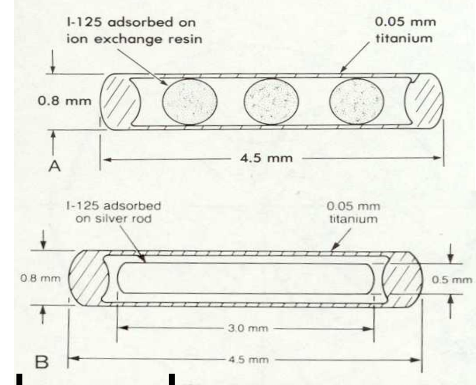
Probability σ: almost ***independent of atomic number Z***;
decreases as the photon energy increases
directly proportional to the number of electrons per gram,
120
80
40
0
Photoelectric effect dominant
Pair production dominant
σ = τ
σ = κ
Compton effect dominant
192Ir
60Co
0.01
0.1
1
10
100
Photon Energy hν, in Mev

Recall
TG-43

Source specification



Previously, source strength specification was based on "contents" , # of desintegrations per time unit

- 1 Ci (3.7×10^{10} s^{-1}) activity of 1g Ra-226
- in SI-units: 1 desintegration per sec = 1 Bq

  example: 1 mCi = 37 MBq

Now, specification of sources is performed in terms of energy deposition, per unit of time at a given distance:

- in air kerma rate: $\mu Gy \cdot h^{-1}$ @ 1 m

Dose calculation accorging to AAPM TG - 43

$$D(r,\Theta) = S_k \cdot \lambda \cdot T \cdot \frac{G(r,\Theta)}{G(r_0,\Theta_0)} \cdot g(r) \cdot F(r,\Theta)$$

S_k … Air kerma strength

λ … Dose rate constant

T … Total time

$\frac{G(r,\Theta)}{G(r_0,\Theta_0)}$ … Geometry factor

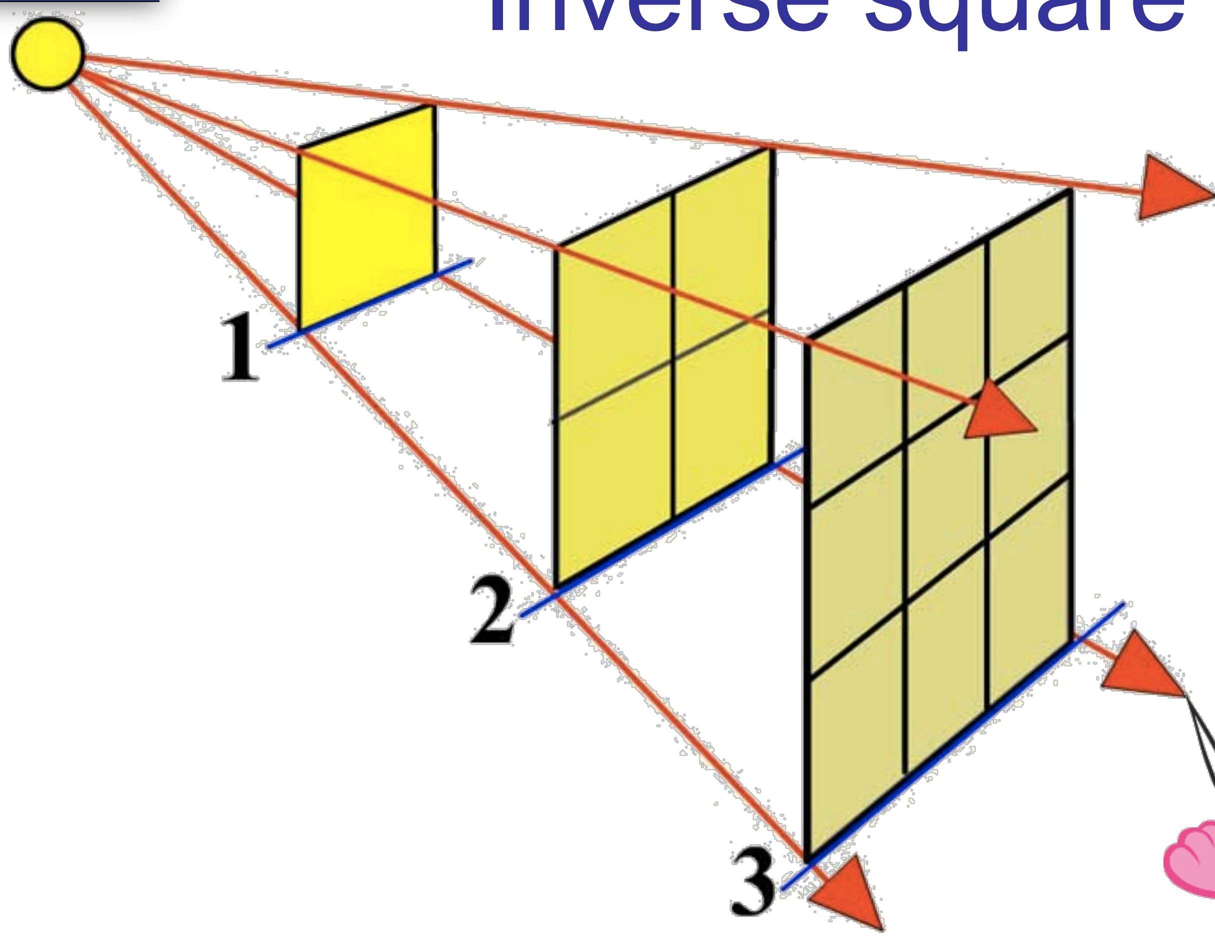
g(r) … Radial dose function

F(r,Θ) … Anisotropy function

Simple approximation with most varying factors:

$$D \approx T \cdot \frac{1}{r^2}$$

Inverse square law



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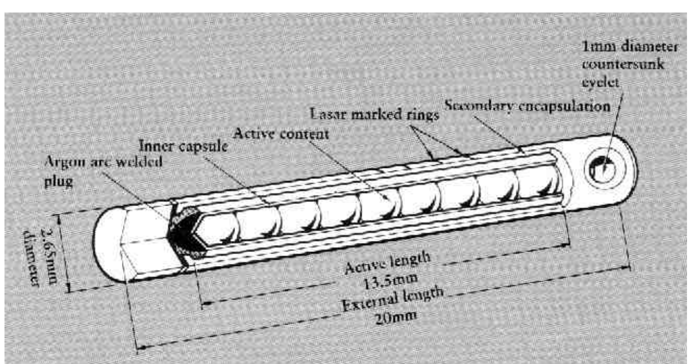
TG43 FORMALISM

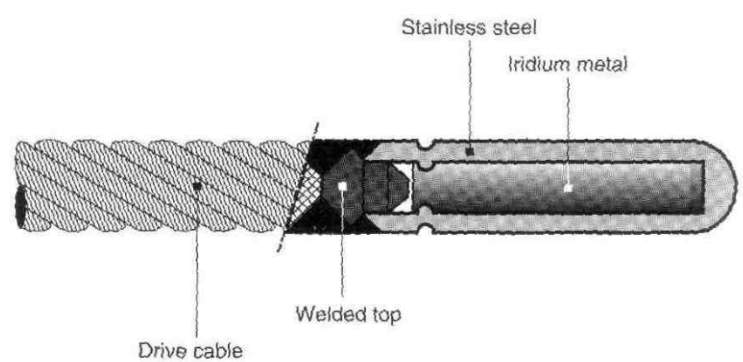
$$D(r,\theta) = S_k \Lambda t \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

The Dose Rate Constant, Λ, has to be given for each source model specifically, in order to include the effects of source geometry, encapsulation, and self-filtration within the source and scattering in water surrounding the source. Its relation with classical formalism is:

$$\Lambda = \overline{\left[\frac{\mu_{en}}{\rho}\right]}_{air}^{m} \varphi(r_0) G(r_0,\theta_0)$$

being $\overline{\left[\frac{\mu_{en}}{\rho}\right]}_{air}^{m}$ the ratio of average mass attenuation coefficients in m (medium) and air, and φ(r) the function that take into account the attenuation of primary photons and the effect of scattered photons in the medium.

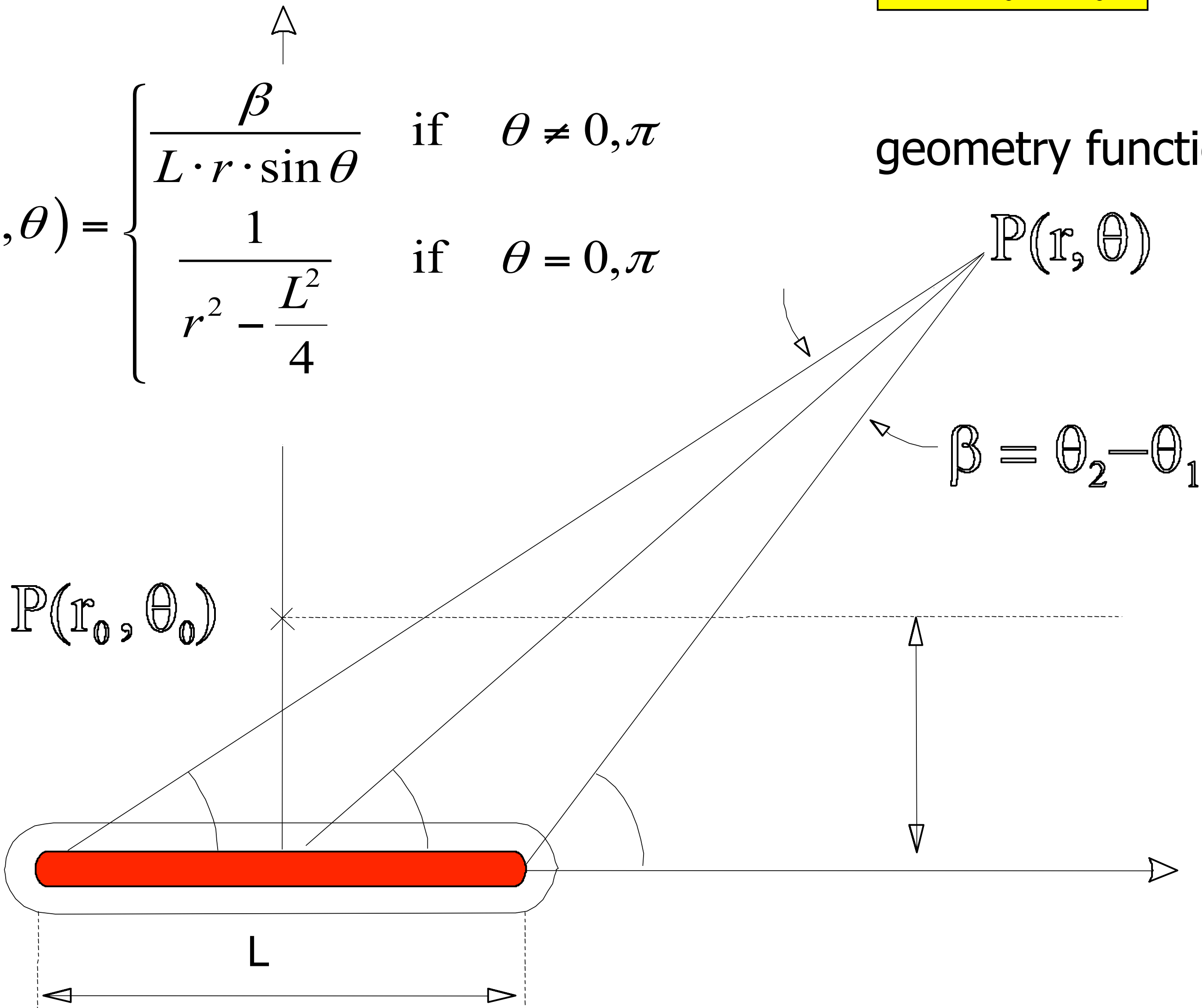




$$D(r,\theta) = S_k \, \Lambda \, t \, \frac{G(r,\theta)}{G(r_0,\theta_0)} \, g(r) F(r,\theta)$$

$$G_L(r,\theta) = \begin{cases} \dfrac{\beta}{L \cdot r \cdot \sin\theta} & \text{if} \quad \theta \neq 0,\pi \\ \dfrac{1}{r^2 - \dfrac{L^2}{4}} & \text{if} \quad \theta = 0,\pi \end{cases}$$

geometry function



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TG43 FORMALISM

$$D(r,\theta) = S_k \Lambda t \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

The Radial Dose Function, g(r), describes the dose fall-off along the transverse axis of the source accounting for the effects of absorption and scatter in water. It is de

$$G_L(r,\theta) = \begin{cases} \frac{\beta}{L \cdot r \cdot \sin\theta} & \text{if} \quad \theta \neq 0,\pi \\ \frac{1}{r^2 - \frac{L^2}{4}} & \text{if} \quad \theta = 0,\pi \end{cases}$$

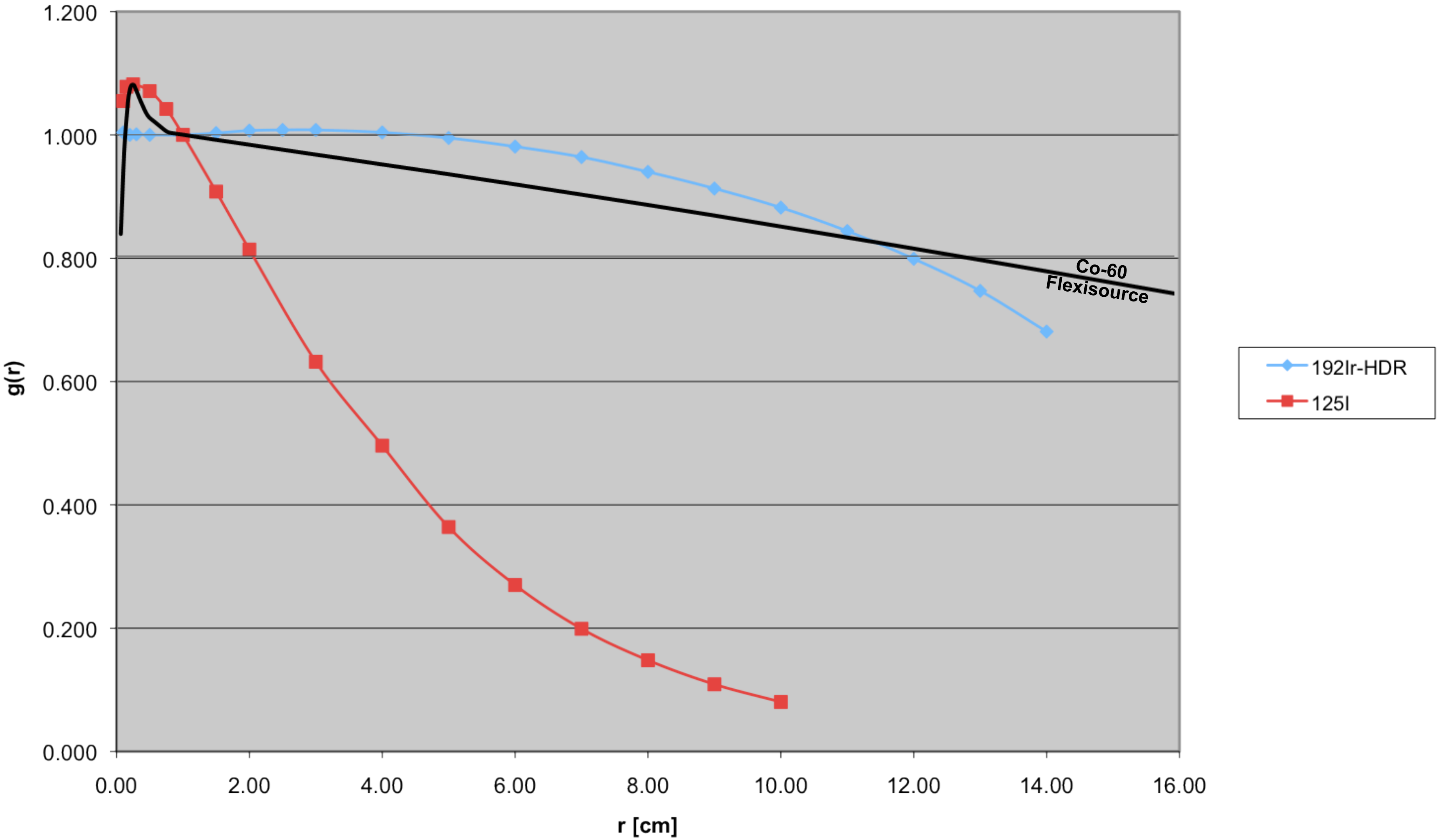
$$g(r) = \frac{\dot{D}(r,\theta_0)G(r_0,\theta_0)}{\dot{D}(r_0,\theta_0)G(r,\theta_0)}$$

It can also be influenced by filtration of photons by the encapsulation and source materials. Its relation with the classical formalism is the tissue attenuation and scatter function normalized at 1 cm distance:

$$g(r) = \frac{\varphi(r)}{\varphi(r_0)}$$

$$D(r,\theta) = S_k \Lambda t \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

Radial Dose Function



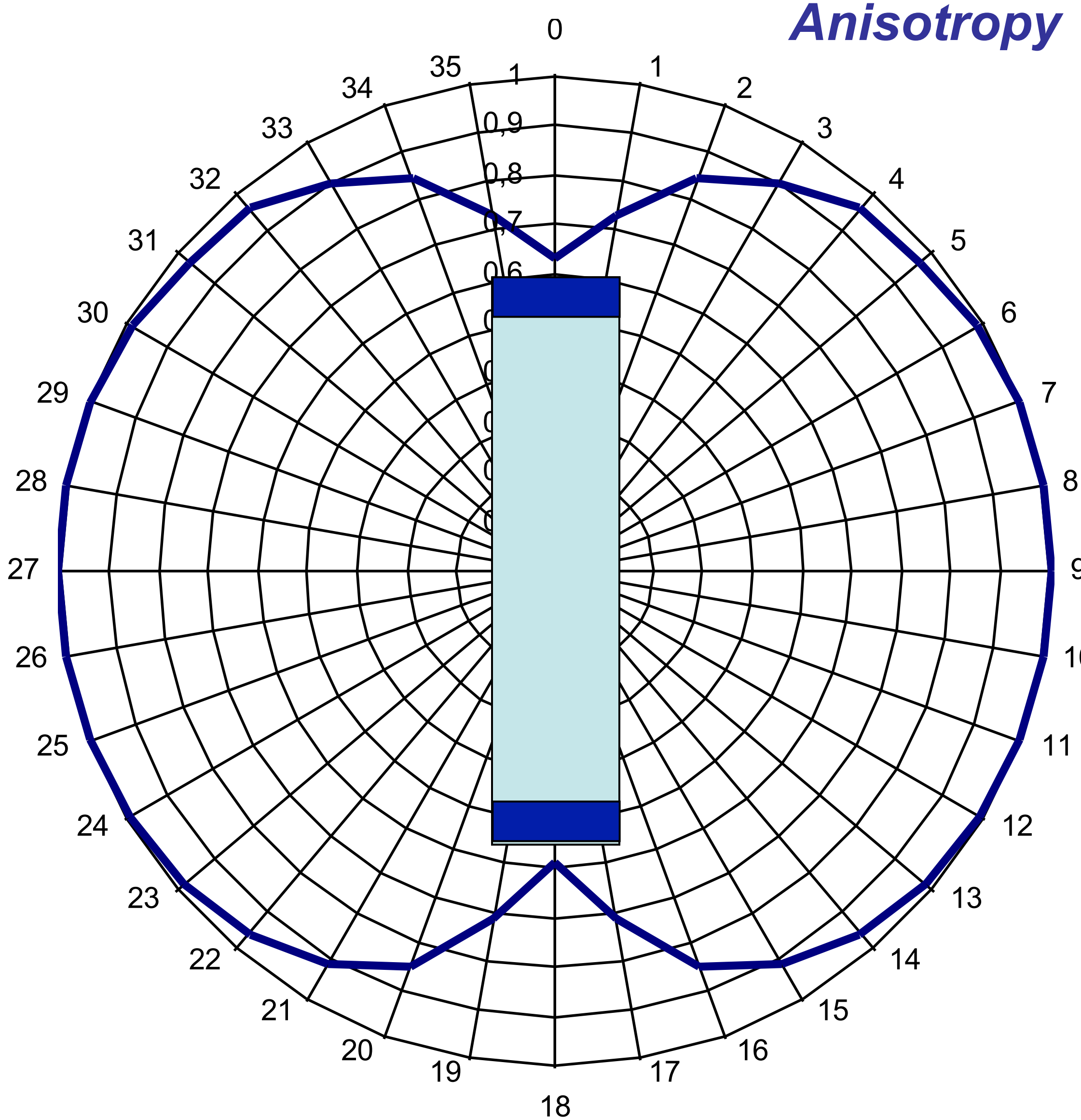
$$D(r,\theta) = S_k \Lambda t \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

TG43 FORMALISM

The Anisotropy Function, $F(r,\theta)$, accounts for the anisotropy of dose distribution around the source, including the effects of absorption and scatter in the source construction and water. It gives the angular variation of dose rate around the source at each distance due to self-filtration, oblique filtration of primary photons through the encapsulating material, and scattering of photons in water. It is defined as:

$$F(r,\theta) = \frac{\dot{D}(r,\theta)G(r,\theta_0)}{\dot{D}(r,\theta_0)G(r,\theta)}$$

Anisotropy



r(cm)	Radial Dose
0,00	0,8120
0,30	0,9380
0,40	0,9800
0,50	1,0050
1,00	1,0000
1,50	0,9460
2,00	0,8770
2,50	0,7980
3,00	0,7210
3,50	0,6440
4,00	0,5740
4,50	0,5080
5,00	0,4480
5,50	0,3930
6,00	0,3430
6,50	0,2970
7,00	0,2570
8,00	0,2060

Aniso Constant | Aniso Fact

Aniso Constant

0,950

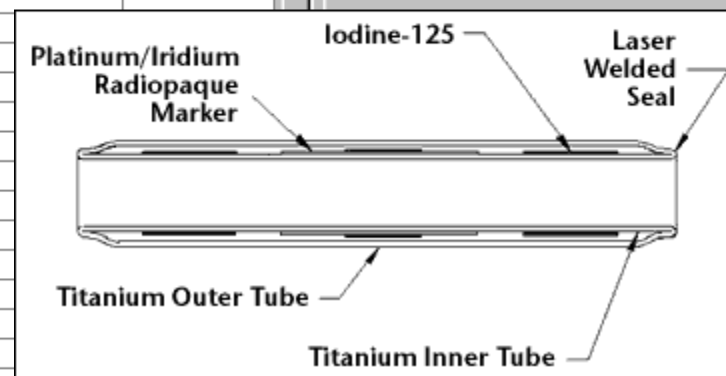
S_k... air - kerma strength

Λ... dose rate constant

$g(r)$... radial dose function

$\bar{\phi}_{an}$... anisotropy constant

$\dot{D}_0$... initial dose rate



For some brachytherapy applications it is not possible or practical to define the orientation of each source: Some TPS consider sources as one-dimensional isotropic point source. Implanted seeds are often randomly oriented and due to the source dimensions it is difficult to reconstruct their actual orientation. So the 2-D distributions can not be applied properly. In these situations, the dose rate contribution to tissue of each seed can be well approximated by the average radial dose rate as estimated by integrating the dose of the single anisotropic seed source over an entire sphere:

$$\dot{D}(r) = \frac{1}{4\pi}\int_0^{4\pi} \dot{D}(r,\theta)\, d\Omega$$

where $d\Omega = 2\pi \sin\theta\, d\theta$ *in case of cylindrical distribution.*

TG43 FORMALISM

The Anisotropy Factor at distance r, $\Phi_{an}(r)$ *, is defined as the ratio of the averaged dose rate at r and the dose on the transverse axis at the same distance:*

$$\Phi_{an}(r) = \frac{\int_0^{\pi} \dot{D}(r,\theta)\sin\theta d\theta}{2\dot{D}(r,\theta_0)}$$

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TG43 FORMALISM

So, the general expression in this approximation is:

$$\dot{D}(r) = S_k \Lambda \left[\frac{G(r,\theta)}{G(r_0,\theta_0)} \right] g(r) \Phi_{an}(r)$$

Finally, the Anisotropy Factor can be approximated by a distance independent constant named Anisotropy Constant $\overline{\Phi}_{an}$*. With this functions the sources are approximated in the calculations by point isotropic sources. Recently (Nath 2002) the use of the anisotropy constant is discouraged recommending the use of the anisotropy factor in calculations under punctual approximations.*

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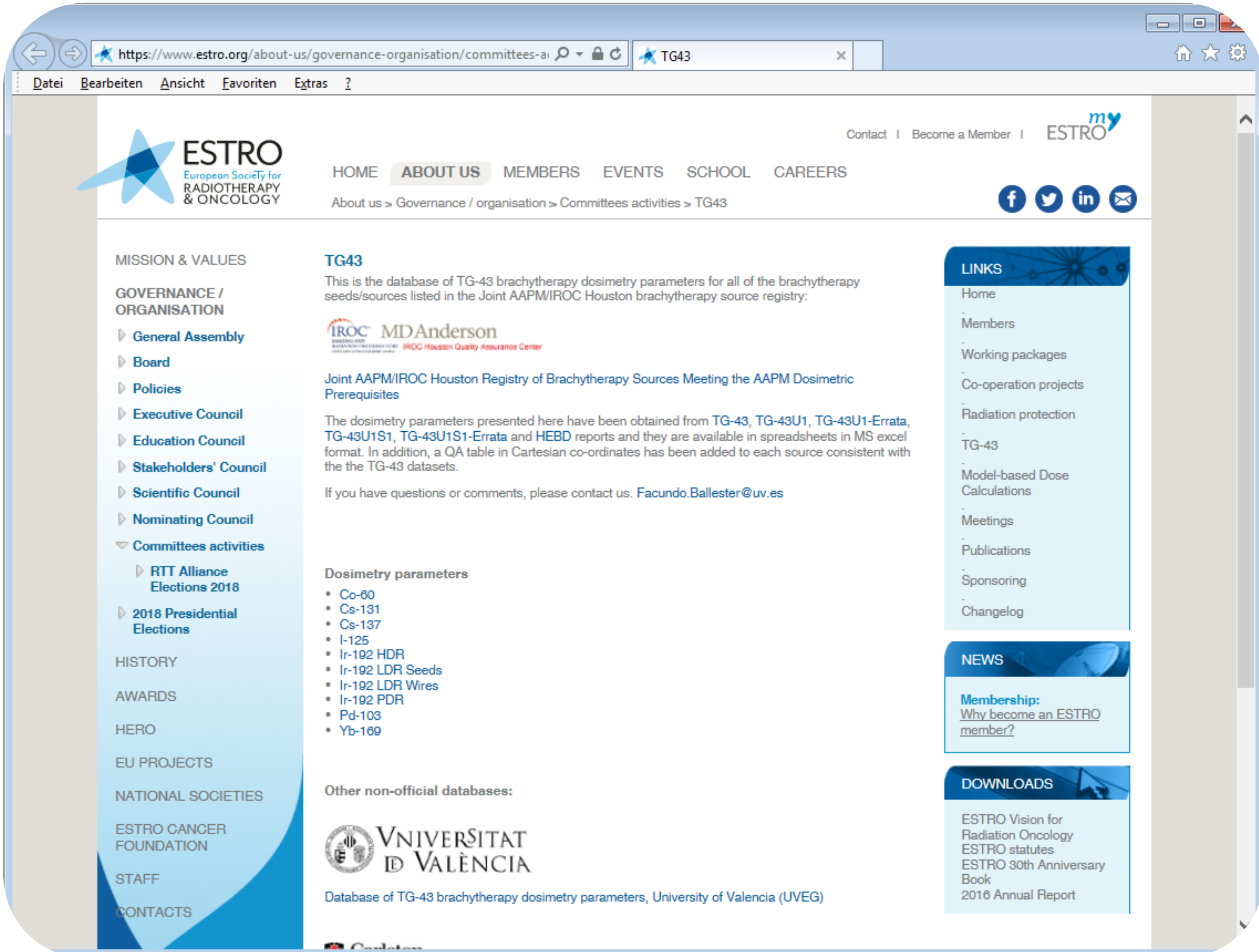
https://www.estro.org/about-us/governance-organisation/committees-activities/tg43



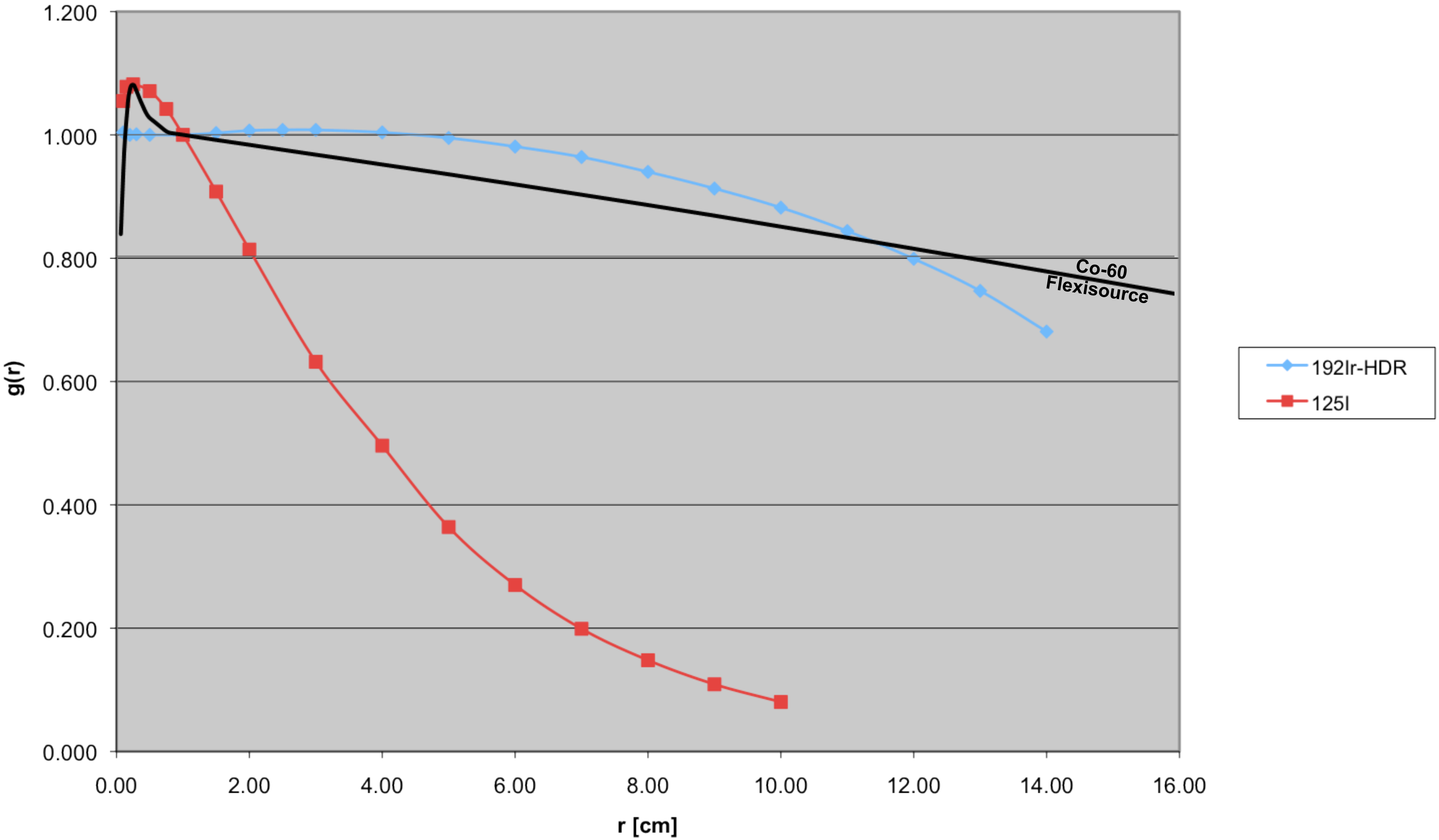
- **TG43 algorithm** is based on water calculation and can be done on CT, MRI and US
- Model based algorithms take tissue into account (based on CT), but has limited impact for GYN-brachy

Implant	% Variation
Surface Mould (Nose)	9 ± 7
Head and Neck (Base of Tongue)	8 ± 8
Breast APBI –Multi Catheter	8 ± 2.0
Lip Implant	11 ± 14
Eye Lid	22 ± 37
Gynaecology – Vienna applicator (Polymer)	1 ± 0.2
Gynaecology – Ring applicator (Stainless Steel)	4 ± 0.7

Courtesy Jamema Swamidas

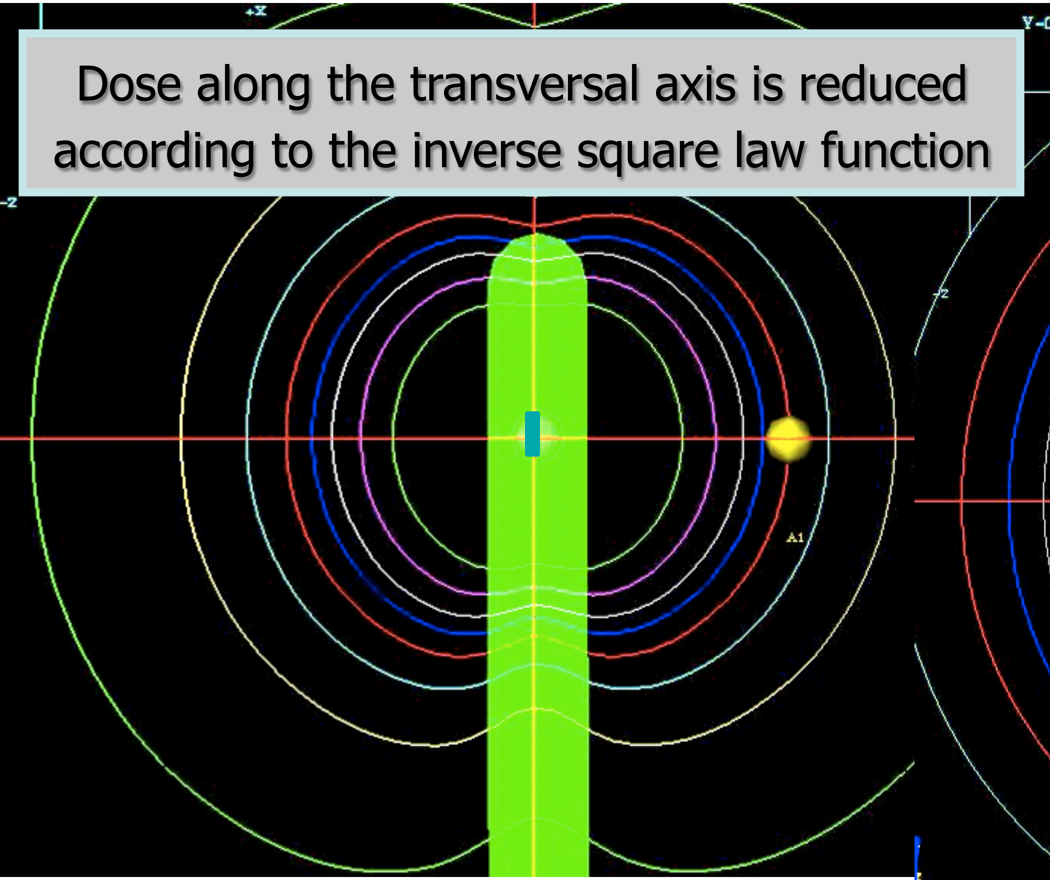
$$D(r,\theta) = S_k \Lambda t \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

Radial Dose Function



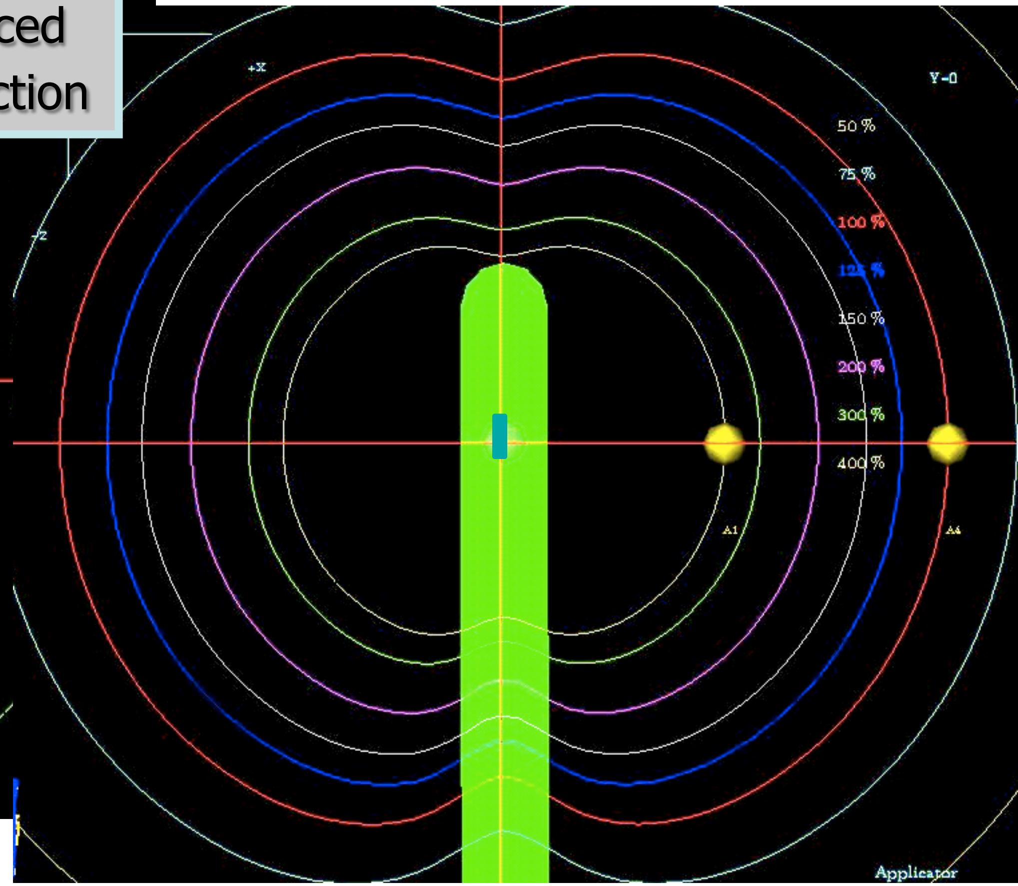
Distribution around one single source

Dose along the transversal axis is reduced according to the inverse square law function



1 Gy at 1 cm distance for a source strength 4.21 cGy/hcm²

15.6 sec

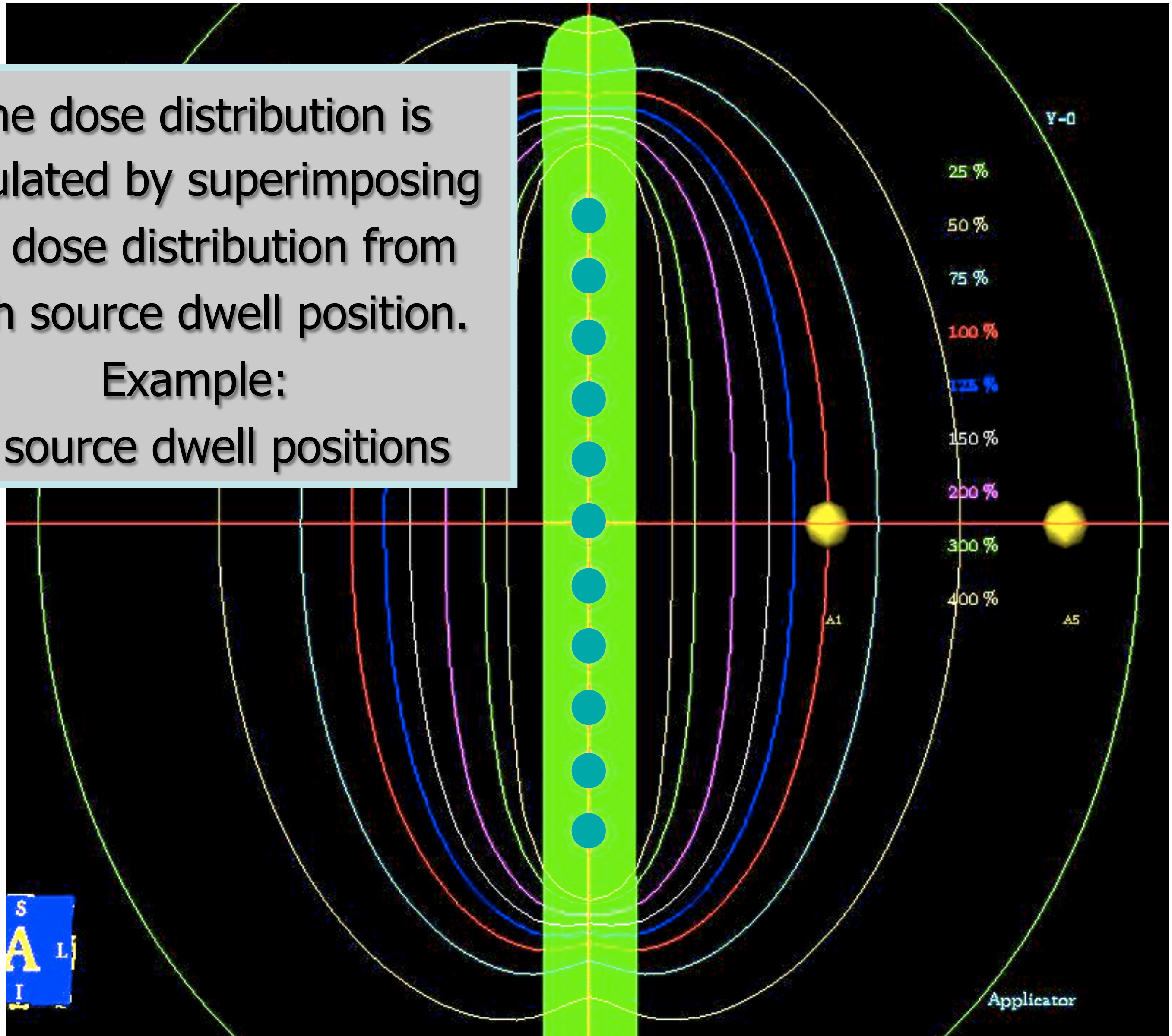


1 Gy at 2 cm distance for a source strength 4.21 cGy/hcm²

62.4 sec

Distribution around a stepping source

The dose distribution is calculated by superimposing the dose distribution from each source dwell position.
Example:
11 source dwell positions

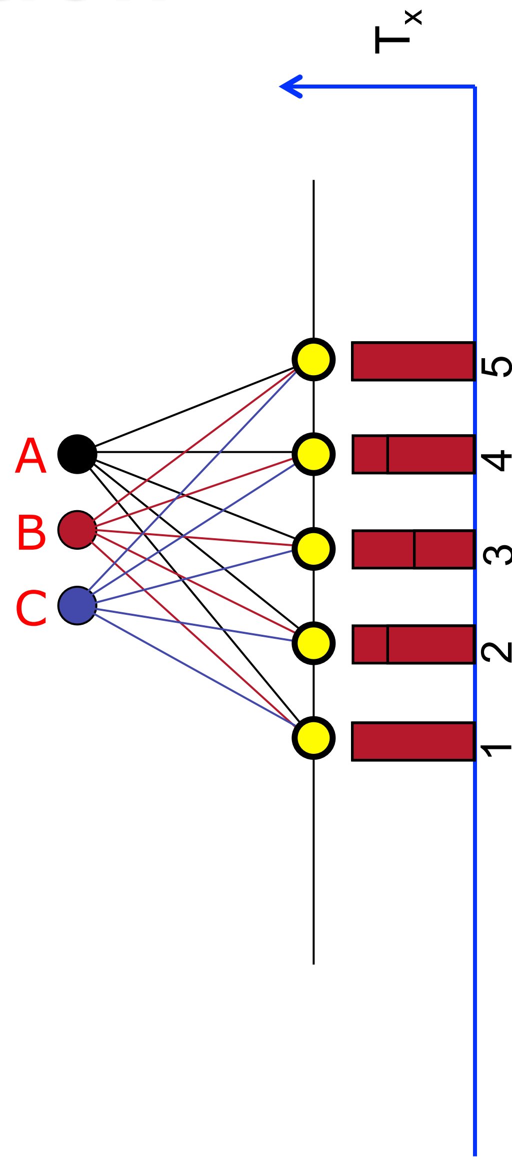


Dose Point Optimization

$$D_A = \left(T_1 \cdot \frac{1}{r_{1A}^2}\right) + \left(T_2 \cdot \frac{1}{r_{2A}^2}\right) + \left(T_3 \frac{1}{r_{3A}^2}\right) + \left(T_4 \cdot \frac{1}{r_{4A}^2}\right) + \left(T_5 \cdot \frac{1}{r_{5A}^2}\right)$$

$$D_B = \left(T_1 \cdot \frac{1}{r_{1B}^2}\right) + \left(T_2 \cdot \frac{1}{r_{2B}^2}\right) + \left(T_3 \frac{1}{r_{3B}^2}\right) + \left(T_4 \cdot \frac{1}{r_{4B}^2}\right) + \left(T_5 \cdot \frac{1}{r_{5B}^2}\right)$$

$$D_C = \left(T_1 \cdot \frac{1}{r_{1C}^2}\right) + \left(T_2 \cdot \frac{1}{r_{2C}^2}\right) + \left(T_3 \frac{1}{r_{3C}^2}\right) + \left(T_4 \cdot \frac{1}{r_{4C}^2}\right) + \left(T_5 \cdot \frac{1}{r_{5C}^2}\right)$$

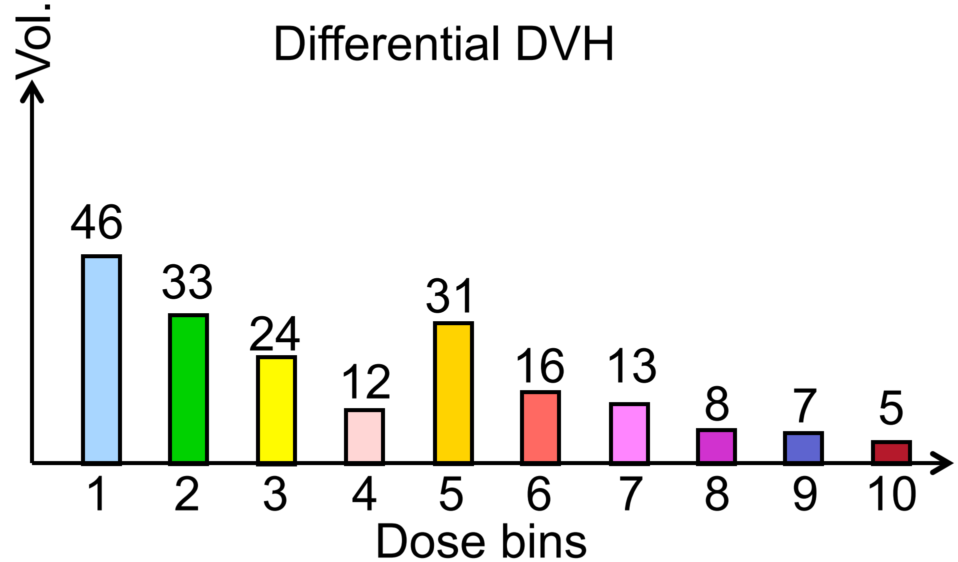


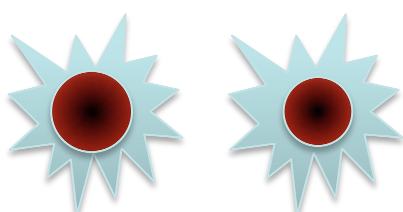
$$D_A = D_B = D_C = 100\%$$

DVH-calculation

Contour

1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
1	1	1	1	2	2	2	2	1	1	1	1	1	1	1
1	1	2	2	2	2	3	2	2	2	2	1	1	1	1
1	2	2	3	3	2	3	4	3	4	3	2	2	1	1
1	2	3	3	4	3	4	5	4	5	4	5	2	1	1
2	3	3	4	5	4	5	6	6	5	6	5	2	1	1
1	3	2	5	5	2	5	6	6	5	6	6	2	1	2
2	3	3	5	5	5	5	4	5	5	6	6	5	1	1
3	4	3	5	5	7	7	5	7	5	7	6	5	2	3
3	4	3	5	7	7	8	7	8	7	5	5	2	1	3
3	5	4	6	8	8	7	8	9	8	8	5	3	2	2
2	5	6	6	6	9	9	9	8	9	9	6	2	1	3
3	6	7	7	7	10	10	10	9	10	10	5	7	1	5



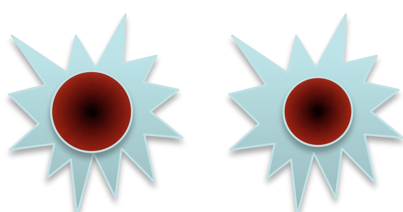


BT-Implant

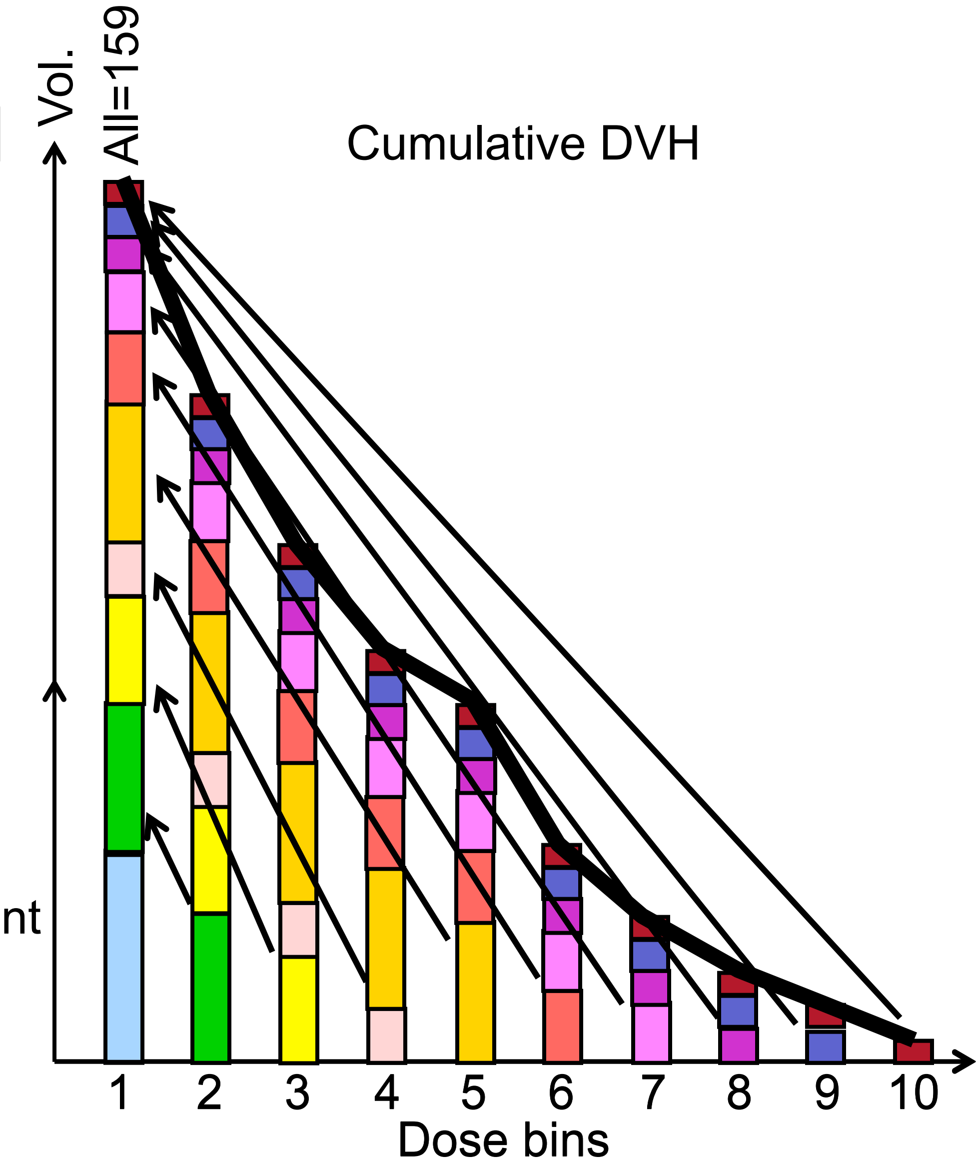
DVH-calculation

Contour

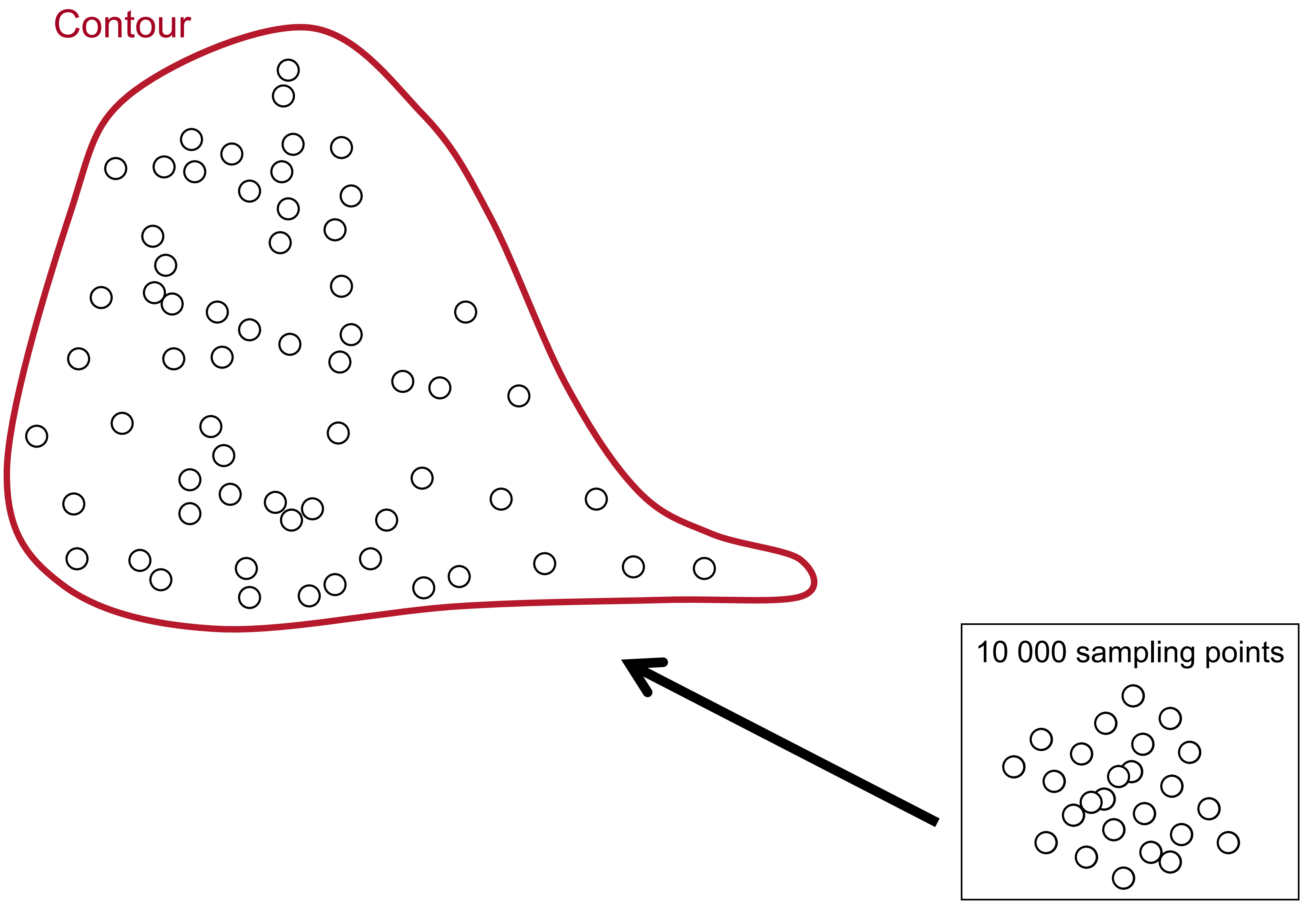
1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
1	1	1	1	2	2	2	2	1	1	1	1	1	1	1
1	1	2	2	2	2	3	2	2	2	2	1	1	1	1
1	2	2	3	3	2	3	4	3	4	3	2	2	1	1
1	2	3	3	4	3	4	5	4	5	4	5	2	1	1
2	3	3	4	5	4	5	6	6	5	6	5	2	1	1
1	3	2	5	5	2	5	6	6	5	6	6	2	1	2
2	3	3	5	5	5	5	4	5	5	6	6	5	1	1
3	4	3	5	5	7	7	5	7	5	7	6	5	2	3
3	4	3	5	7	7	8	7	8	7	5	5	2	1	3
3	5	4	6	8	8	7	8	9	8	8	5	3	2	2
2	5	6	6	6	9	9	9	8	9	9	6	2	1	3
3	6	7	7	7	10	10	10	9	10	10	5	7	1	5



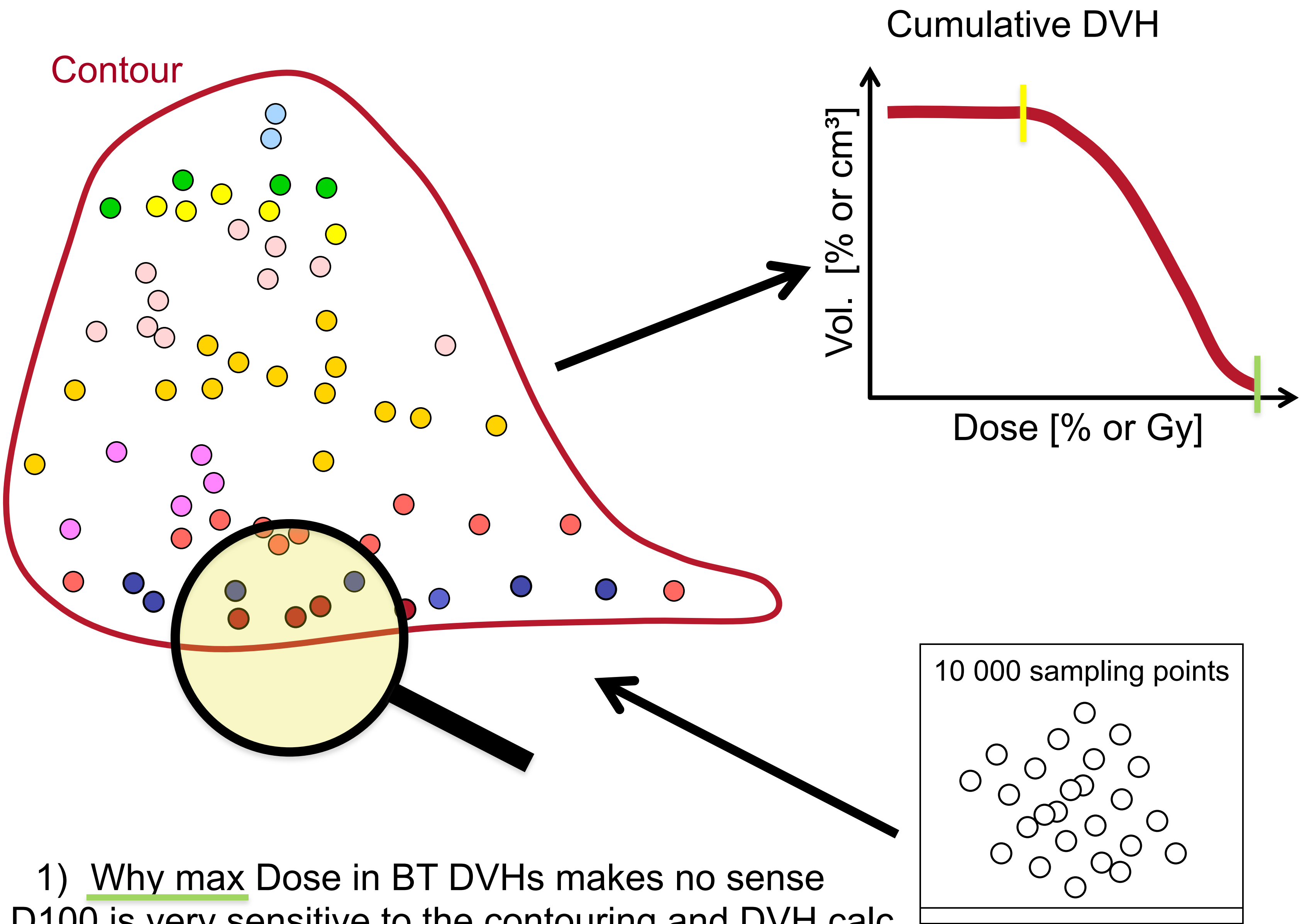
BT-Implant



DVH-calculation

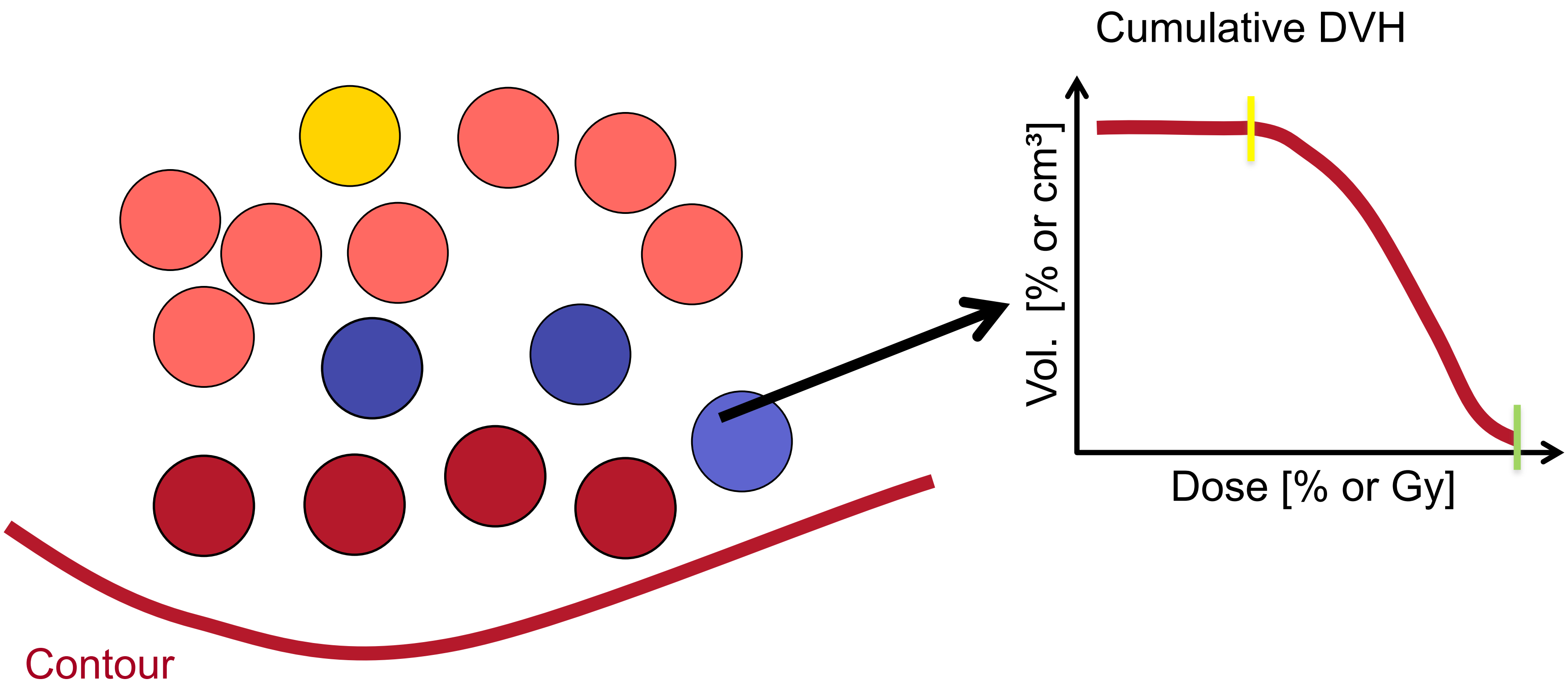


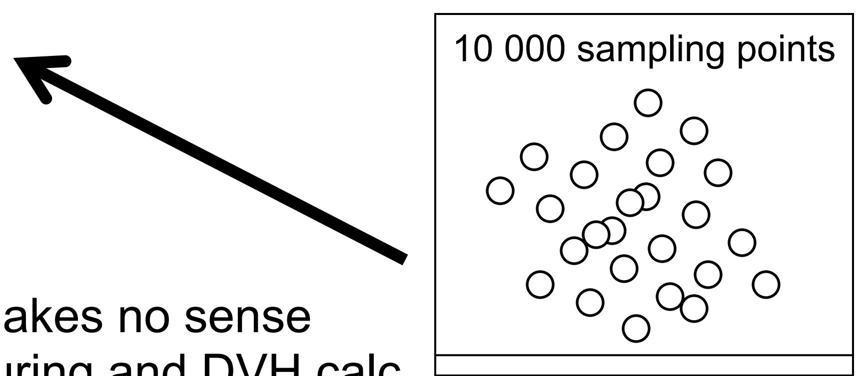
DVH-calculation



1) Why max Dose in BT DVHs makes no sense
2) D100 is very sensitive to the contouring and DVH calc.

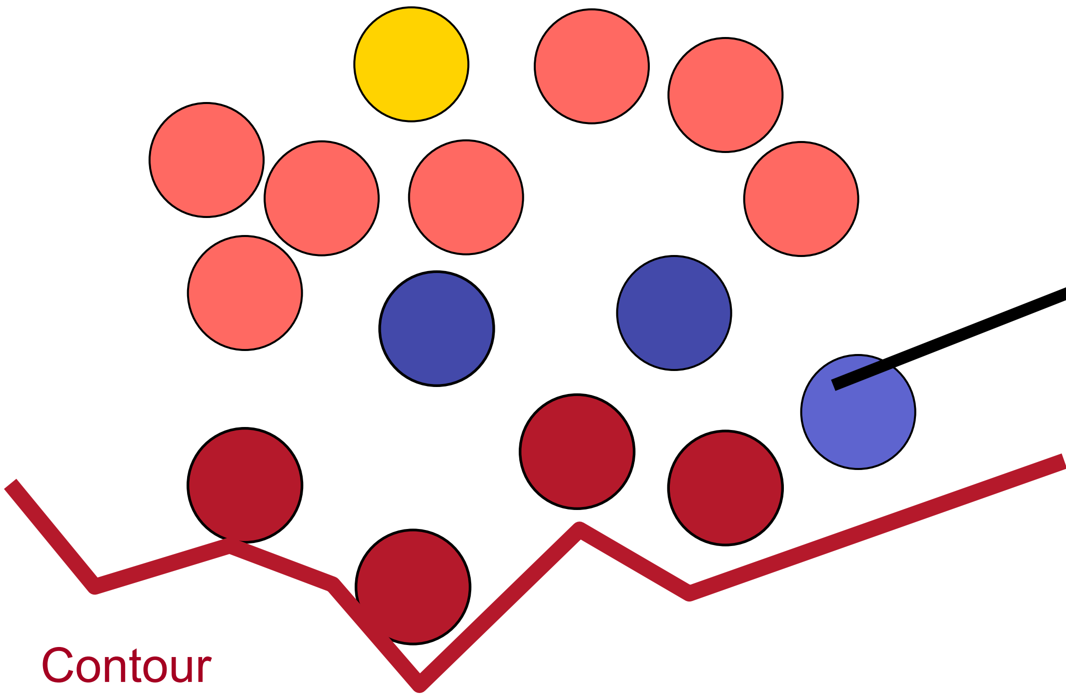
DVH-calculation

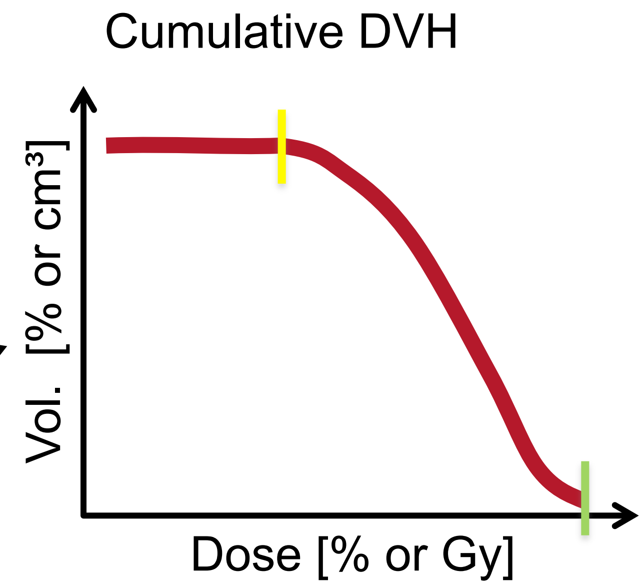


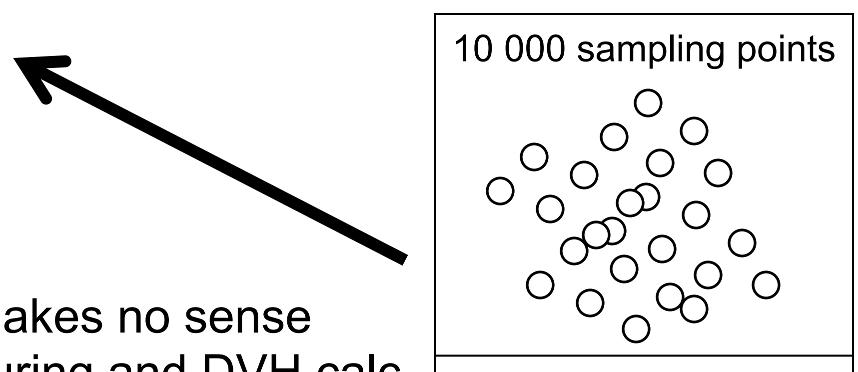


1) Why max Dose in BT DVHs makes no sense
2) D100 is very sensitive to the contouring and DVH calc.

DVH-calculation

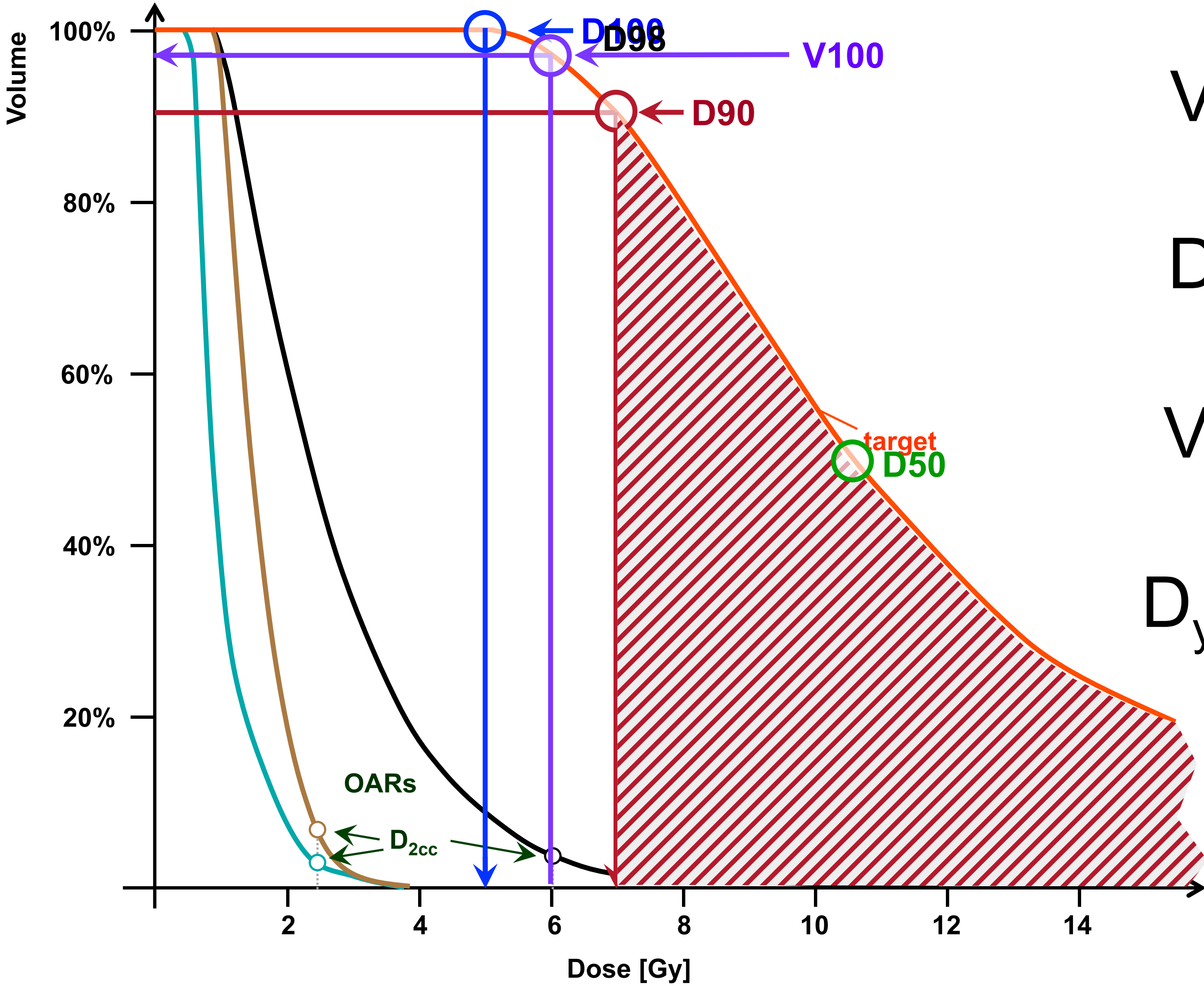






1) Why max Dose in BT DVHs makes no sense
2) D100 is very sensitive to the contouring and DVH calc.

DVH-Parameters



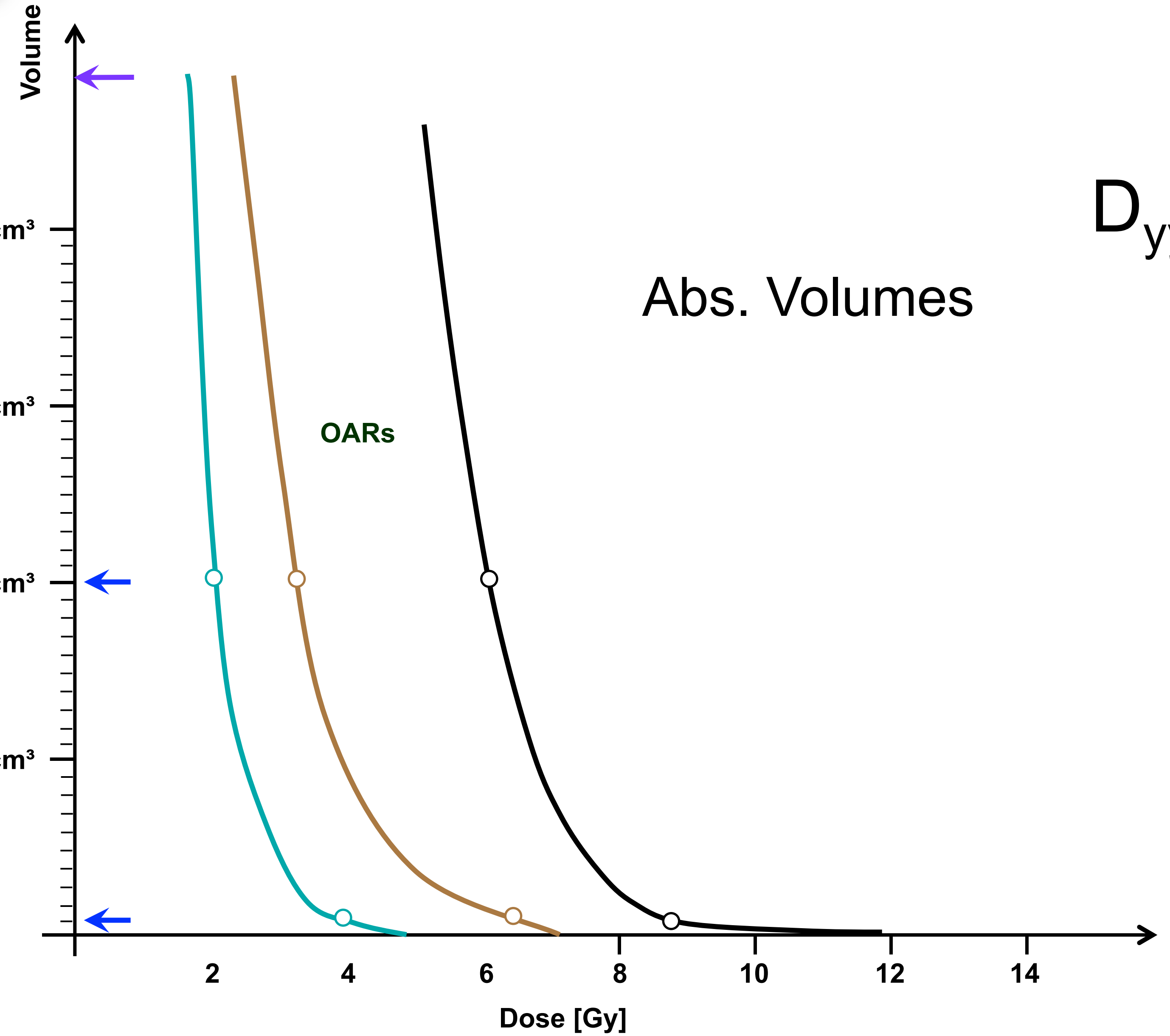
Vxx

Dyy

V_{xGy}

D_{yycm^3}

DVH-Parameters



D_{yycm^3}

Abs. Volumes

IAEA

Patient Workflow

Planning and application
- Clinical Evaluation
- Therapeutic decision making
- Patient preparation
- Applicator placement

3D imaging (with applicator)
- Purpose of imaging
- Imaging methodology
- Imaging protocols

Contouring
- Target and OARs definition

Applicator reconstruction
Defining the source-path in the individual patient

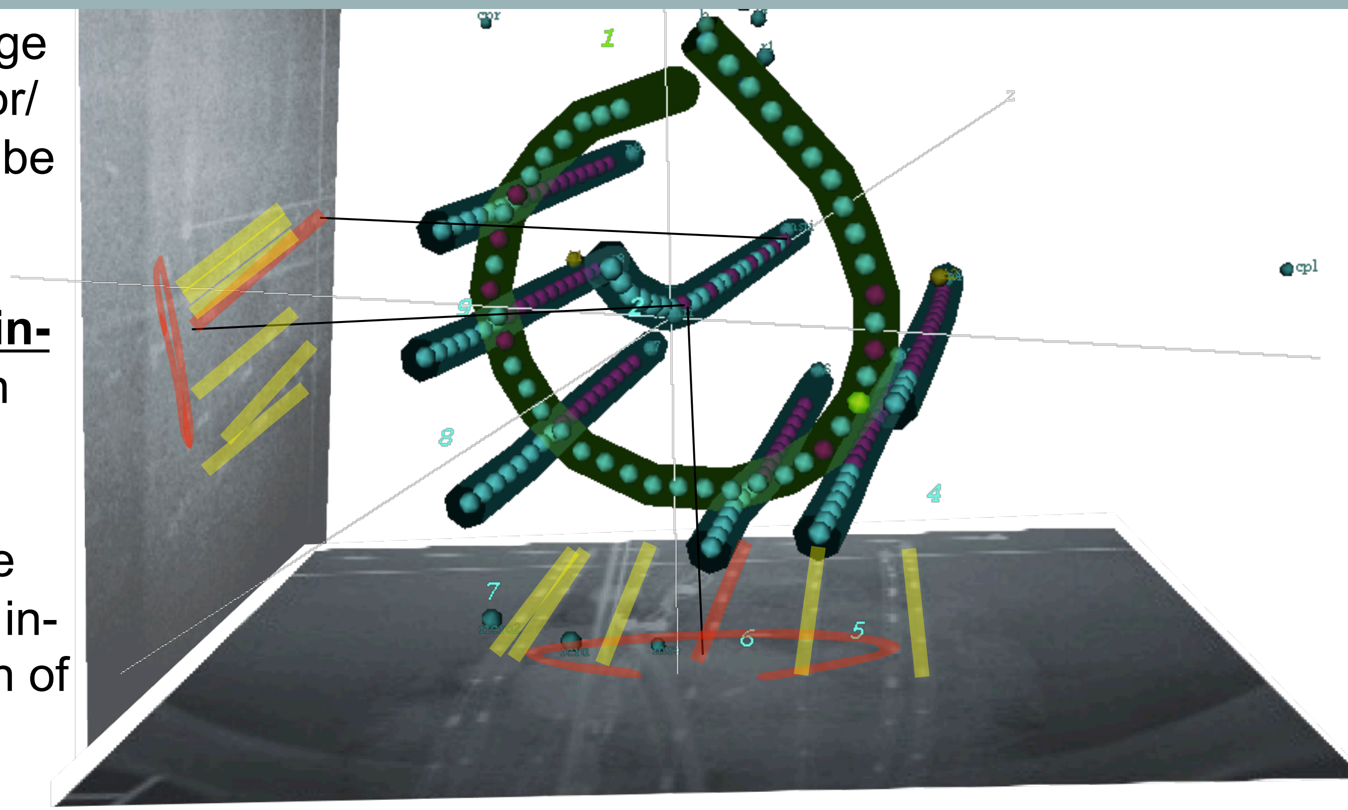
3D dose planning and reporting
- Plan optimisation, evaluation
- Final dose prescription
- Dose reporting
- Plan verification and approval

Dose delivery
- Plan Transfer to afterloader
- Pre-delivery QC
- Dose recording

Post-treatment
- Removal of Applicator
- Follow-up

Defining the source path in <u>relation</u> to the patients <u>anatomy</u>

Defining the source path in relation to <u>the applicator</u> → **‘Commissioning’**

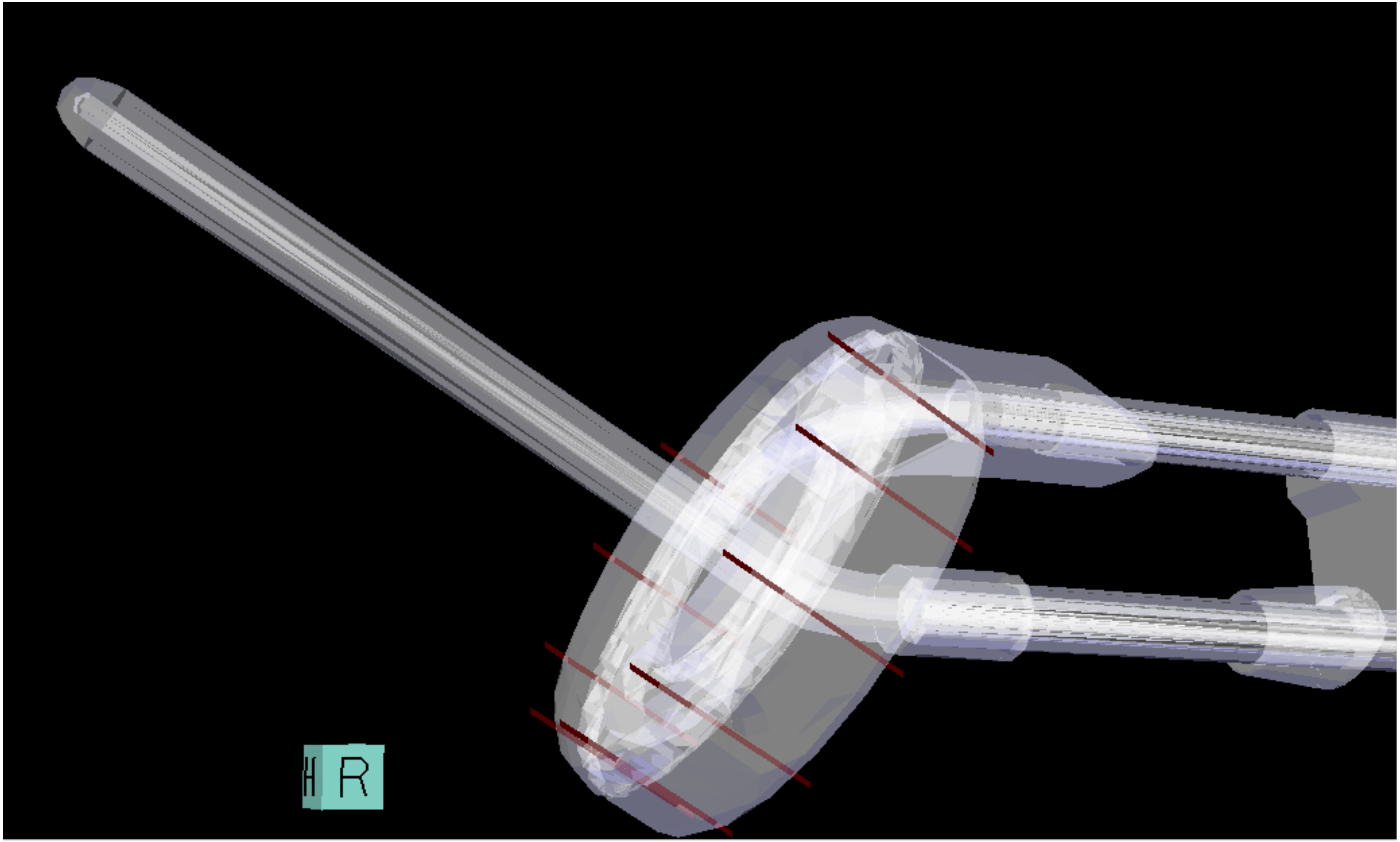


Depending on the image modality, the applicator/ **<u>source path</u>** needs to be defined

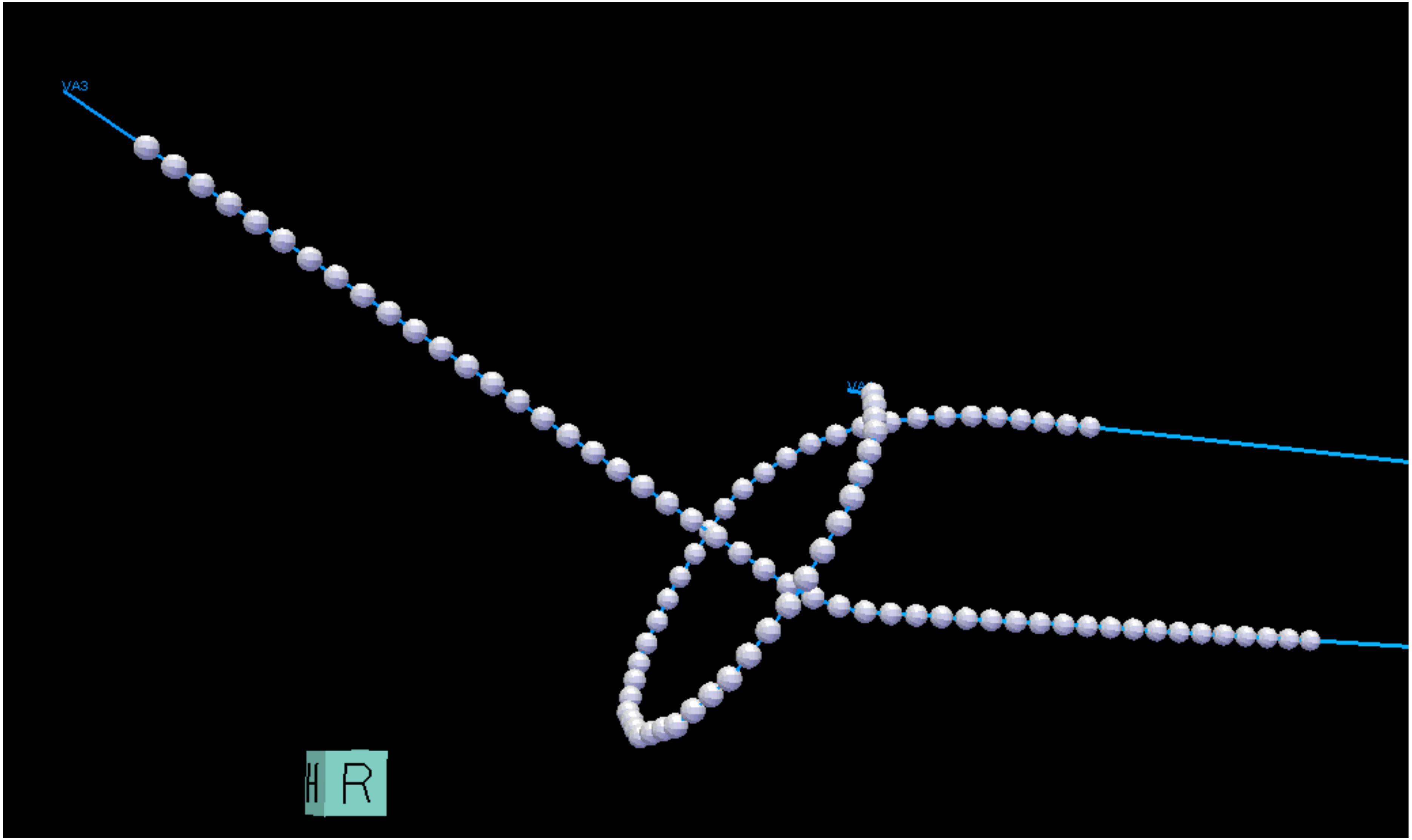
There are **<u>directly or in-directly</u>** visualization techniques

Reconstruction of the Source path (direct, or in-Direct) or reconstruction of the applicator itself

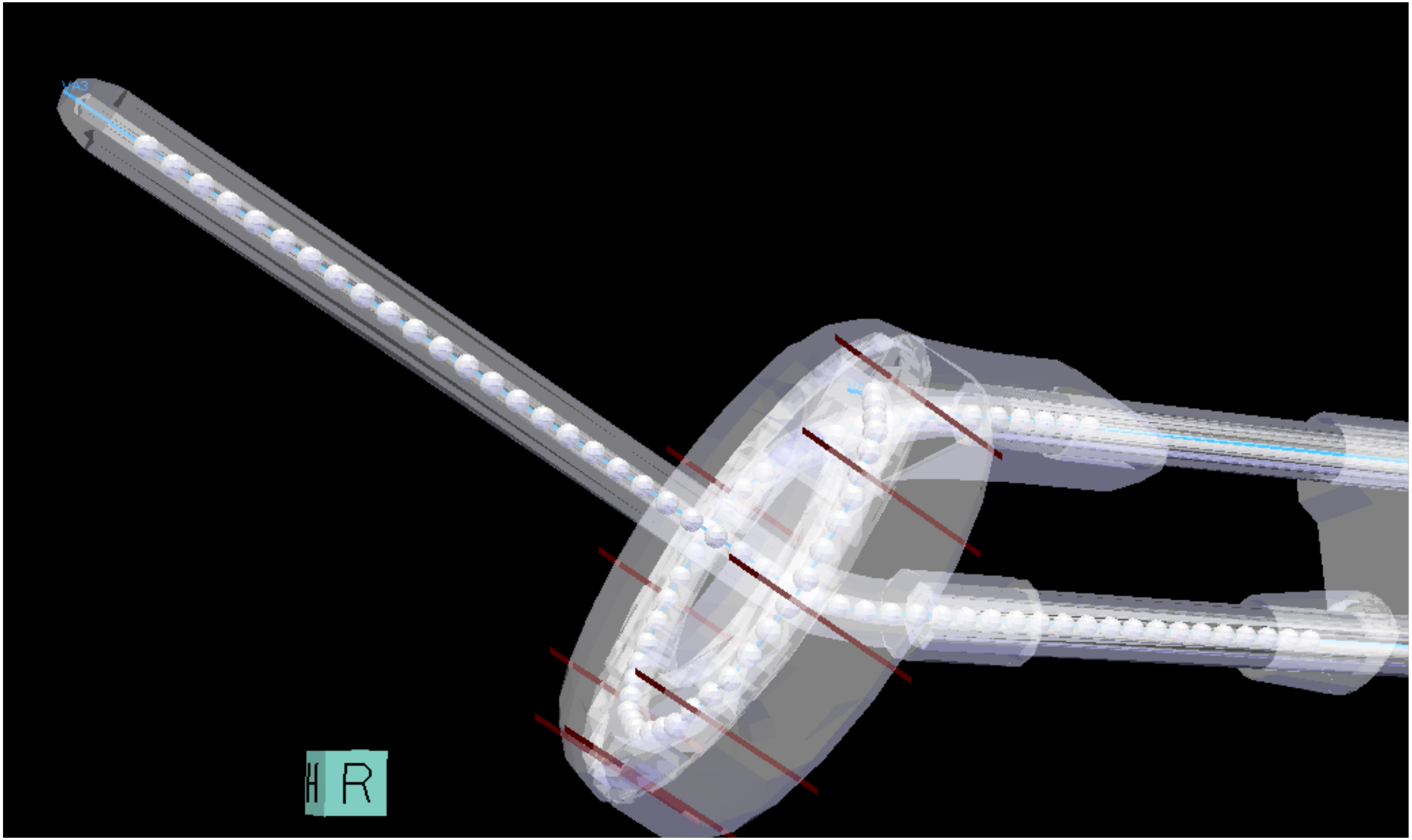
Applicator surface



Source path



Applicator + Source path



Commisioning of Applicators

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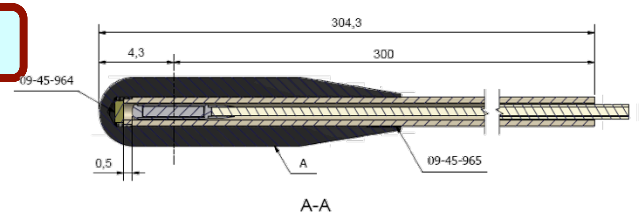
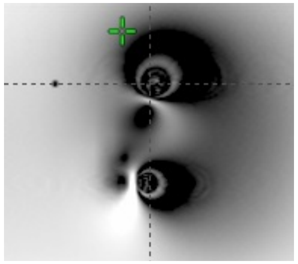


- Visibility of applicator in sectional imaging
  - Distortion of dimensions
  - Artefacts (appearance of applicator tip-end: E.g. needle tip-end)



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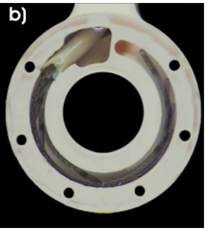
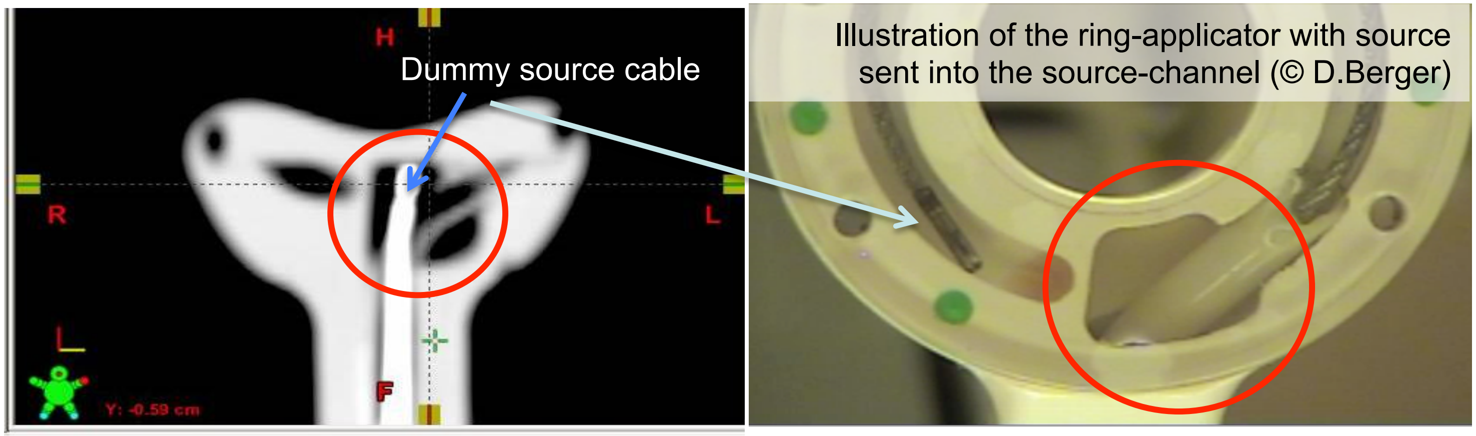
  - Direct reconstructed by the user following direct or in-direct reconstruction methods



Applicator material!

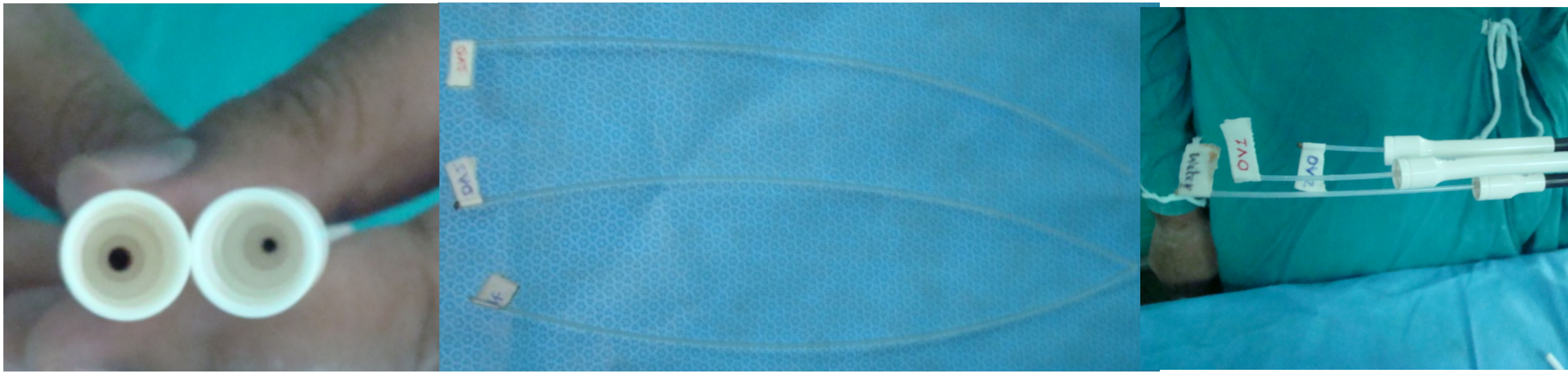
The sterilization procedure (high temperatures) and a frequent use may damage the applicator material and applicator accessories (E.g. screws)



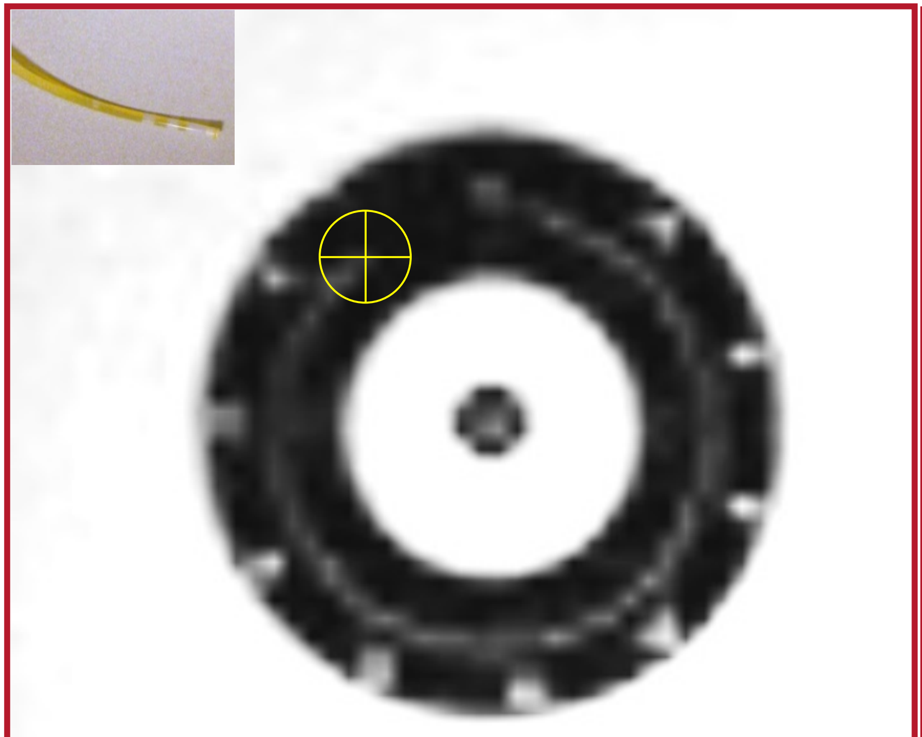
CT imaging of a damaged ring applicator provided by U. Mahanshetty

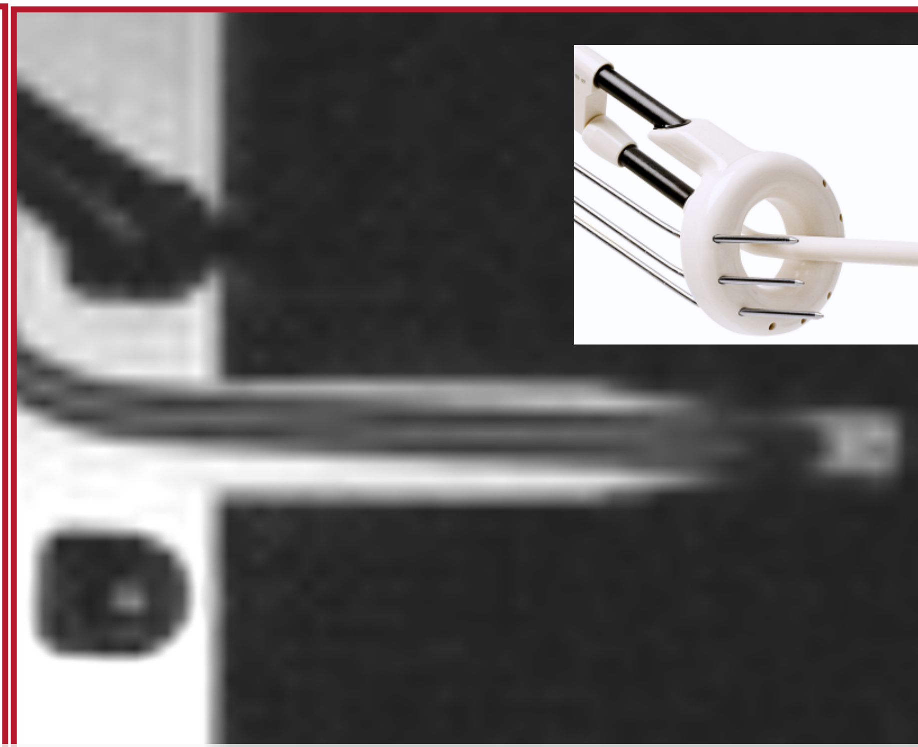
Therefore the visual inspection of applicators before clinical use is mendatory and needs to be included in the quality control procedure.

Ch



Pictures provided by Jamema Swamidas, TATA

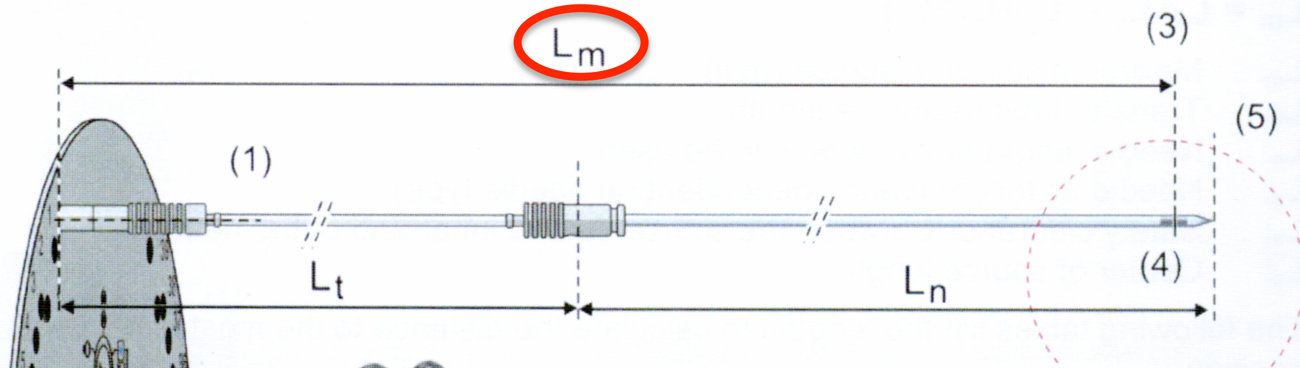


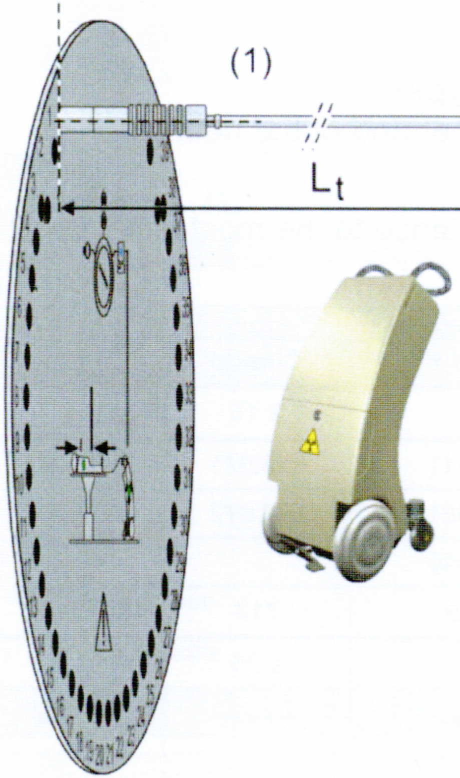


MR markers (Nucleotron) Phantom scan at open MR 0.2T

Indexer Length and Offset

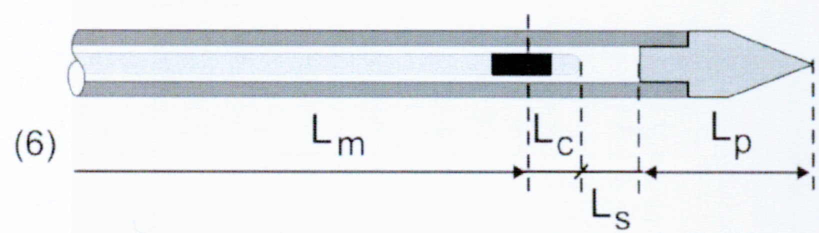
20. Flexitron; Distance to Most Distal Dwell Position → **Indexer length**





$$L_m = L_t + L_n - (L_p + L_s + L_c)$$

- L_m: Maximum source distance (mm)
- L_t: Transfer tube reference length
- L_n: Needle length of the needle to be used
- L_p: Needle tip length (varies dependent on needle type)
- L_s: Safety clearance between the source tip and inner end of the needle
- L_c: Center of source length

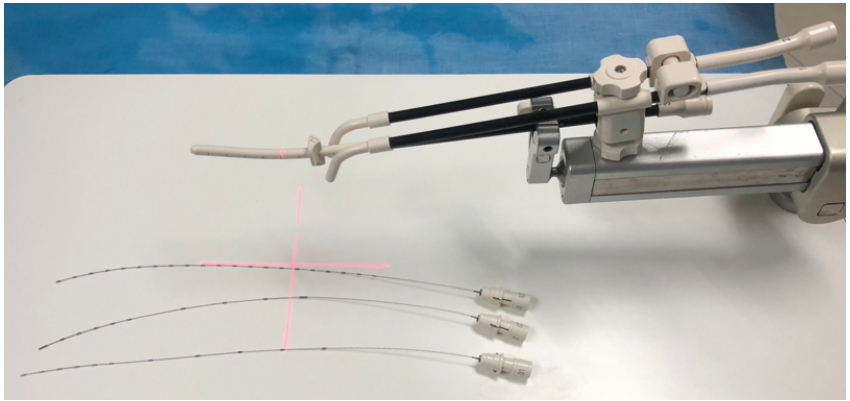


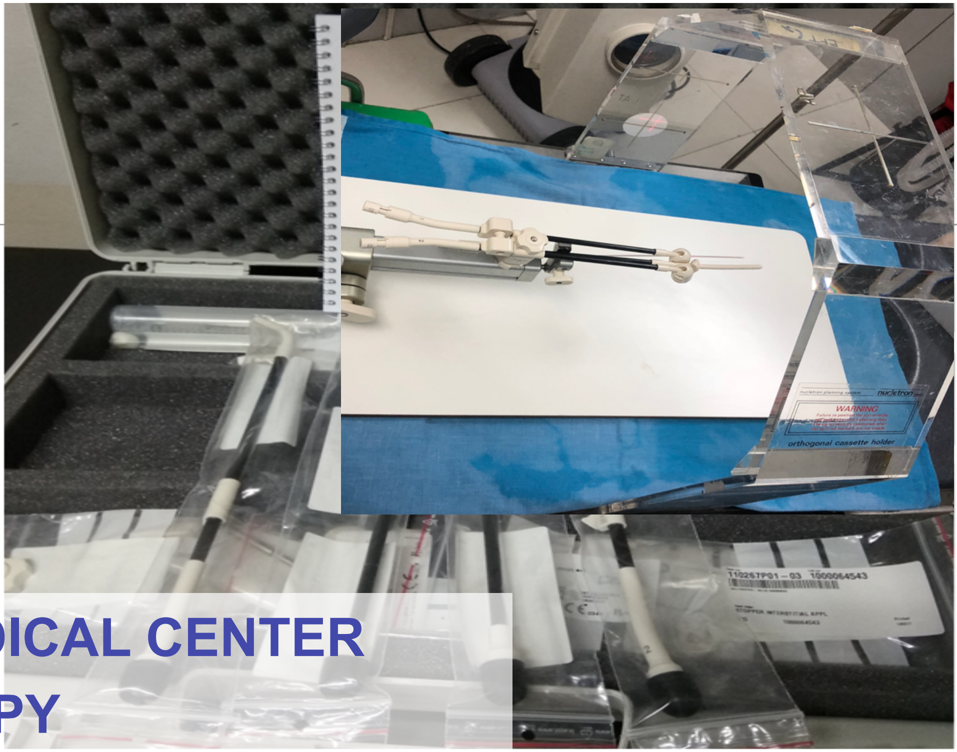
s+Lp= Off-set

(1) Channel selector
(3) Centre of source
(4) Most Distal Dwell Position
(5) See Detail A
(6) Detail A

Example from Manila 25-27.4.2018

Commissioning performed by
Jake John P. Galingana
Medical Physicist



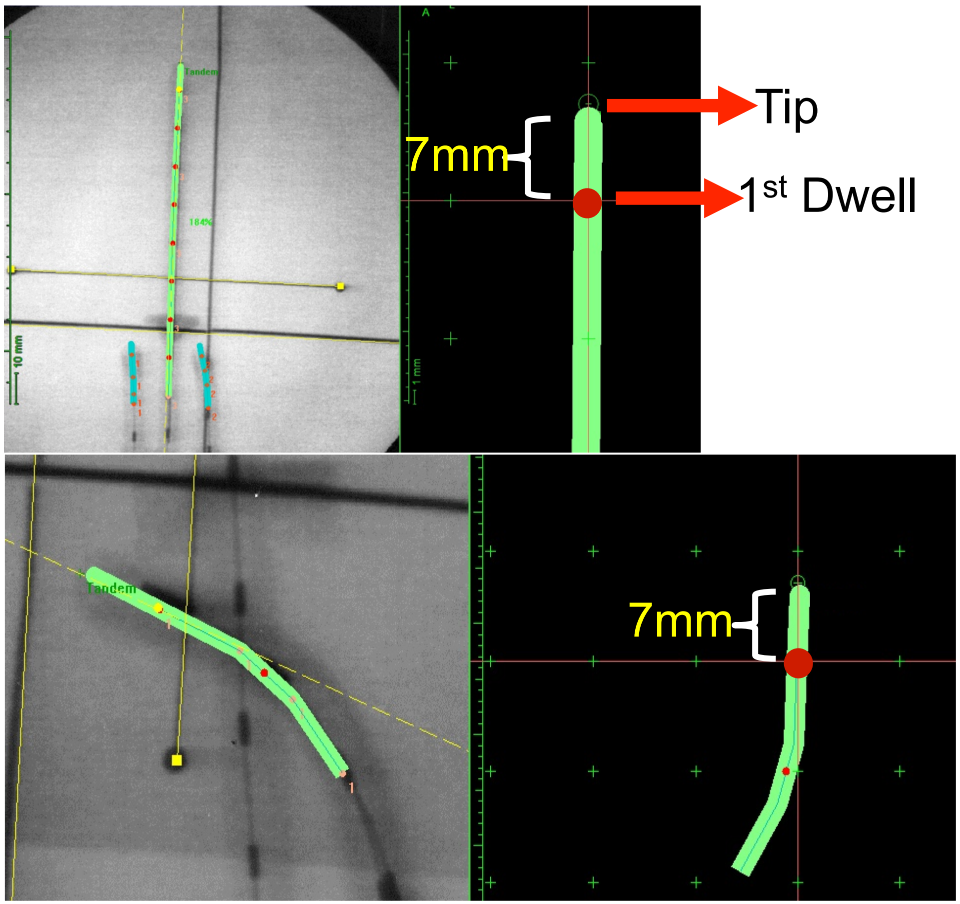


- **JOSE R. REYES MEMORIAL MEDICAL CENTER**
- **DEPARTMENT OF RADIOTHERAPY**

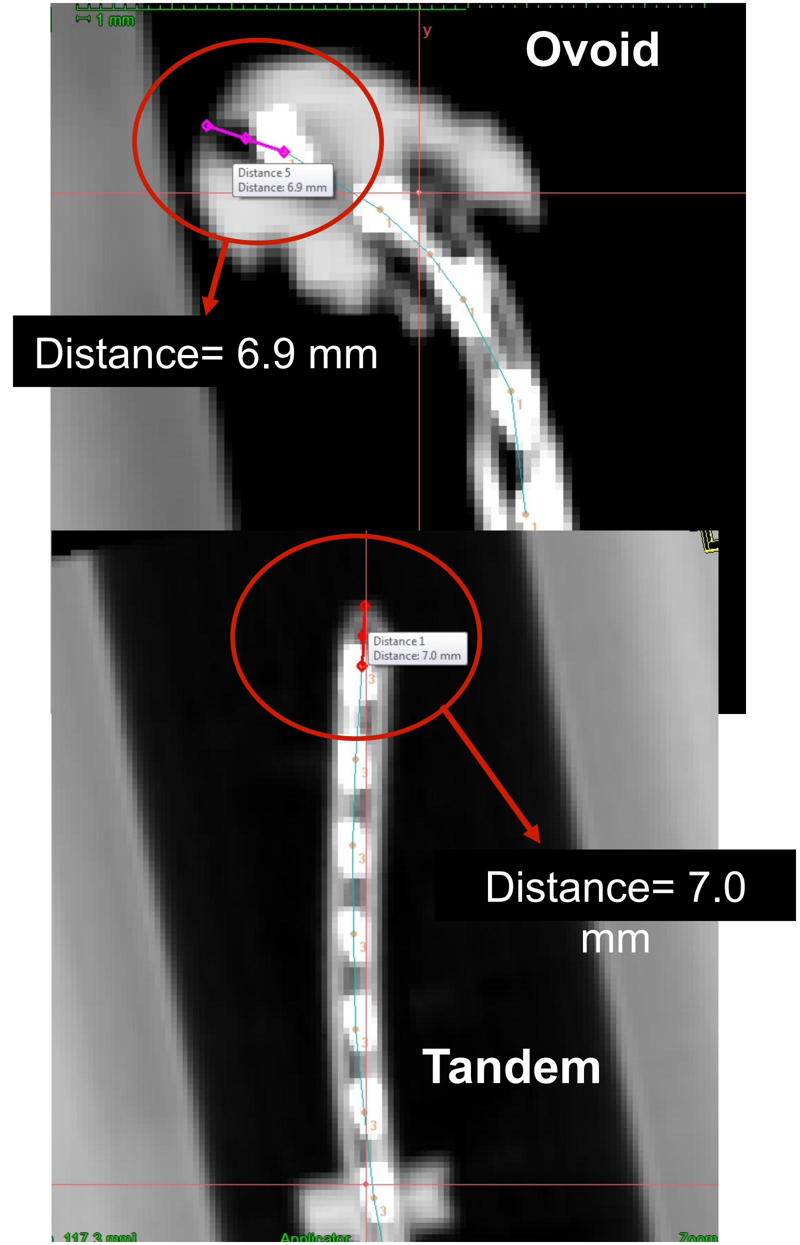
Offset Verification:

Manufacturer specification: offset= 7.0 mm

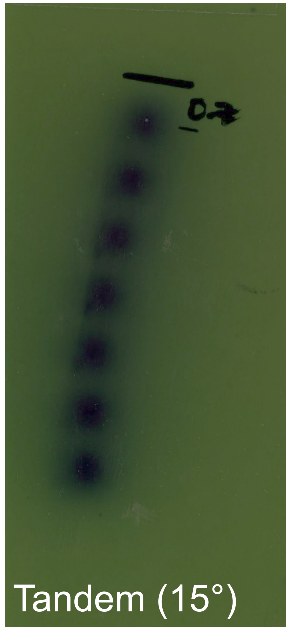
On Radiograph



On CT



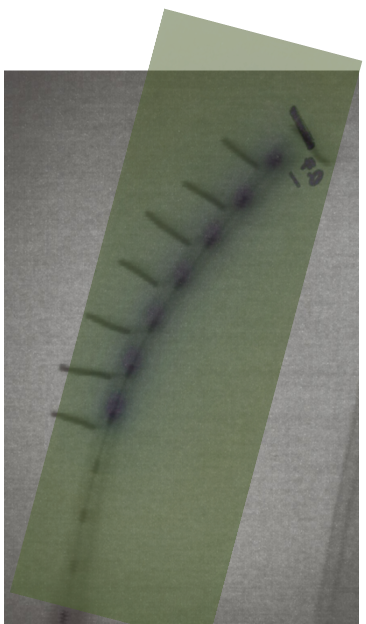
Offset Verification: Auto-radiograph

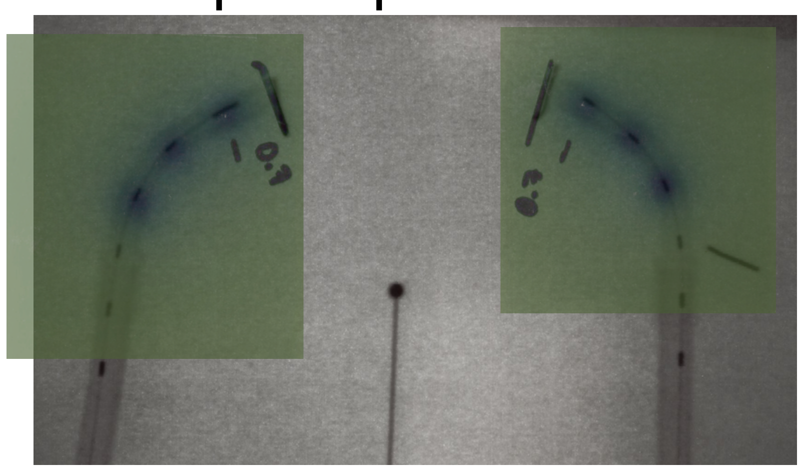


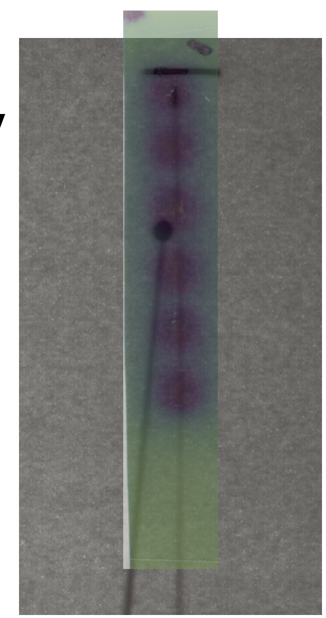
ProGuide round needle

Applicators	Offset
Right Ovoid	7mm
Left Ovoid	7mm
Tandem 15	7mm
Tandem 30	7mm
ProGuide needle	2mm

and superimposed with X-ray

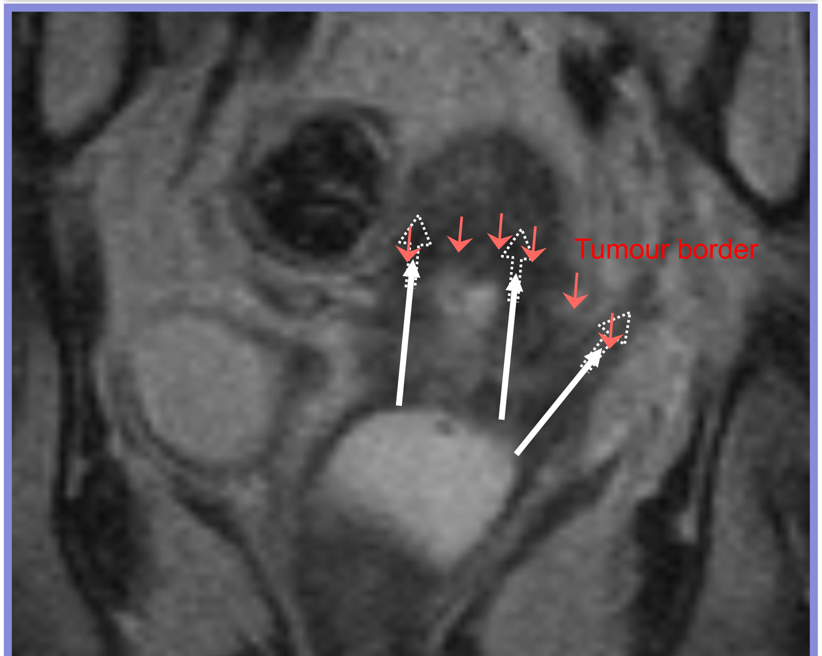




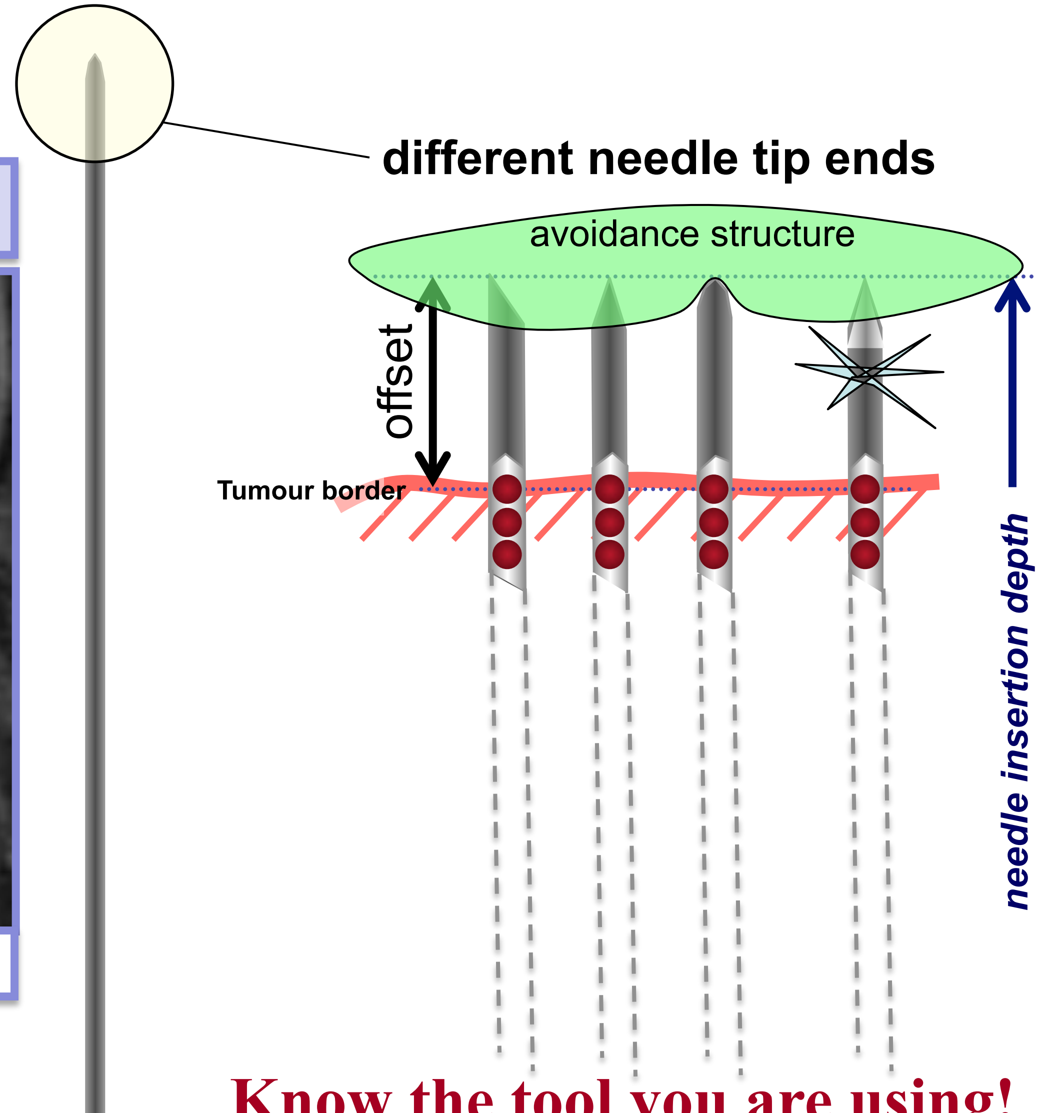


Offset will effect the insertion depth

Pre-planning of needle insertion



cor. MRI after 45Gy EBRT



Know the tool you are using!

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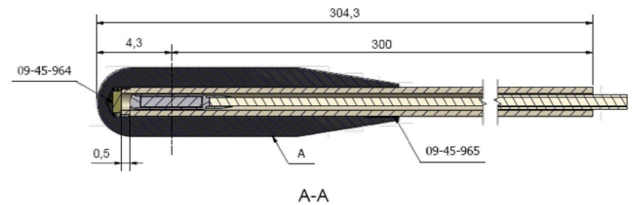
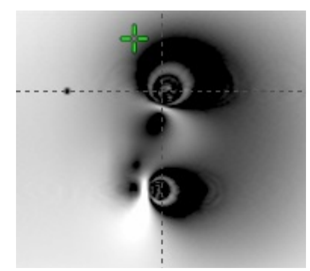


- Visibility of applicator in sectional imaging
  - Distortion of dimensions
  - Artefacts (appearance of applicator tip-end: E.g. needle tip-end)



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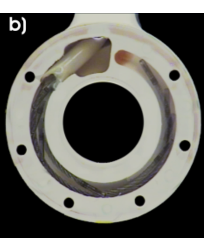
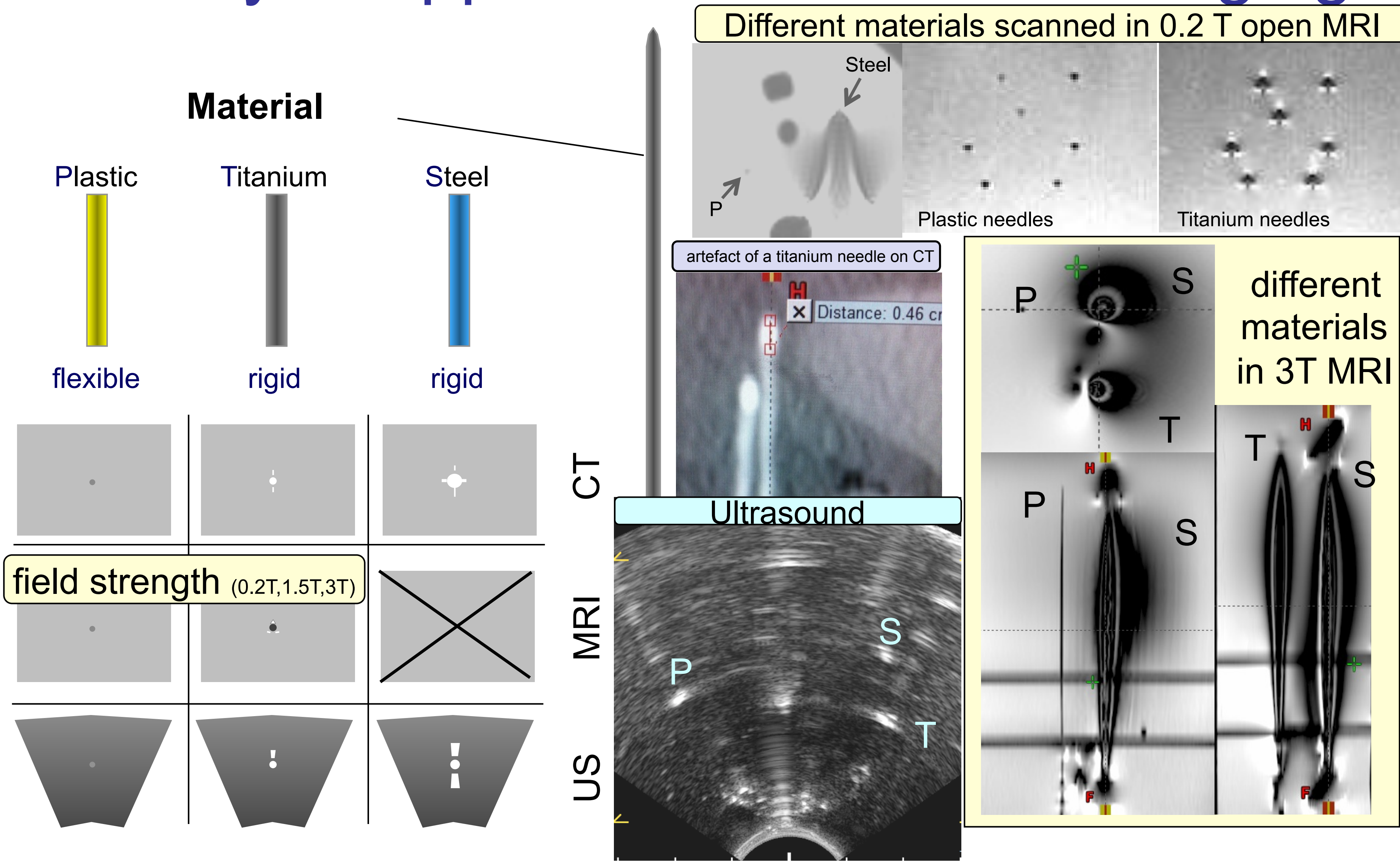
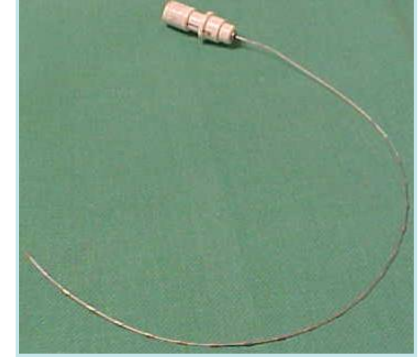


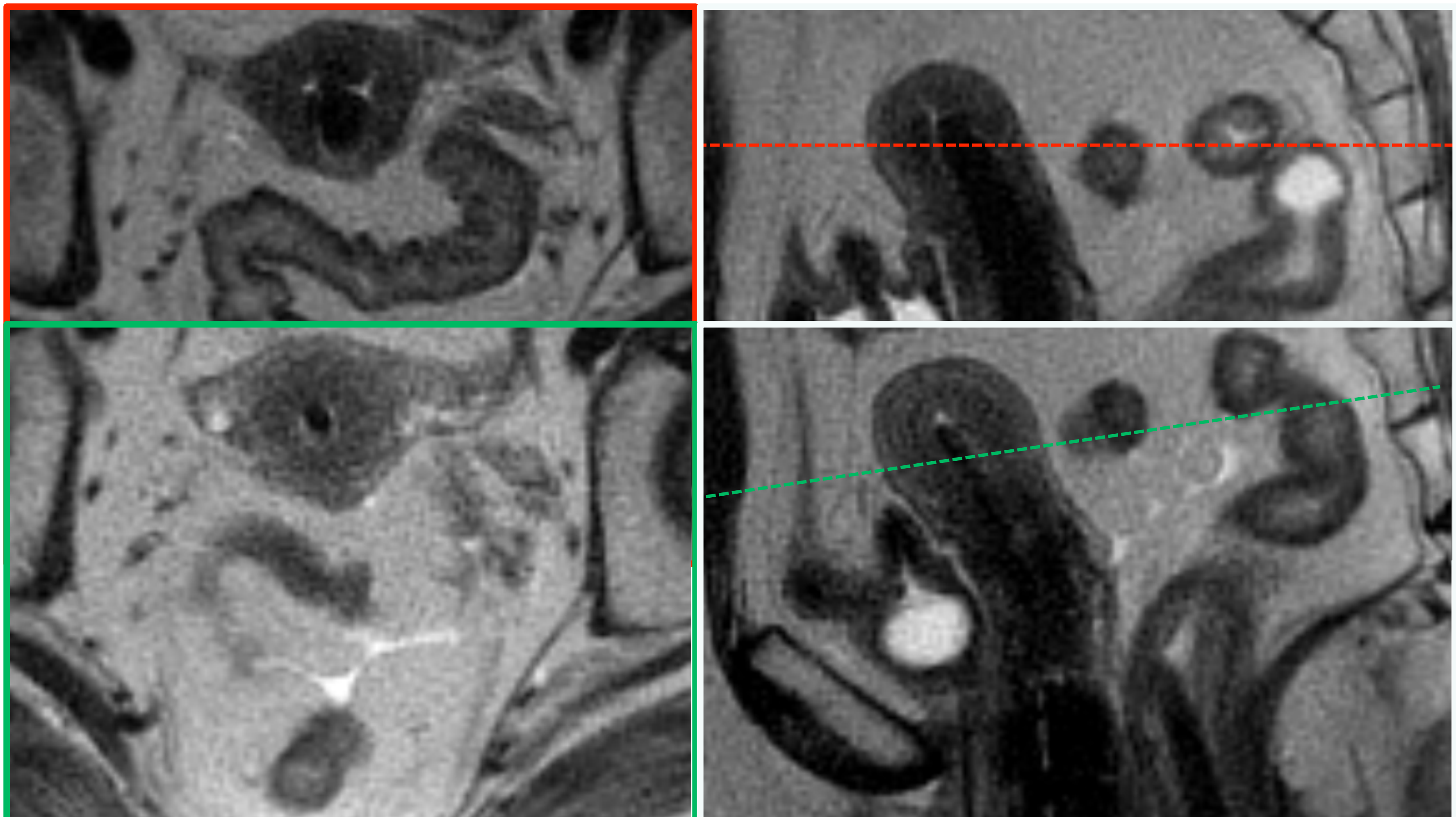
Visibility of applicator in sectional imaging



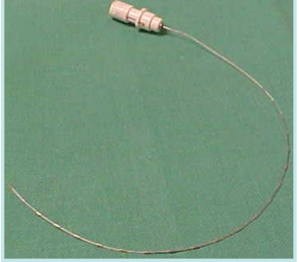
Know the tool you are using!

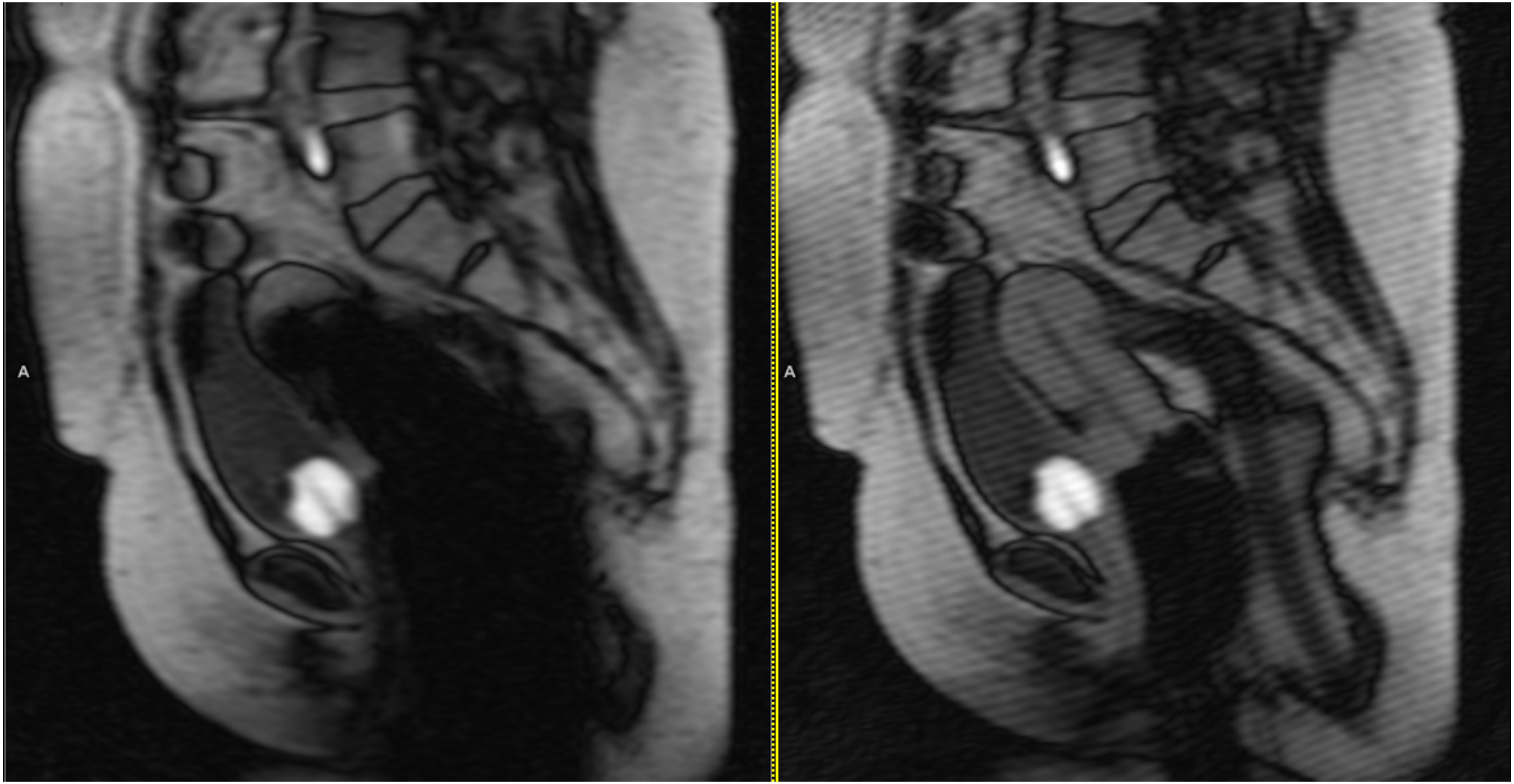
What is wrong with these MR Images ?



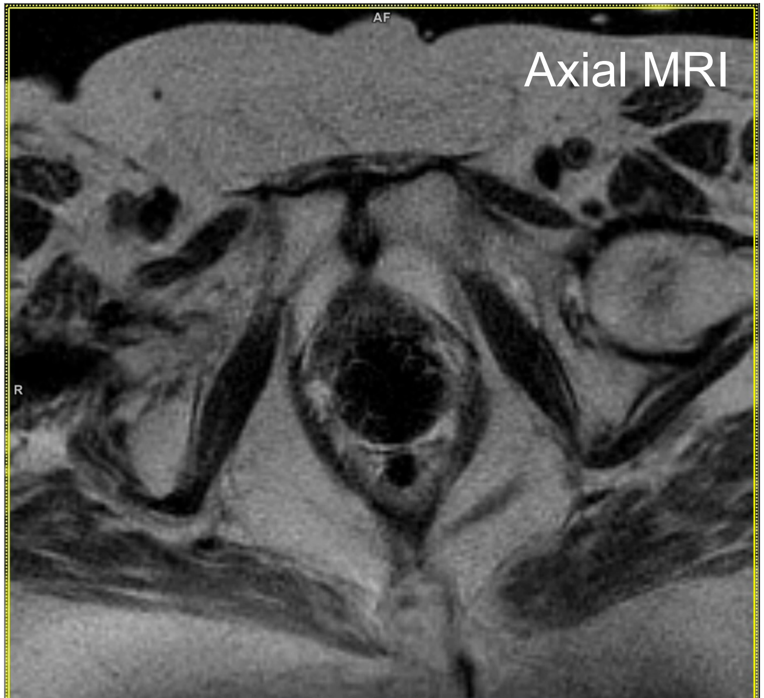


Early detection of the forgotten dummy wire inside the applicator – *could be seen? "localizer"*





Which artefacts are tolerable ?



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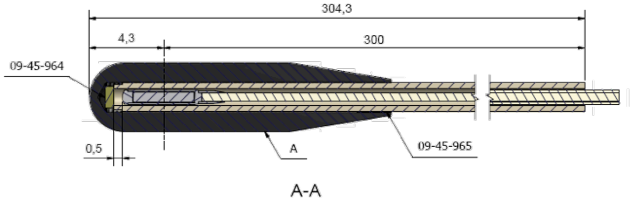

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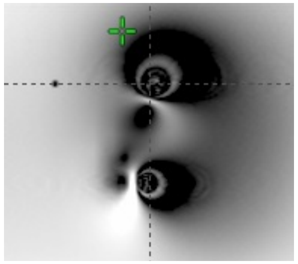

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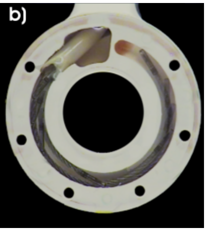
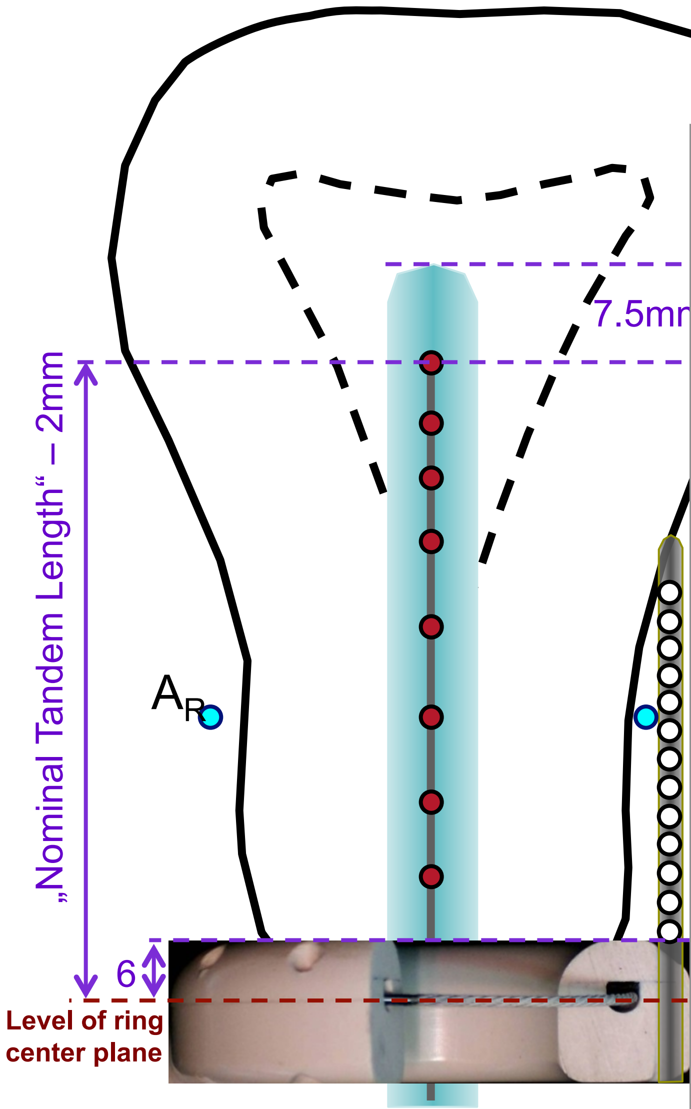
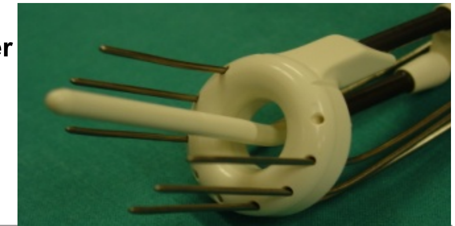


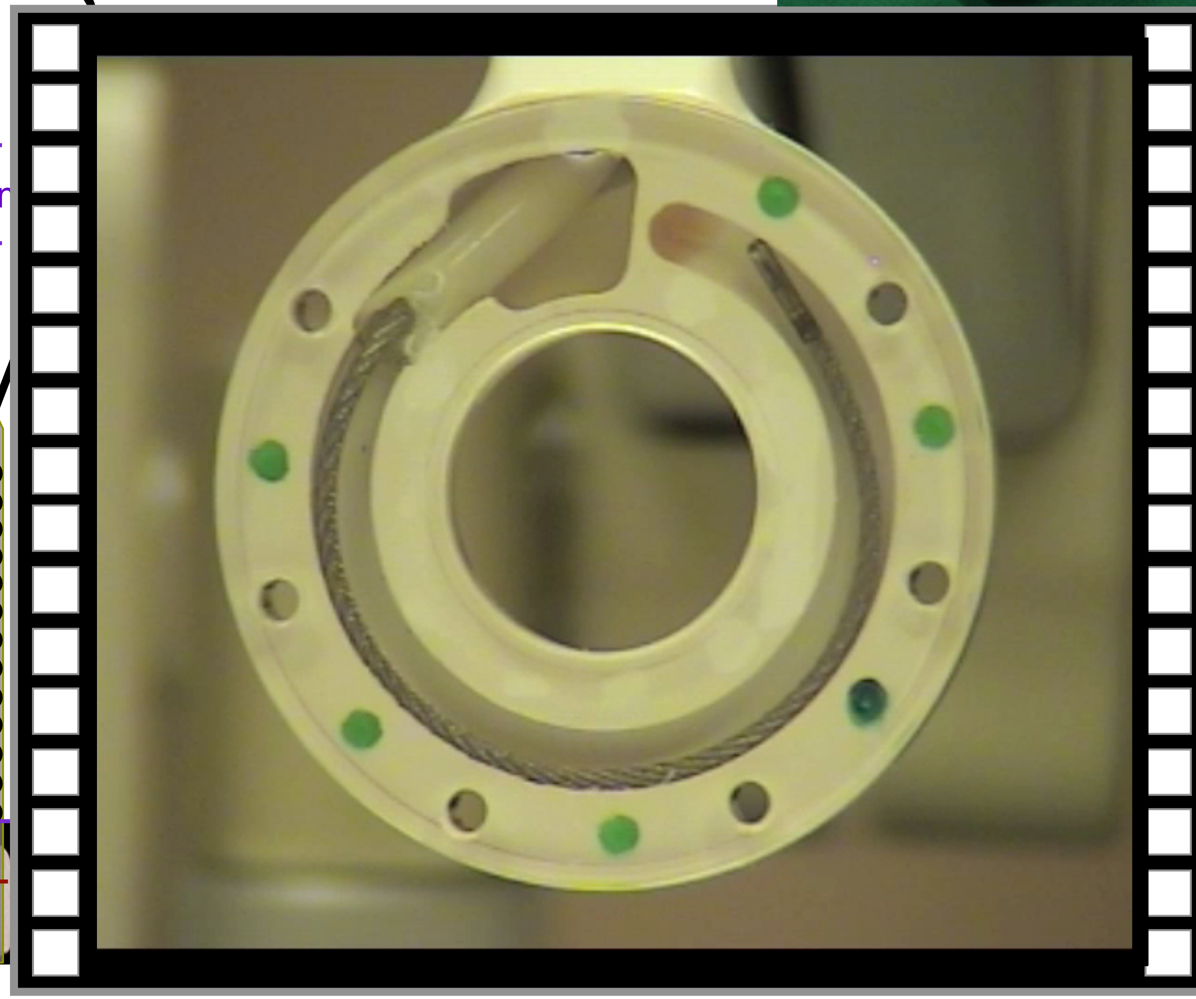
Geometry and dimensions of the applicator



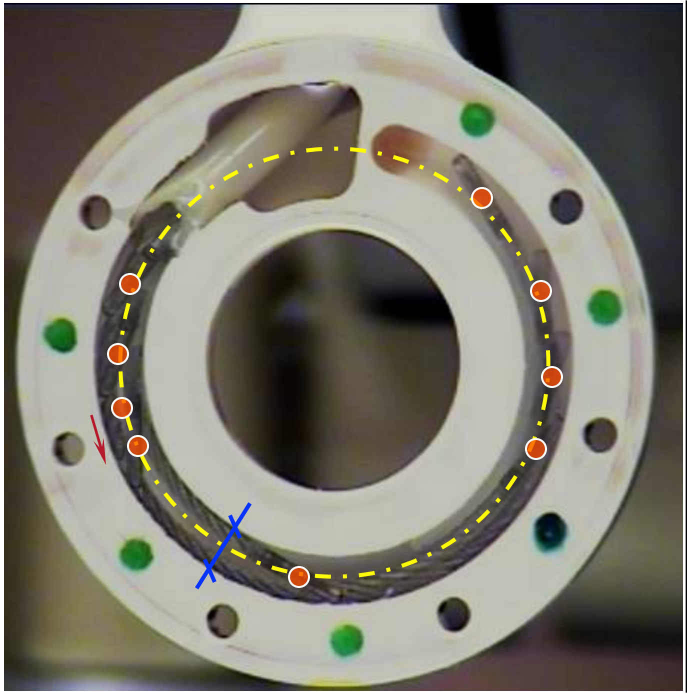
Ring Diameter

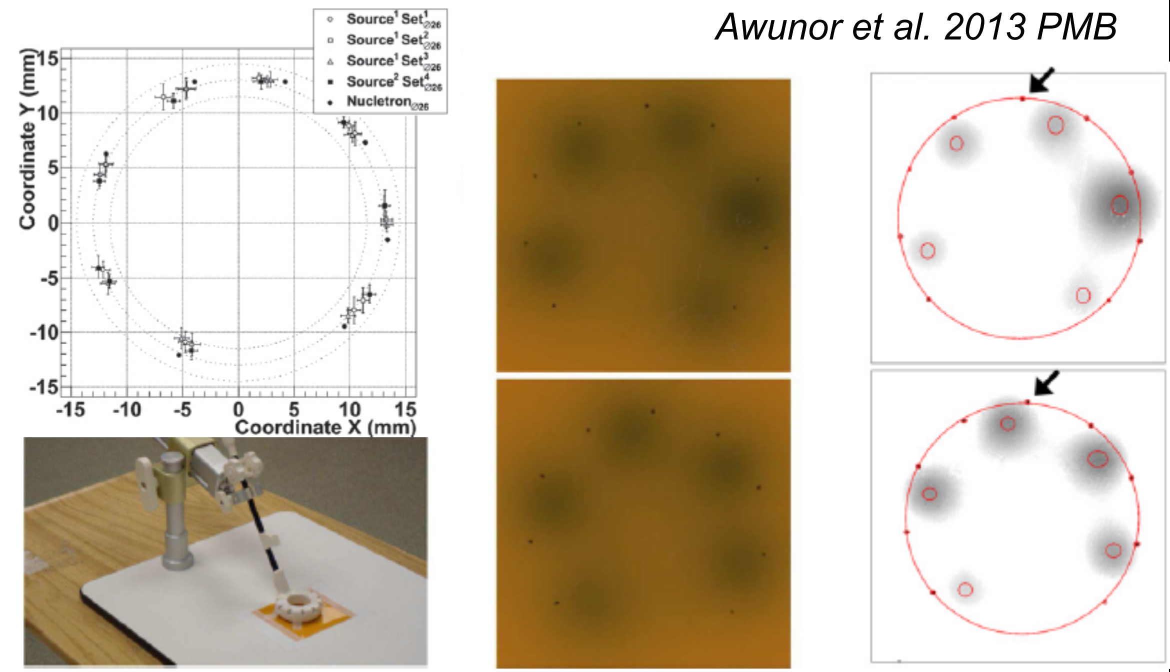
nominal	outer
26	38
30	42
34	47





associated uncertainties of 192Ir source dwell positions in ring applicator





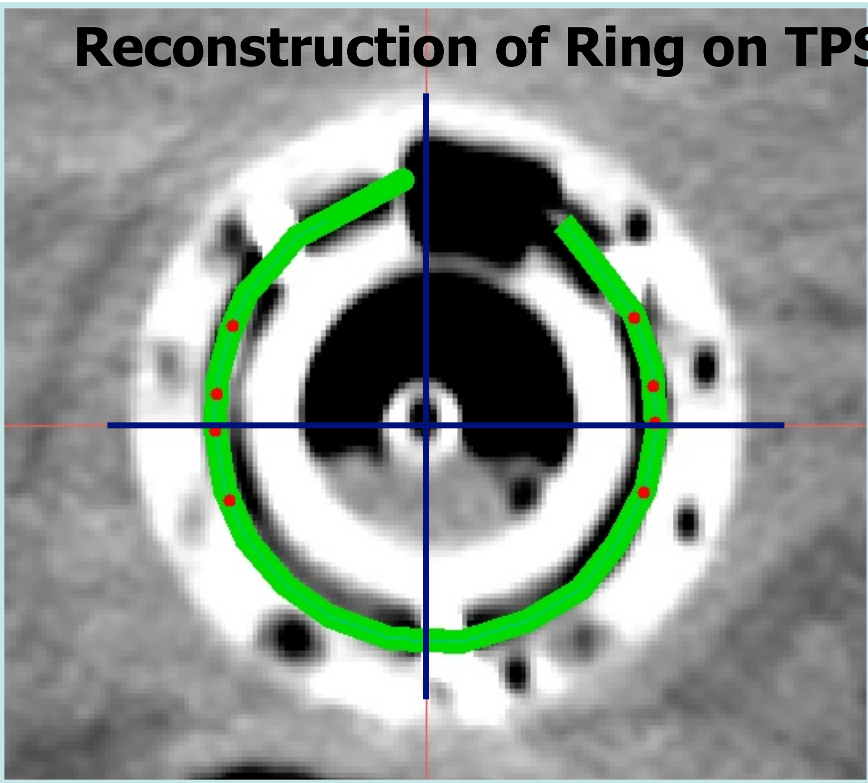
Awunor et al. 2013 PMB

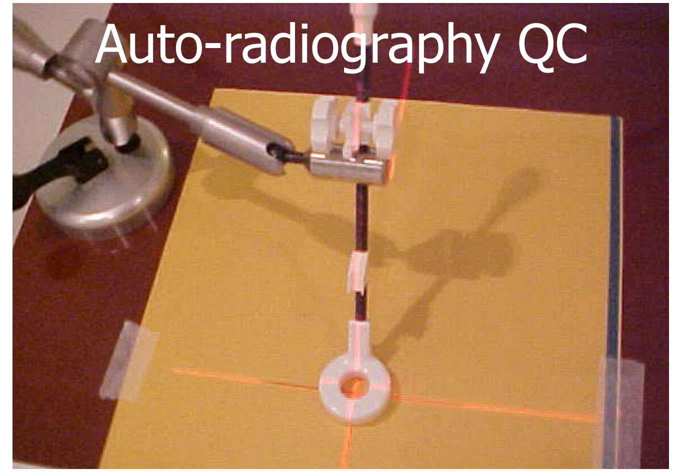
The total expanded measurement uncertainty averaged over all dwell positions was observed to be 1.1 ± 0.1mm(Ø26 and Ø30 mm) and 1.0 ± 0.3 mm (Ø34 mm)

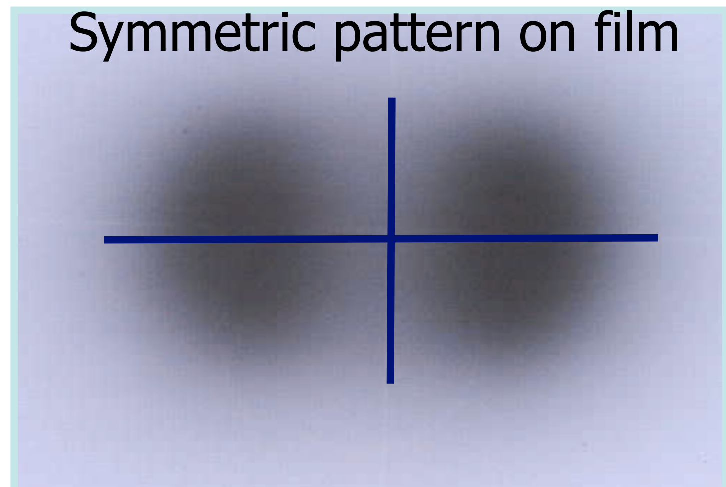
1) Real step-size in ring dwell positions varies depending on the location

2) A dummy wire dose not represent the real source path

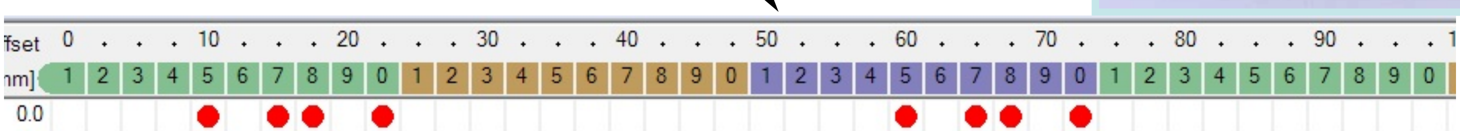
Auto-radiography to verify the reconstruction of the source path in the TPS (or pre-defined Applicator Library)



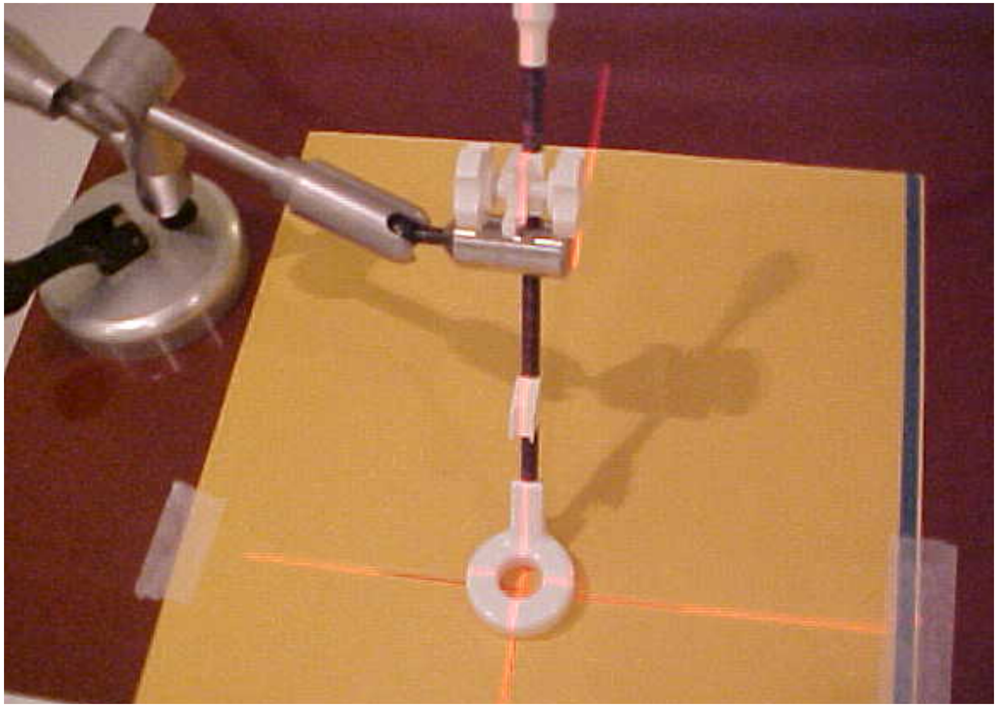


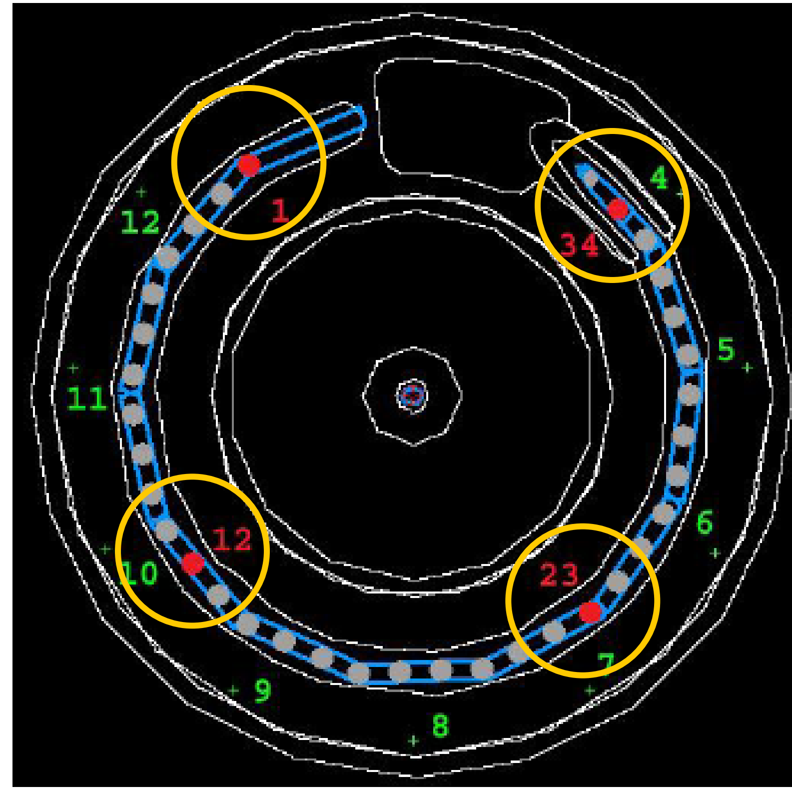


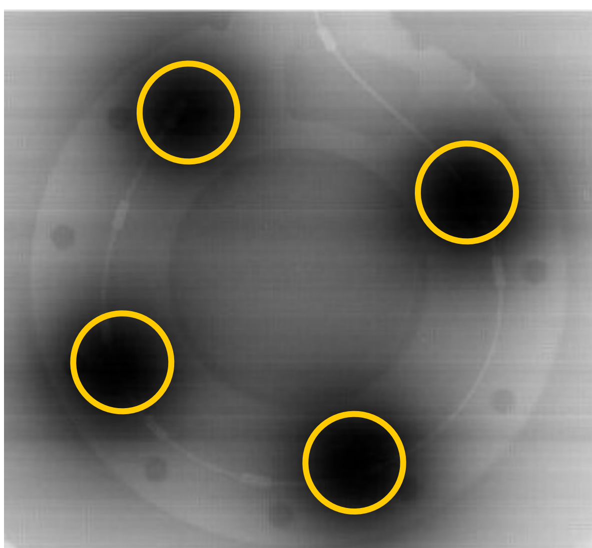
Standard loading

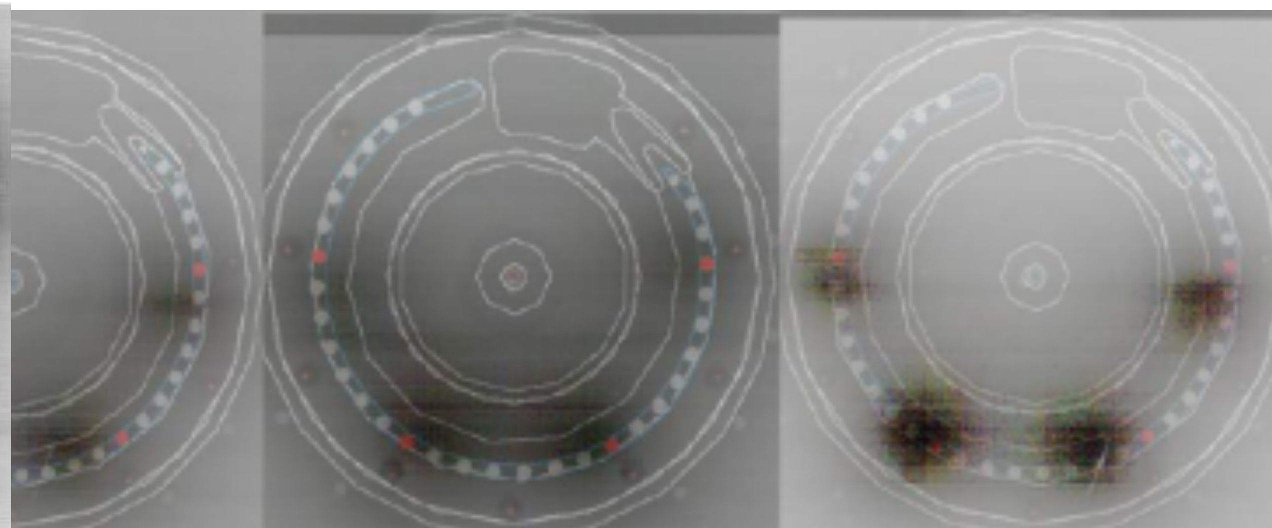


Do acceptance tests and check





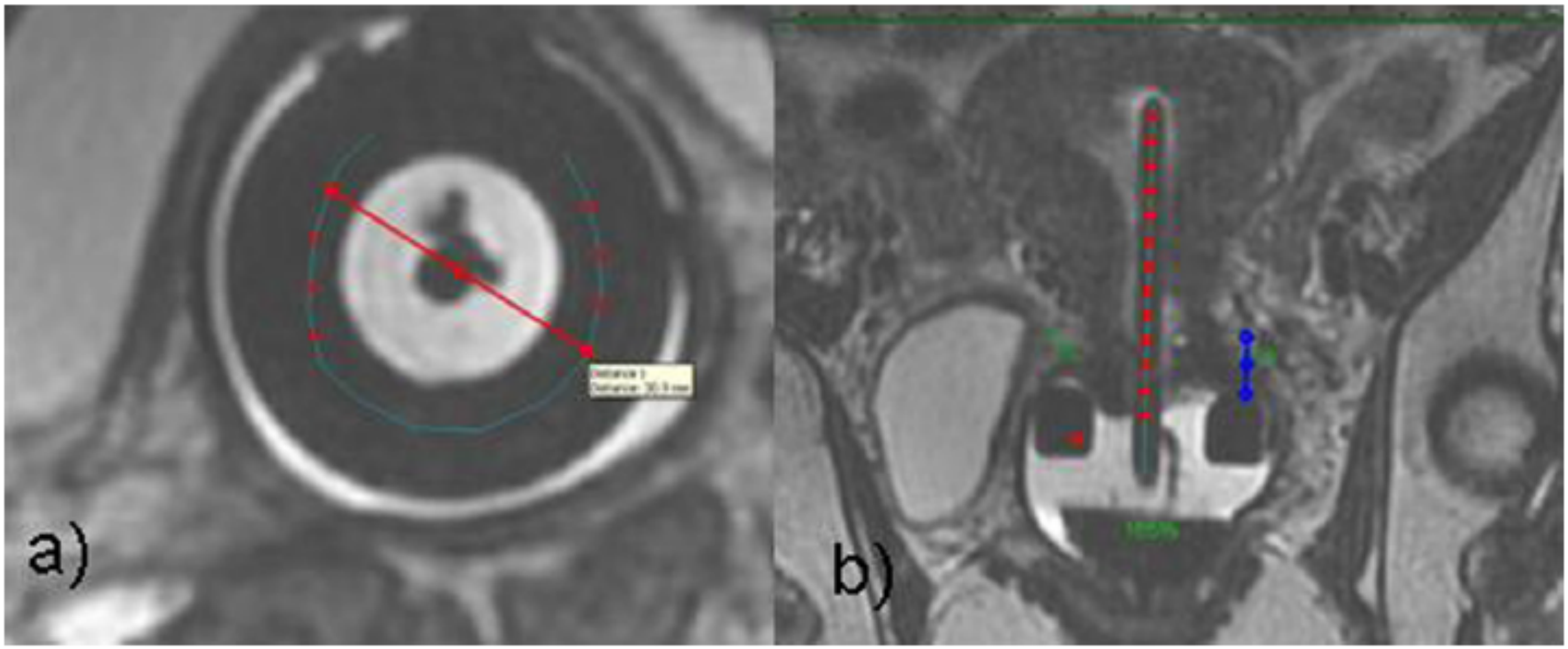




Quality assurance in MR image guided adaptive brachytherapy for cervical cancer: Final results of the EMBRACE study dummy run

Christian Kirisits [a,*], Mario Federico [a,c], Karen Nkiwane [a], Elena Fidarova [a], Ina Jürgenliemk-Schulz [d], Astrid de Leeuw [d], Jacob Lindegaard [b], Richard Pötter [a], Kari Tanderup [b]

[a] *Department of Radiation Oncology, Comprehensive Cancer Center, Medical University of Vienna, Austria;* [b] *Department of Oncology, Aarhus University Hospital, Denmark;* [c] *Radiation Oncology Department, HUGC Dr. Negrin, Las Palmas, Spain; and* [d] *Department of Radiation Oncology, University Medical Centre Utrecht, The Netherlands*

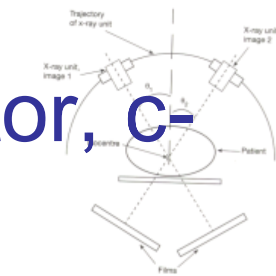


(a) **Incorrect reconstruction of the source path** within the ring using direct digitalization not according to the true dwell positions. (b) incorrect definition of point A using wrong distance from upper ring surface plus incorrect source path with wrong offset to the tip of the tandem and wrong location of source path inside the ring.

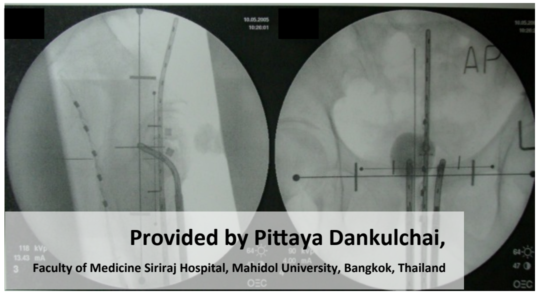
Kirisits et a.l 2015, Radiotherapy and Oncology

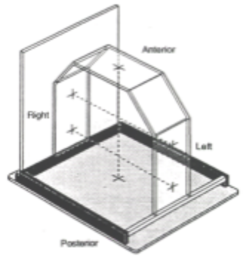
Localization techniques in “2D” and 3D

Depending on your equipment (2D:simulator, c-arm, ceiling mounted,3D: US,CT,MRI)

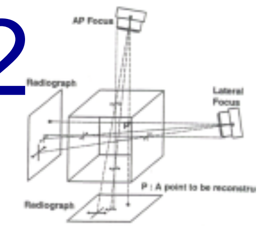


- ➢ Orthogonal images
- ➢ Semi-orthogonal
- ➢ Variable angle
- ➢ Stereo-shift





“2D”:Level 2



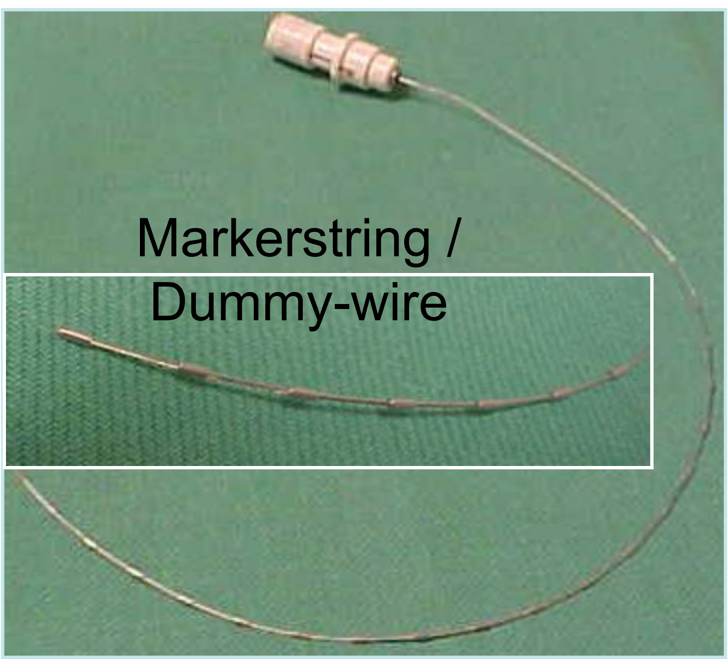
- ➢Sectional Images (CT,MRI)
- ➢Volumetric (US,MRI)

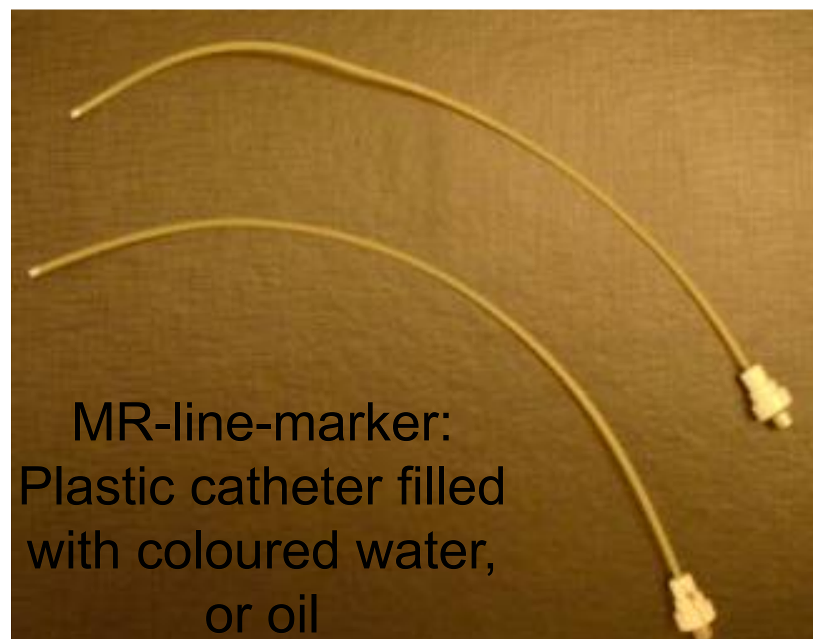
3D Level3

Direct Visualizing the Source Path

- Find a surrogate of the the source path→ inserting a “marker-string” –

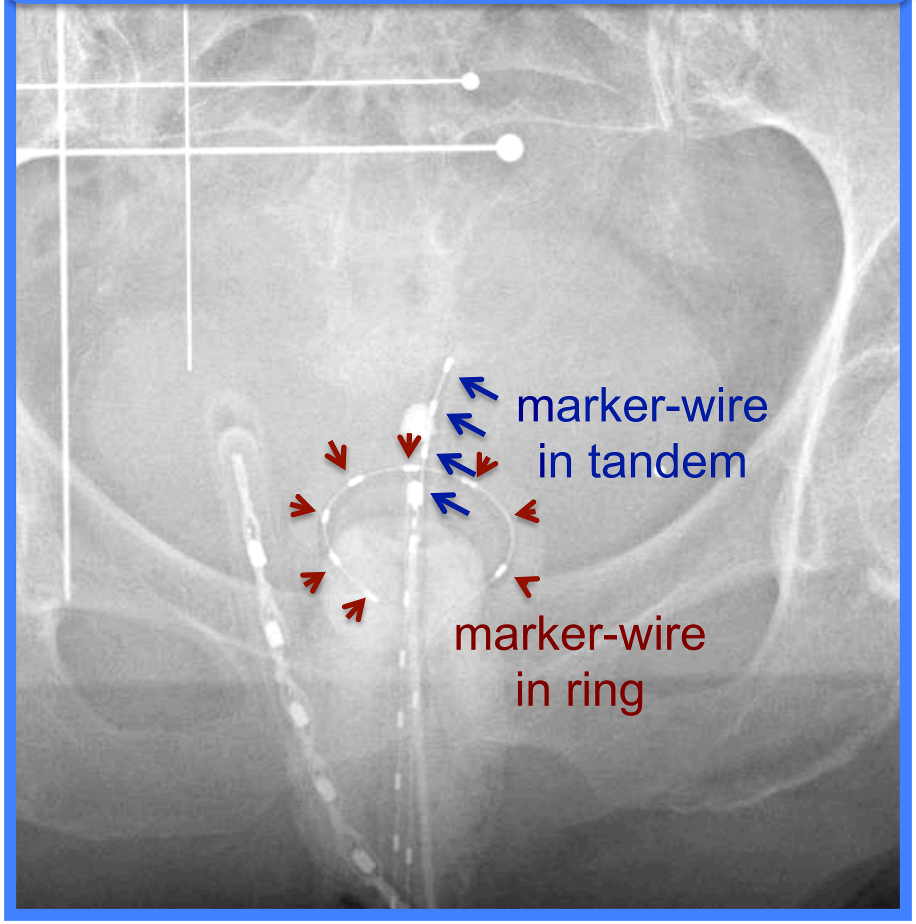
dummy wire or MRI (liquid filled) line marker



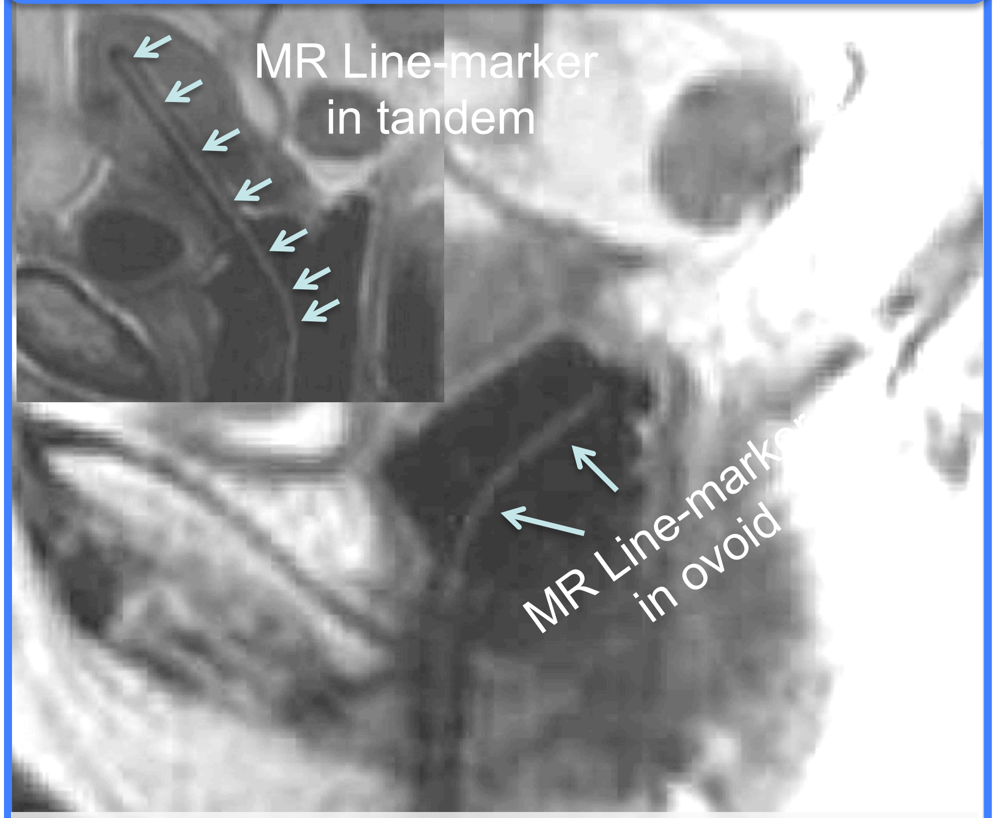


Direct Visualizing the Source Path

AP- radiograph

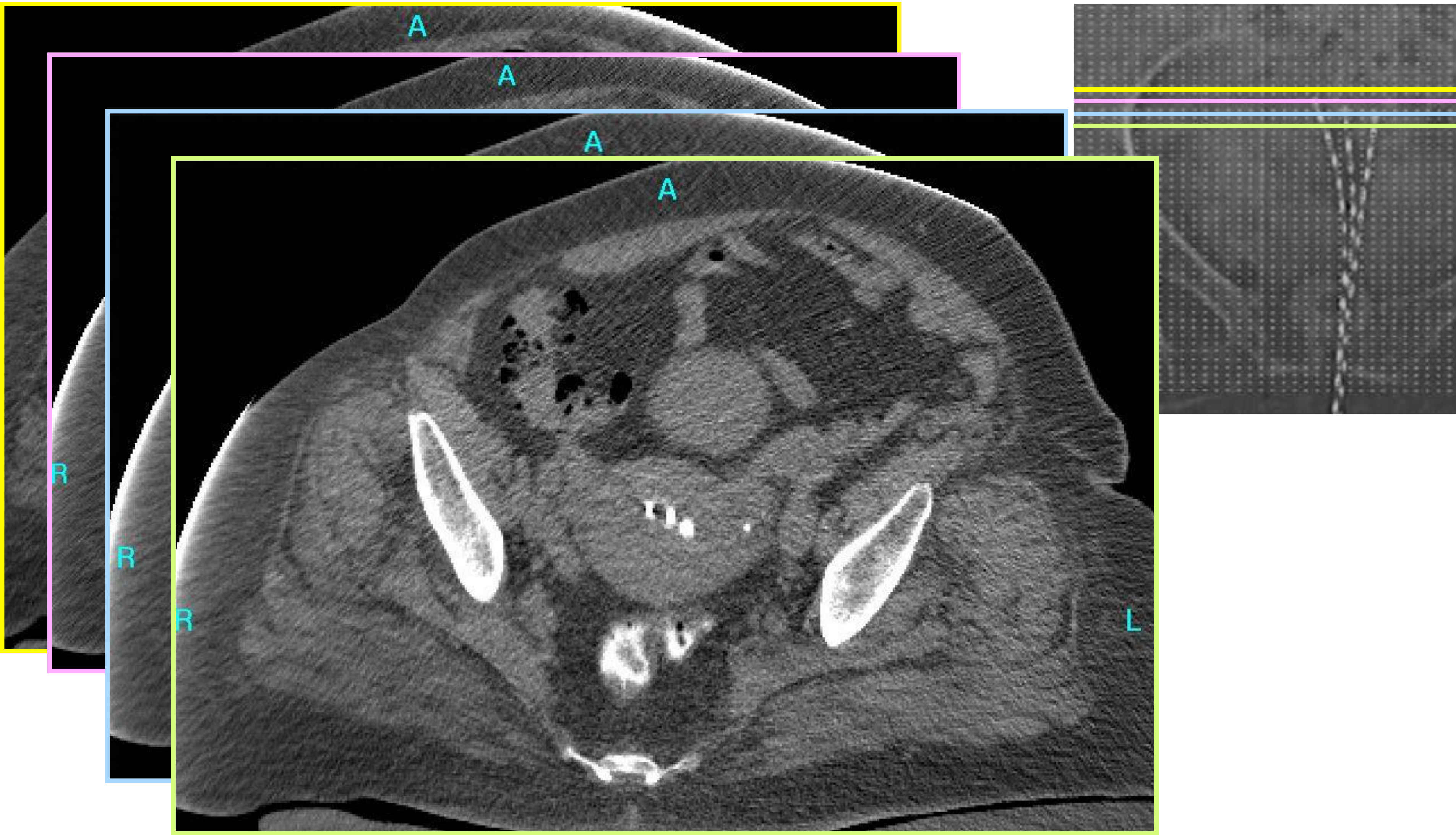


Sagittal MRI

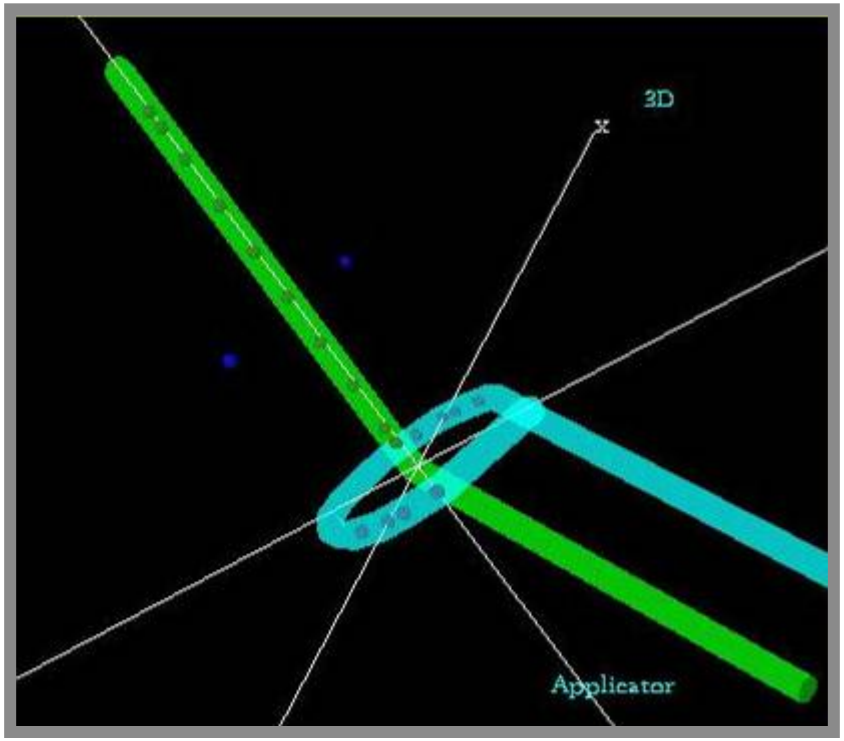


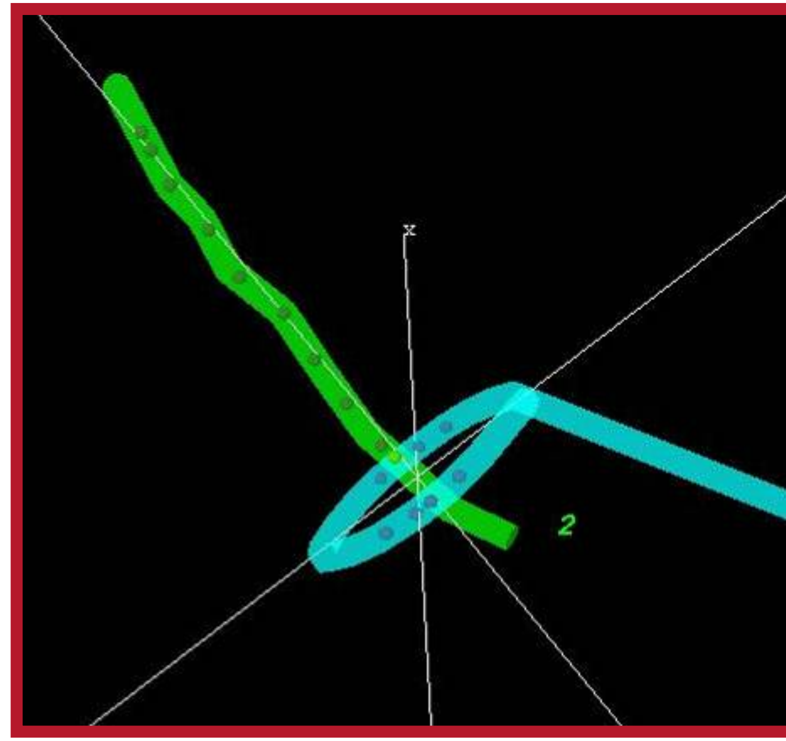
MR markers in Ovoids provided by
U. Mahantshetty, TATA, Mumbai

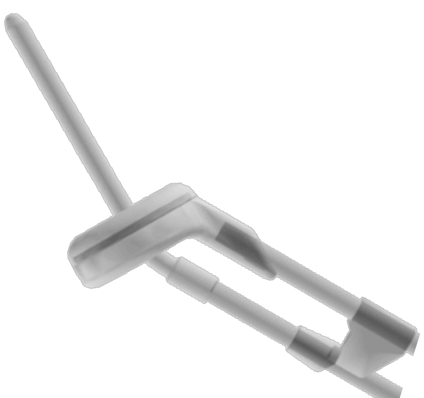
Reconstruction on sectional images

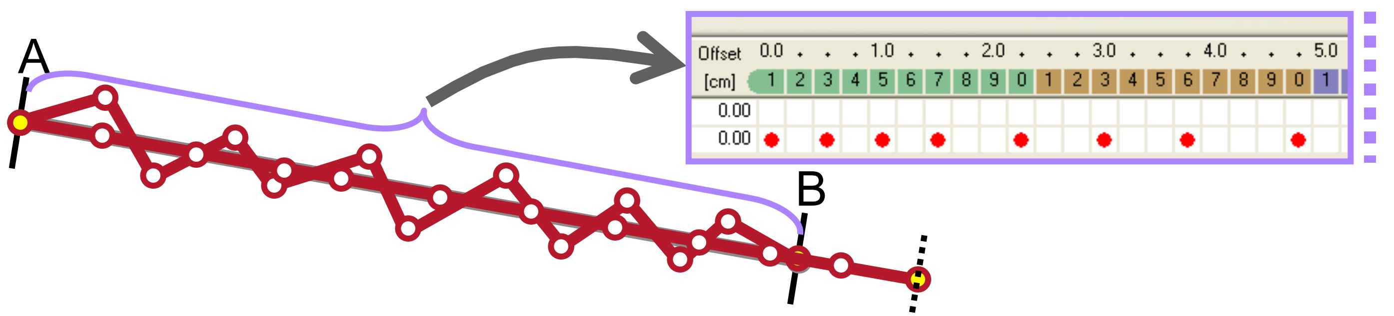


Reconstructed applicator = real applicator ???





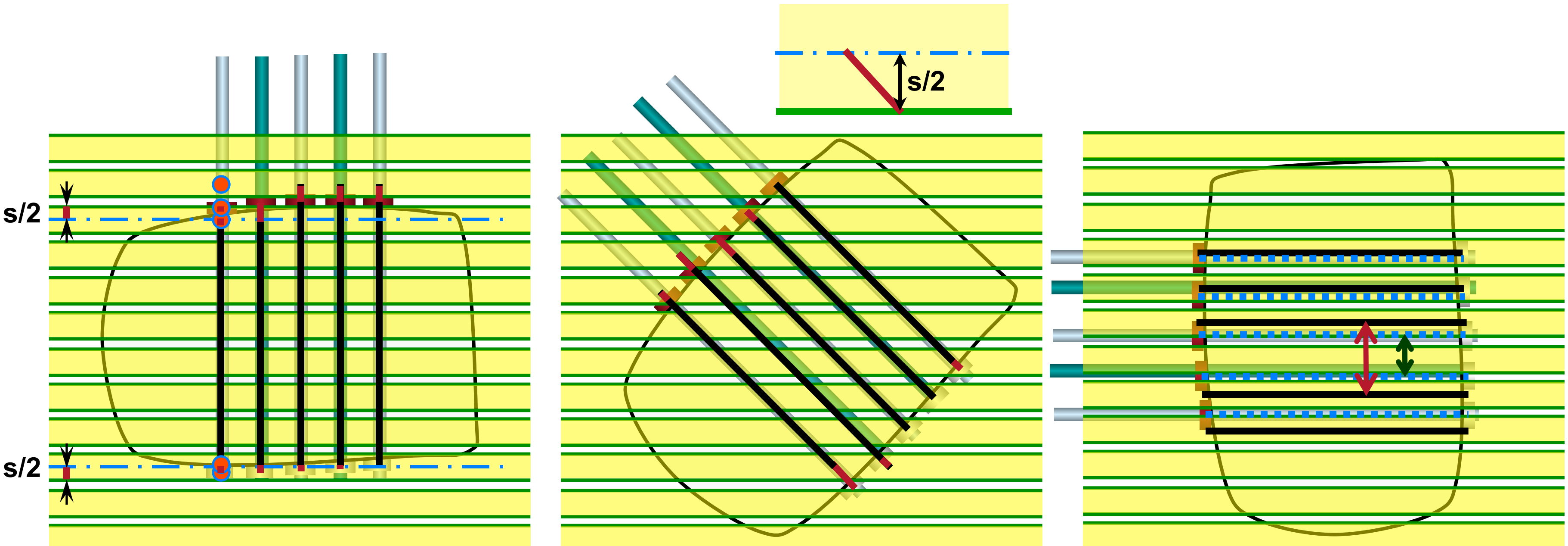




L1(A-B) < L2(A-B)

Reconstruction accuracy depending on slice thickness demonstrated using different scanning directions

scan 6*mm slices 0° | scan 6*mm slices 45° | scan 6*mm slices 90°



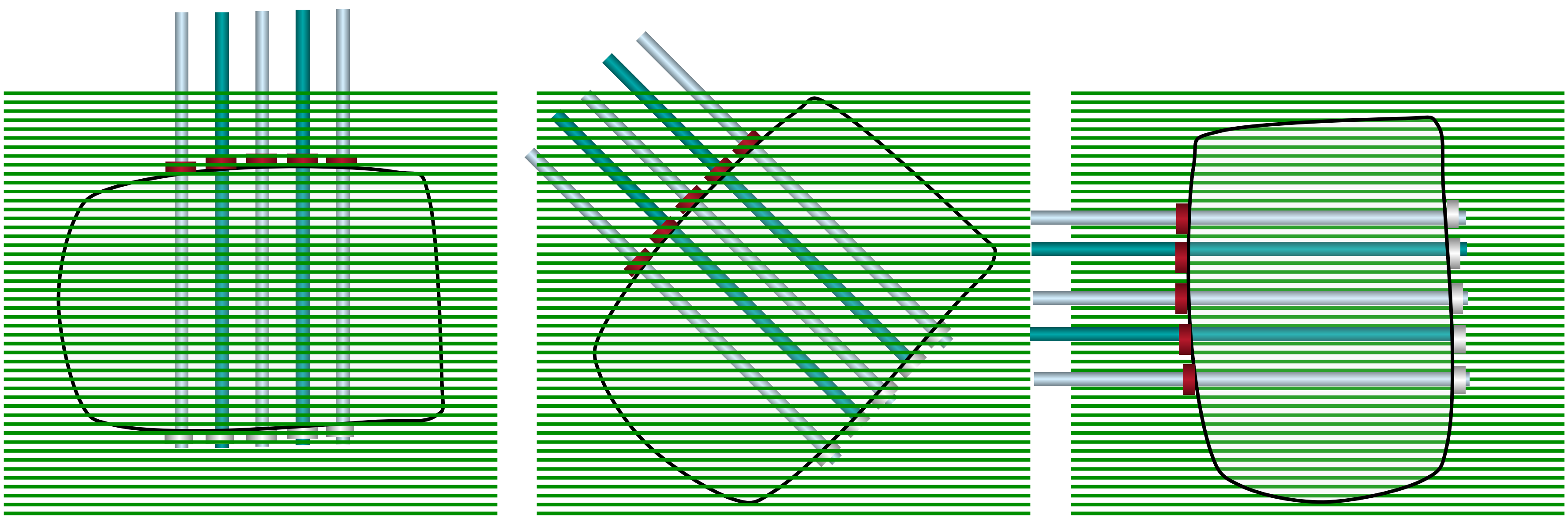
Reconstruction accuracy- half a slice thickness!

6mm + gap 0.5mm

Reconstruction accuracy depending on slice thickness demonstrated using different scanning directions

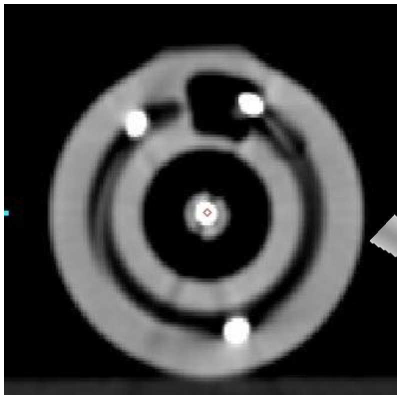
acceptable result can be achieved by using a slice thickness ≤ 3mm

scan 2mm slices 0° | scan 2mm slices 45° | scan 2mm slices 90°

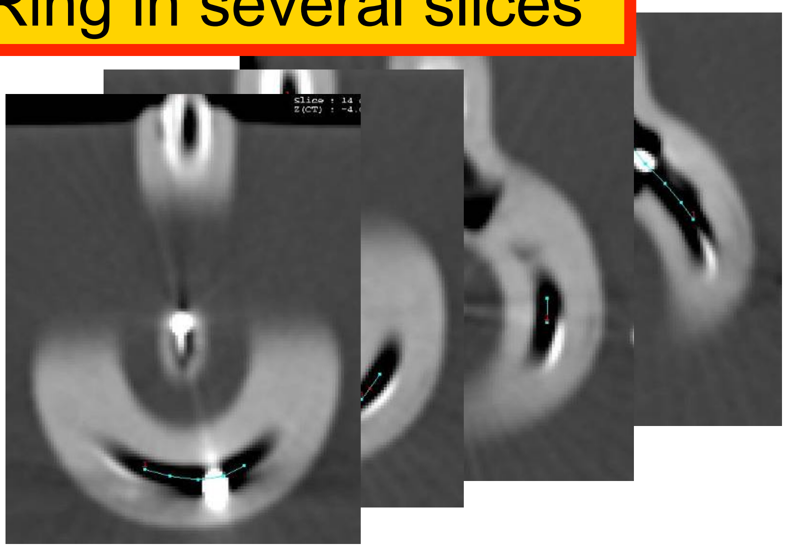


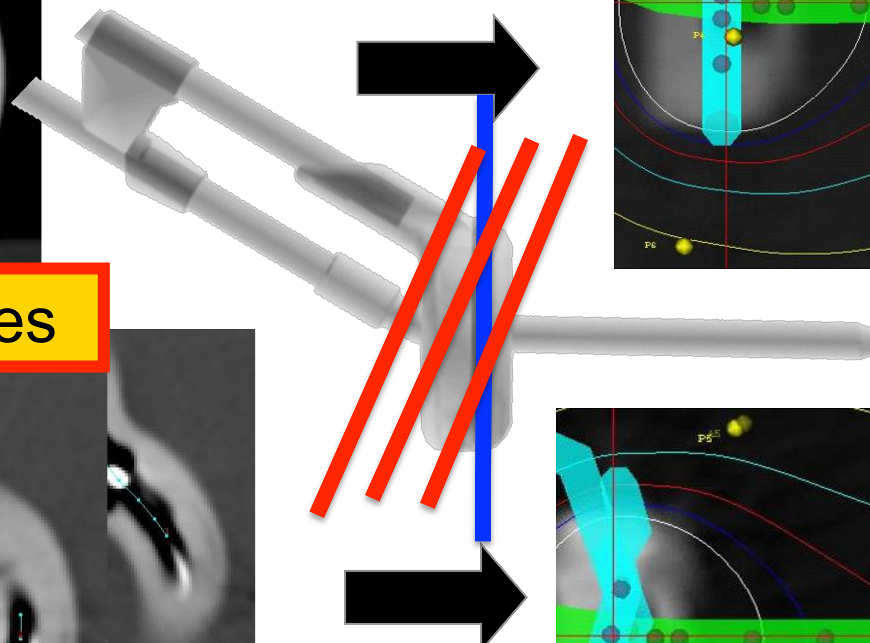
Direct reconstruction - challenge

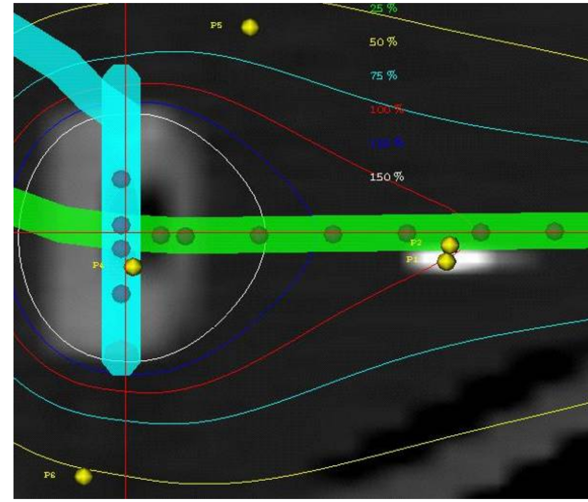
Ring in one slice

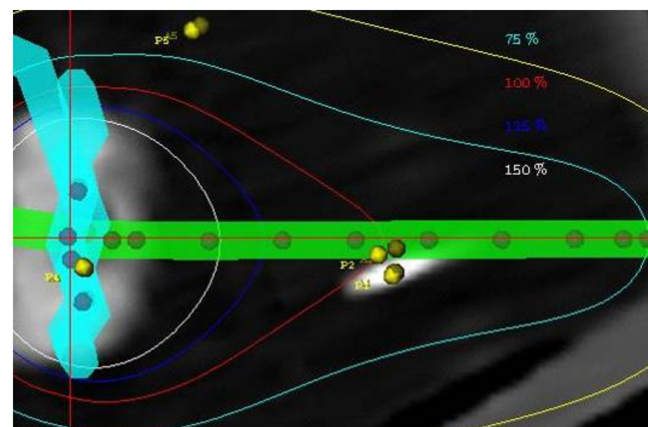


Ring in several slices

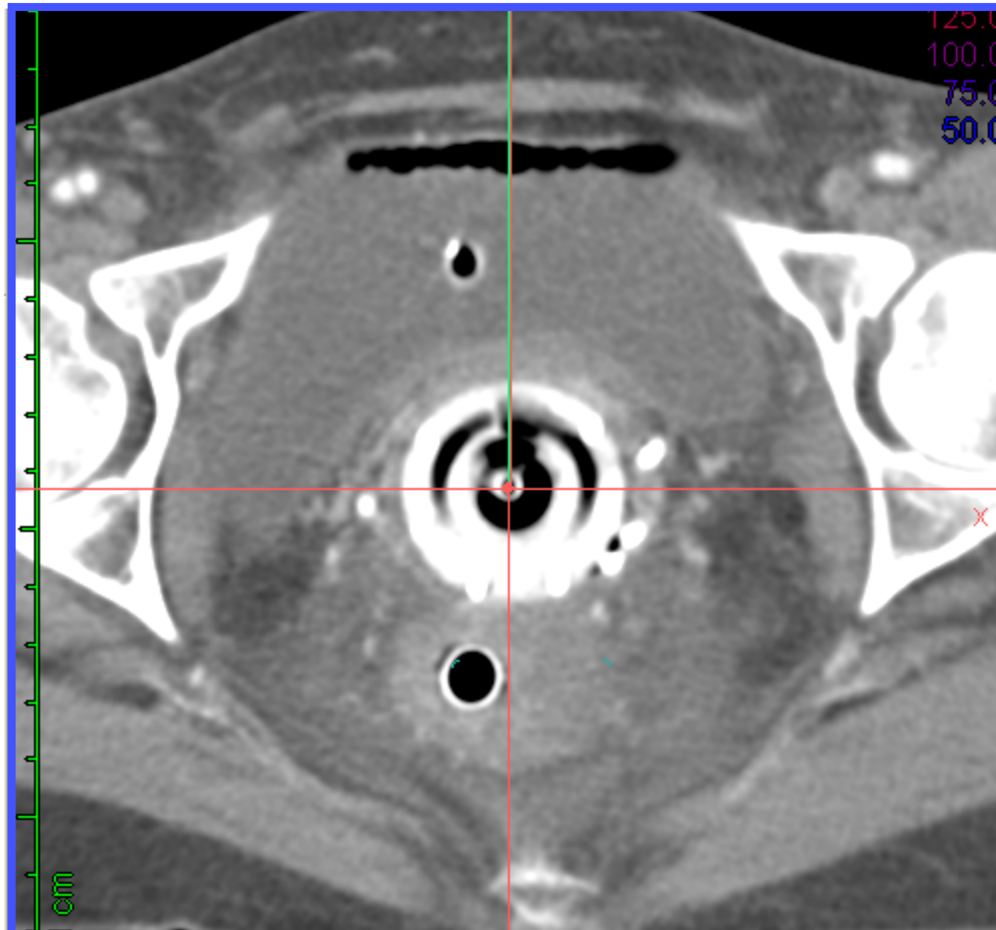






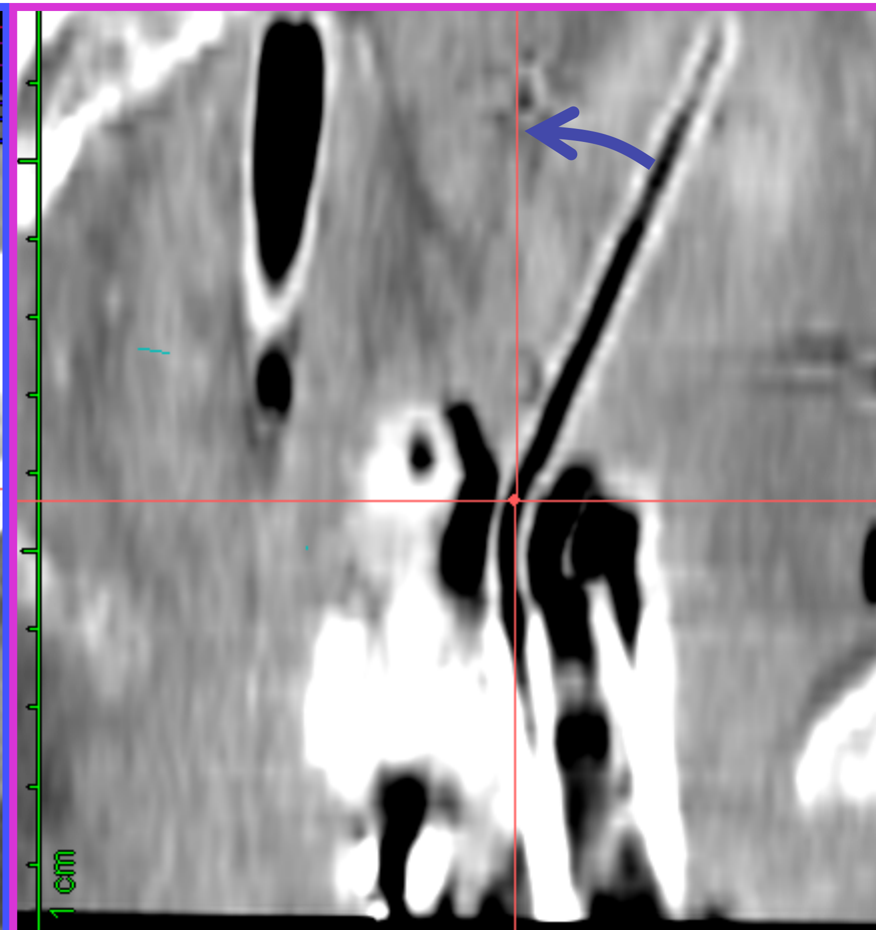


Multi Planar Reconstrucion



„native“ CT para-axial

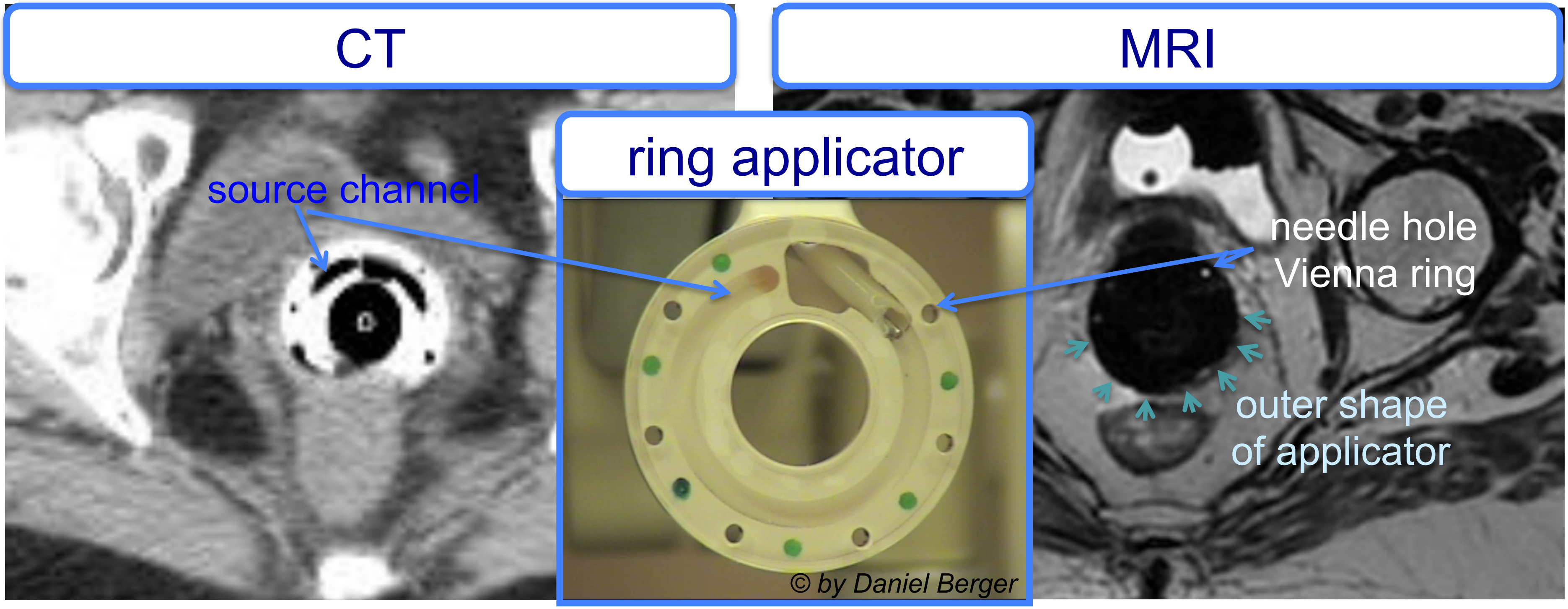
MPR transversal



MPR sagittal

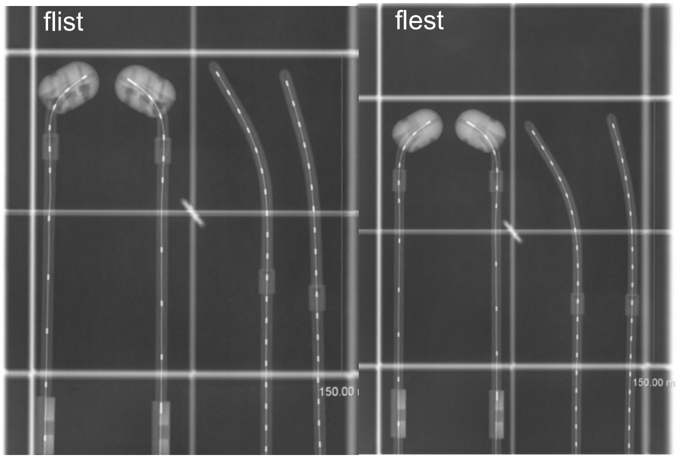
In-Direct Visualization of the Source Path

- define the source path by use of visible landmarks ➔ applicator geometry

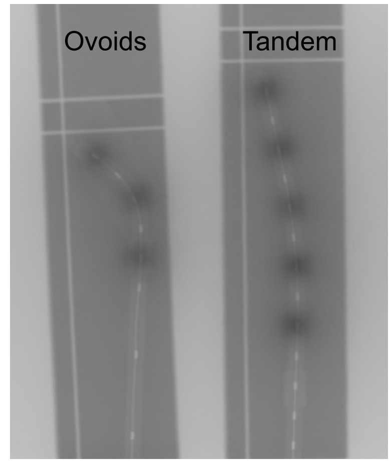


A. De Leeuw *et al.* *Tandem- Ovoids applicator reconstruction on MRI*

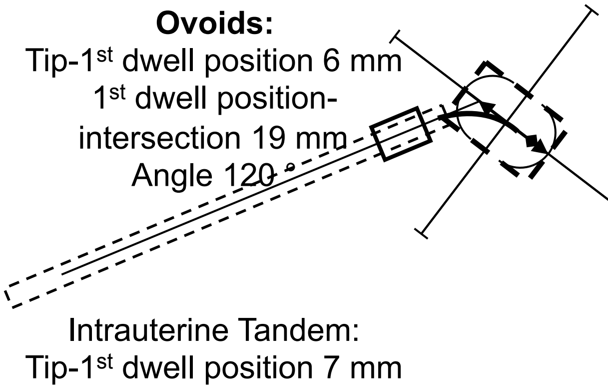
Radiographs



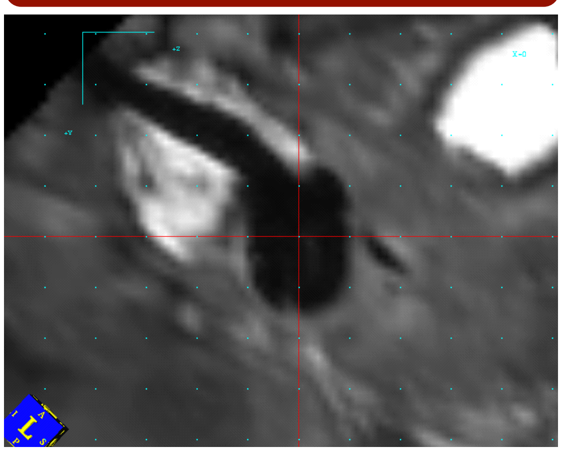
Auto-Radiography



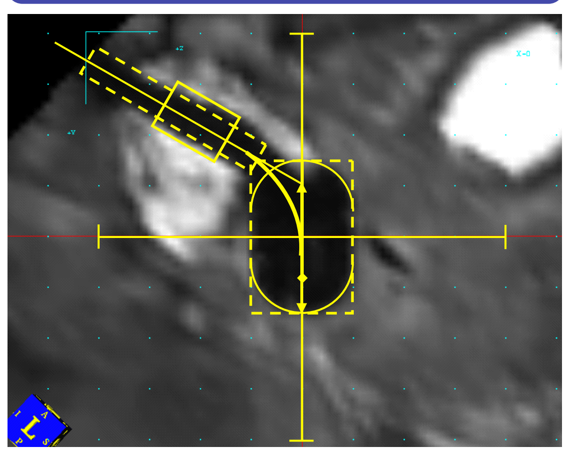
Template for Reconstruction



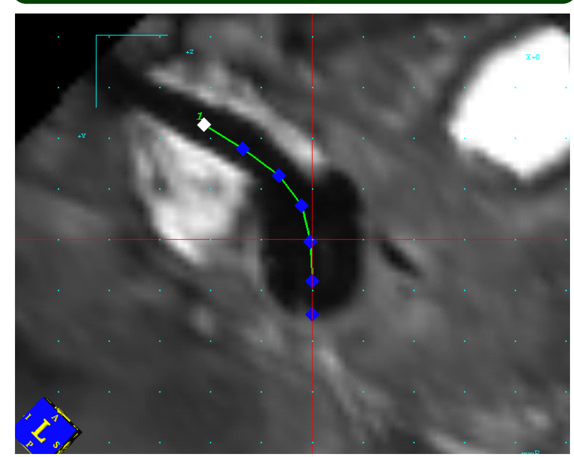
MR Imaging



Template in place



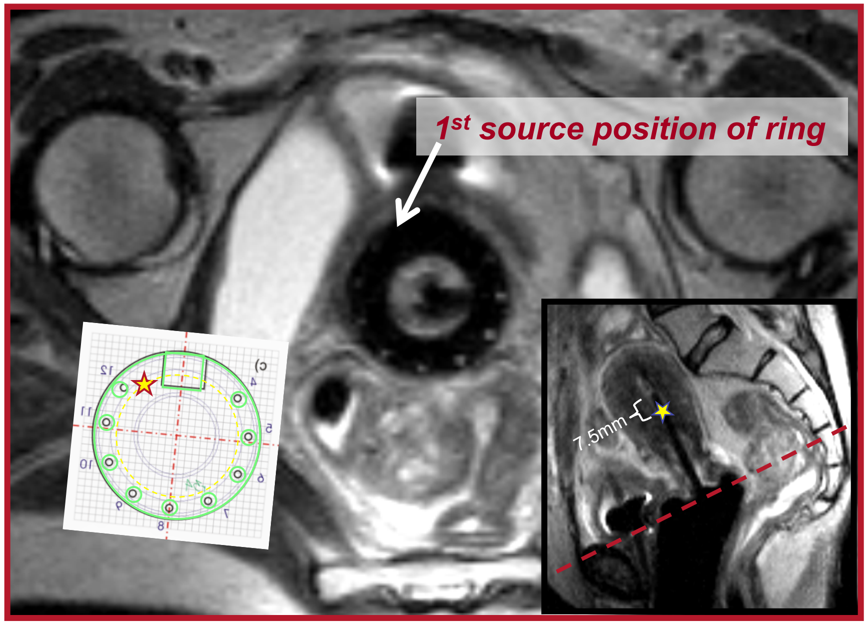
Reconstruction of source path



D. Berger *et al.*

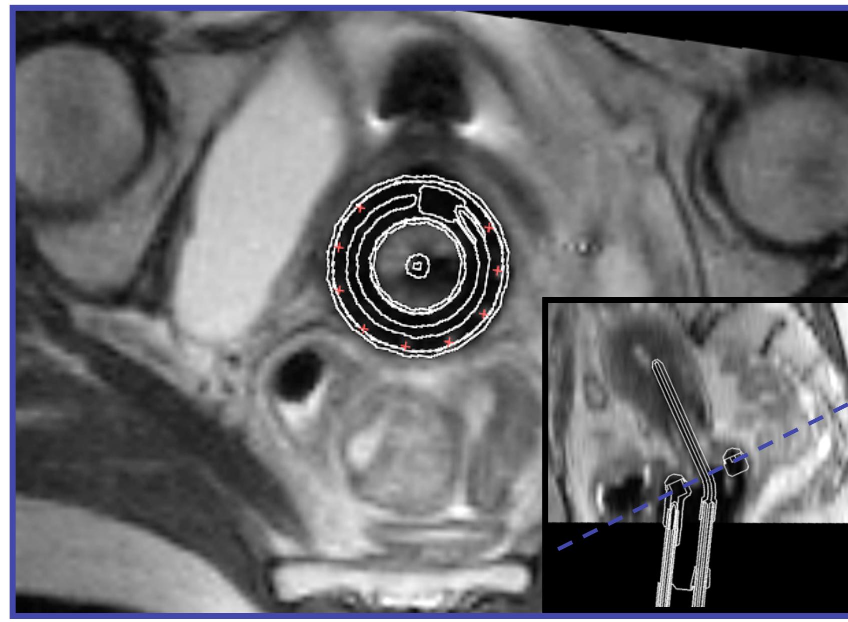
Direct reconstruction of the Vienna applicator on MR images

manual direct



5 – 10 min

software integrated



less than 5 min

If the relation between applicator shape and the source path is defined once,
the reconstruction process can be performed by directly placing the applicator in the MRI dataset.

End of Part I

Do u need a short break ?

Thank You

Daniel.Berger@akhwien.at

on behalf of

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

Department of Radiotherapy
Medical University of Vienna