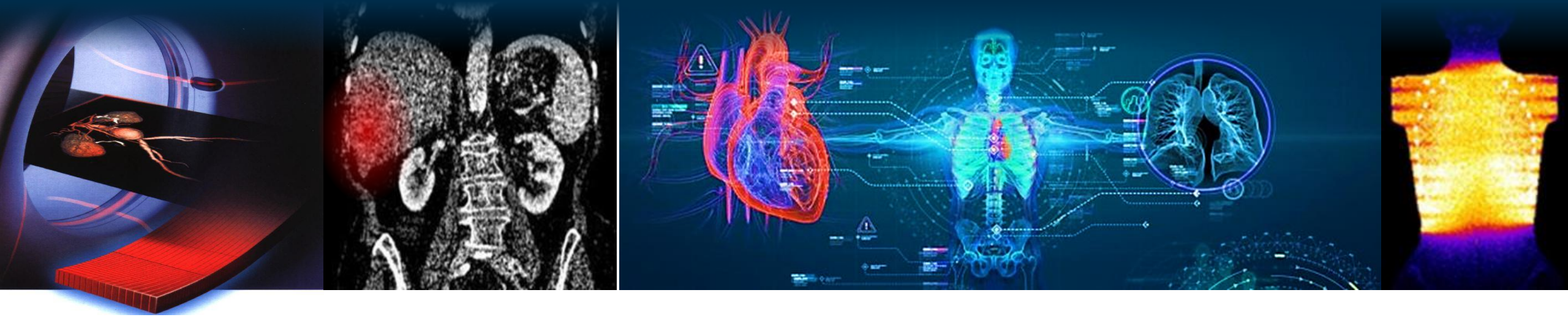

CT (including wide beam)

TraMeXI

Session: Introduction on imaging modality specific measurement procedures, In: Workshop on X-ray imaging dosimetry – Helsinki, Finland, 20-22 November 2024

20 min vNov-2024

HELSINKI UNIVERSITY
DEPARTMENT OF PHYSICS

HUS Diagnostic Center

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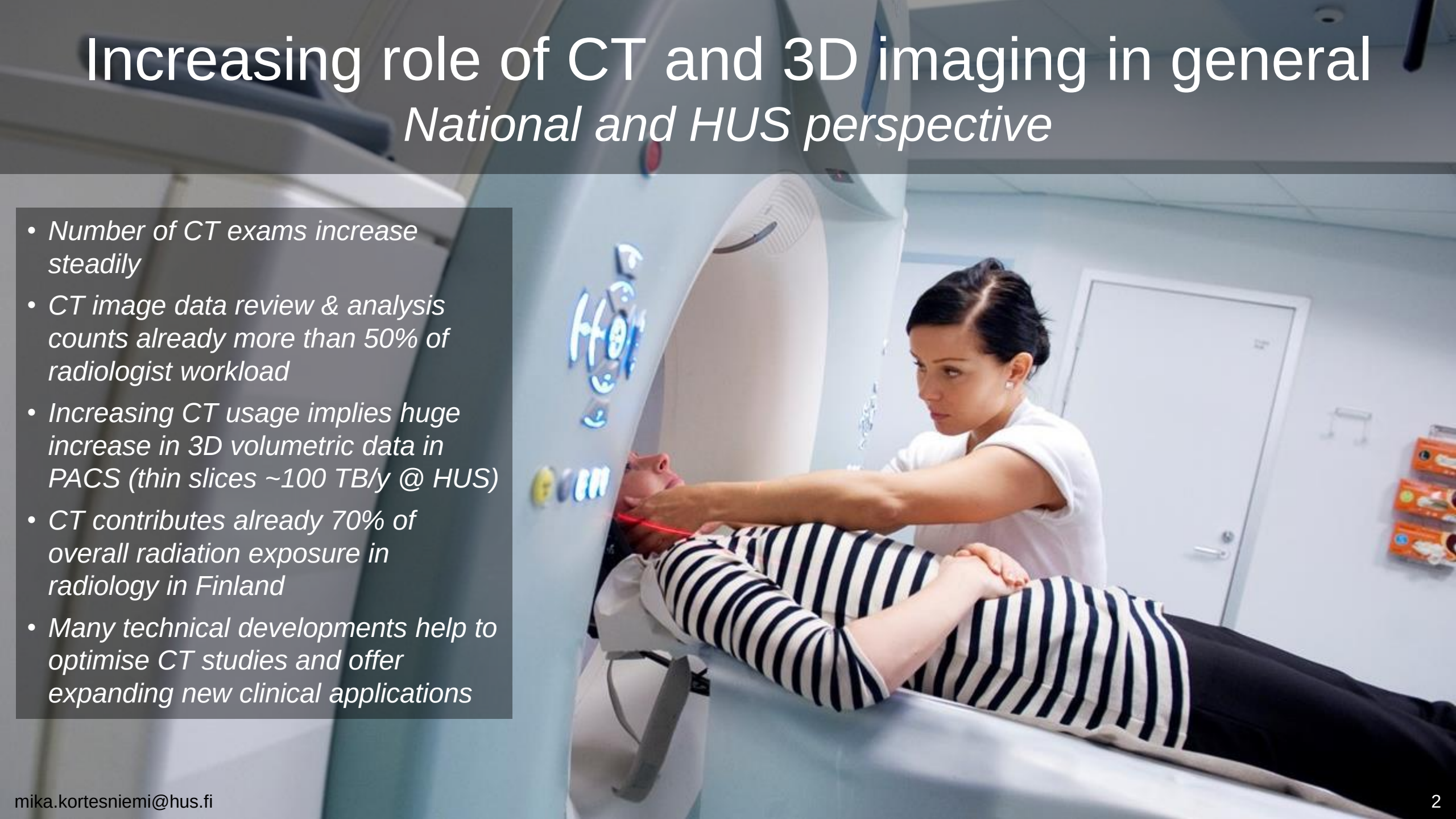
Increasing role of CT and 3D imaging in general

National and HUS perspective



- *Number of CT exams increase steadily*
- *CT image data review & analysis counts already more than 50% of radiologist workload*
- *Increasing CT usage implies huge increase in 3D volumetric data in PACS (thin slices ~100 TB/y @ HUS)*
- *CT contributes already 70% of overall radiation exposure in radiology in Finland*
- *Many technical developments help to optimise CT studies and offer expanding new clinical applications*

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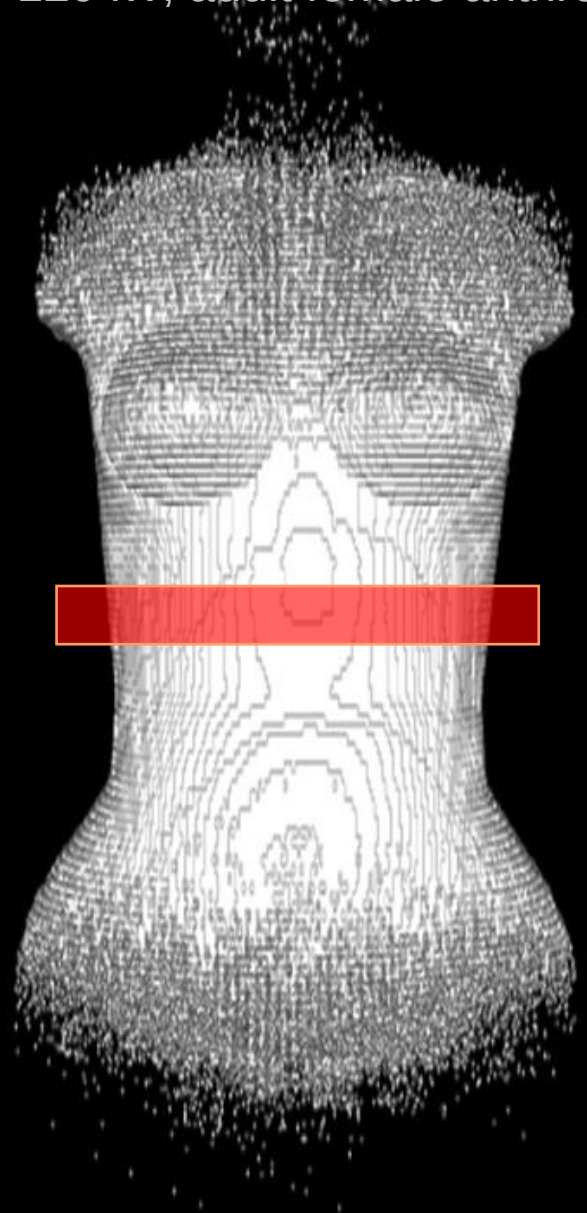
Dosimetry is an essential part of CT quality assurance
⇒ Medical physicist key responsibilities in radiology

Total dose volume in a single axial rotation in CT

4 cm beam collimation, 120 kV, adult female anthropomorphic phantom model



Directly irradiated slice region
with z-coverage of 4 cm
projected to isocenter

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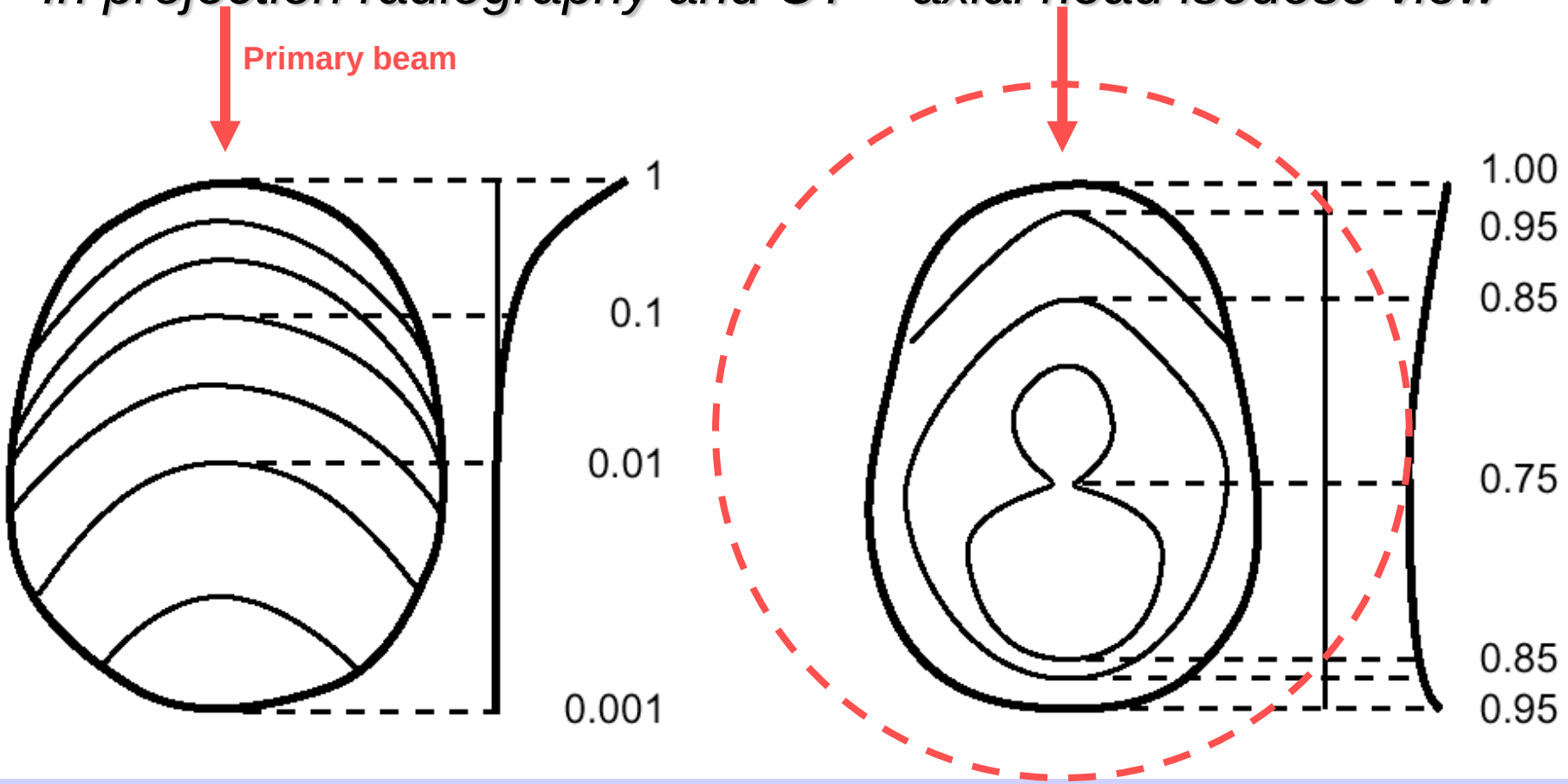
Dose distribution

In projection radiography and CT – axial head isodose view



Projection radiography

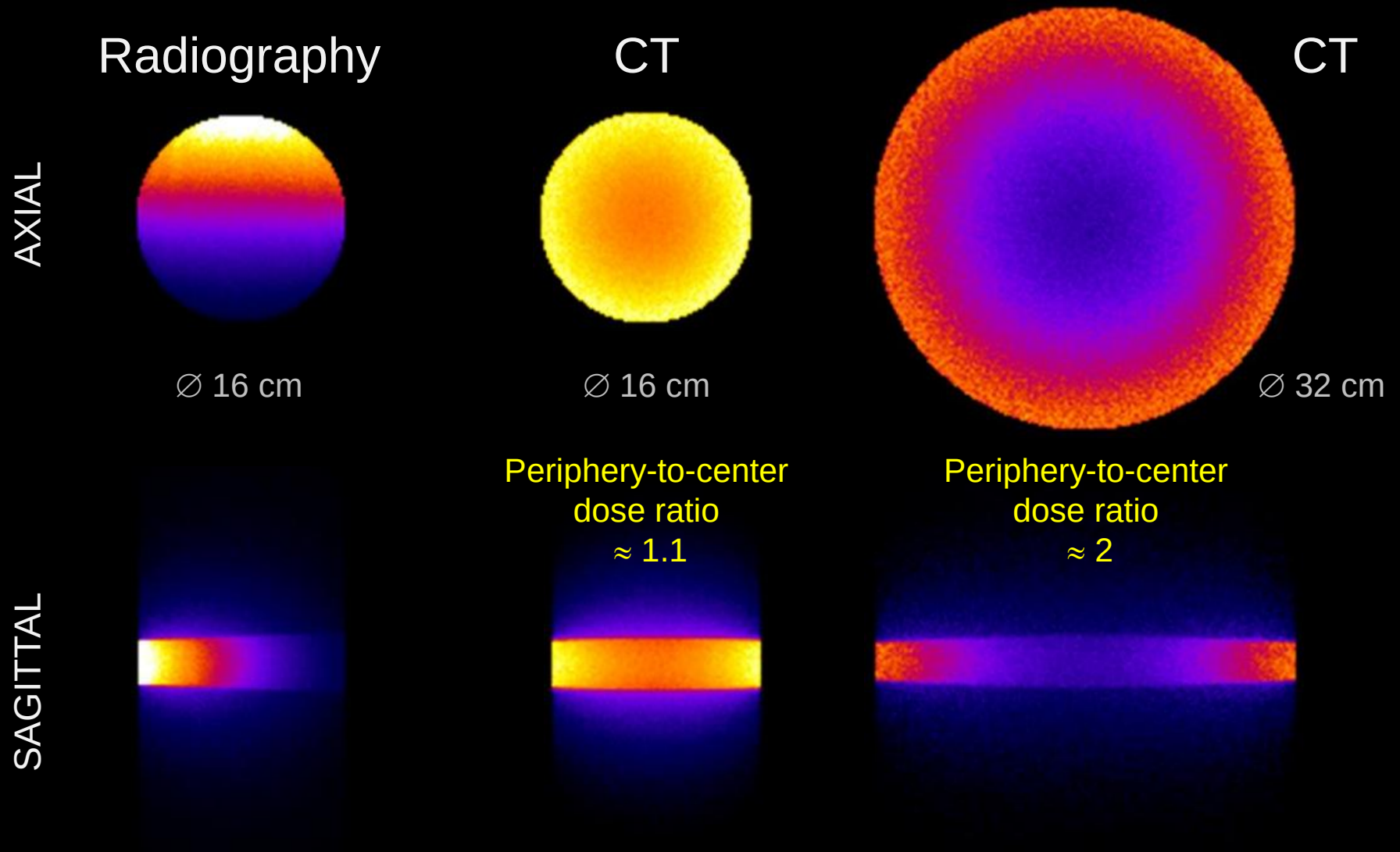
Entrance surface dose as a significant local dose descriptor

Computed tomography (CT)

More uniformly distributed dose in the imaging slice plane

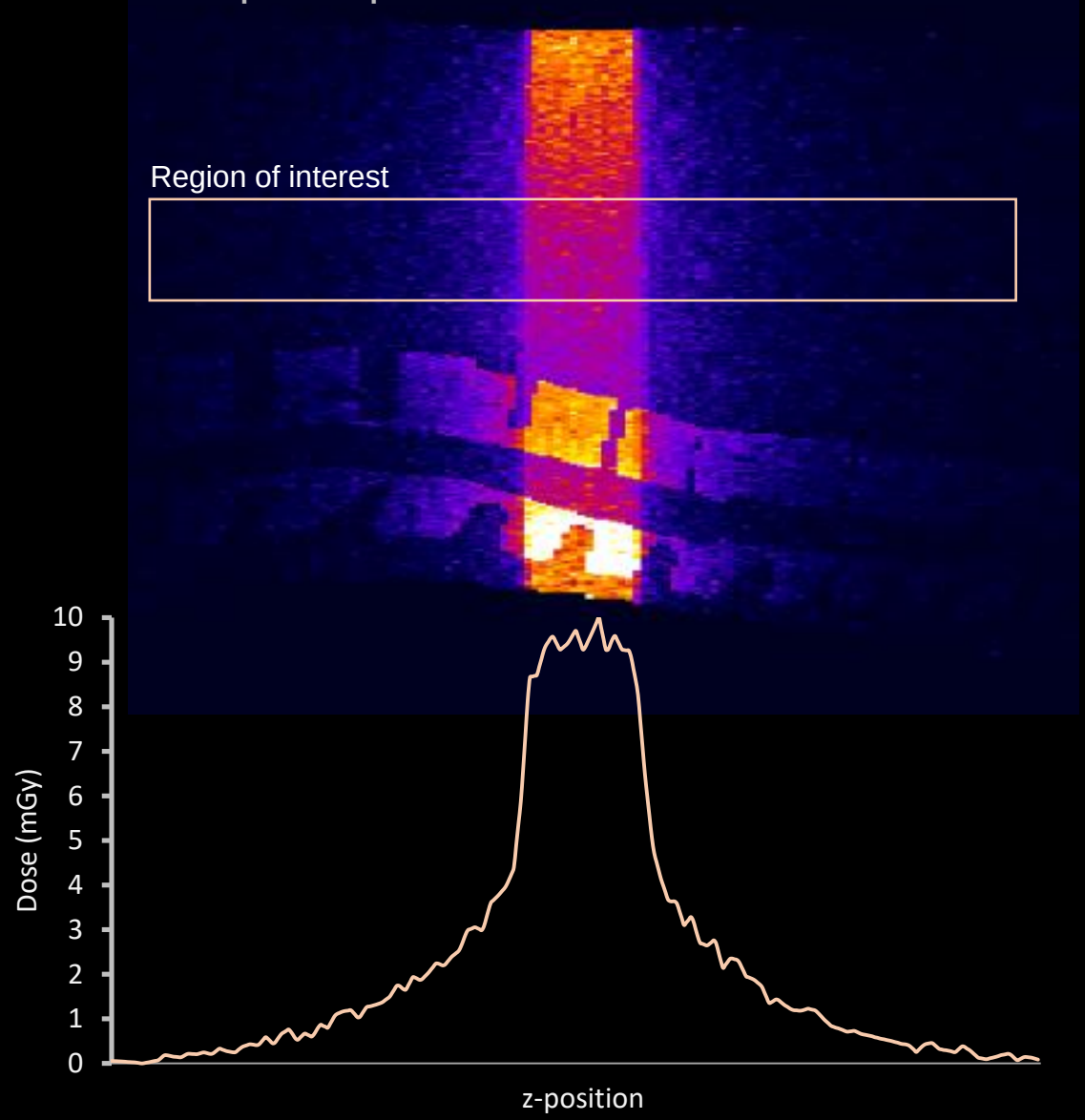
Dose distributions in PR and CT in cylinder

120 kV, ∅ 16 cm and ∅ 32 cm phantoms, axial rotation with 4 cm beam collimation



CT dose distribution in a single axial rotation

GE Discovery CT750 HD, 40 mm beam collimation in chest region, 120 kV, adult female anthropomorphic model, Monte Carlo dose simulation



There will be stronger scatter tails when scanning a thicker patient and when using higher kV spectra

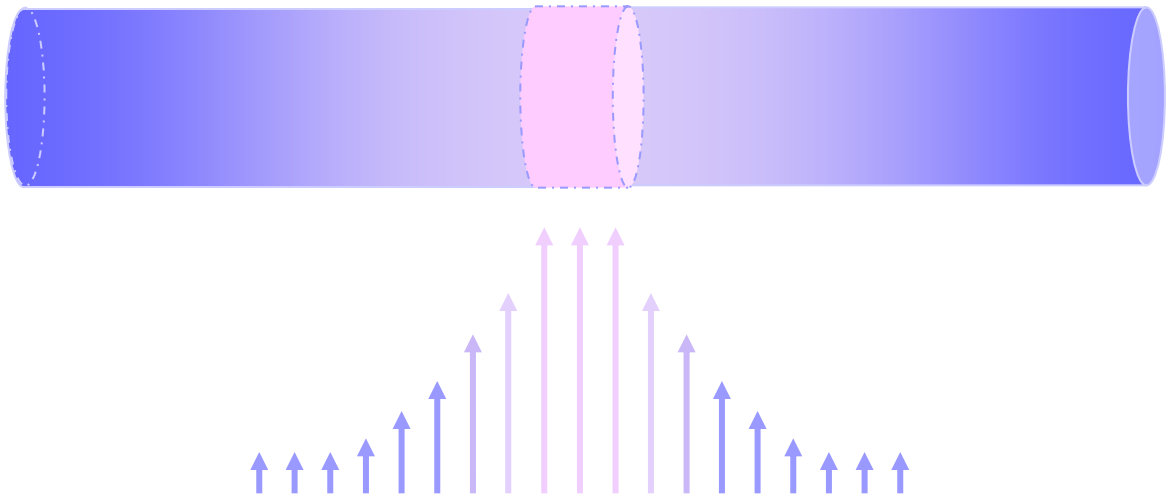
CT Dose Index: CTDI

ICRU,IAEA: Computed Tomography Kerma Index: $C_{PMMA,100}$ *or* $CTKI_{PMMA,100}$

$$ {}_{n}CTDI_{100,x} = \frac{1}{M \cdot S} \int_{-5cm}^{+5cm} D(z)dz $$

mGy

Direct and scattered radiation dose is integrated from 10 cm distance (in z-direction) and normalised according to the effective beam width (number of simultaneous slices x nominal slice width; M·S).



Weighted and volume CTDI: $CTDI_w$ and $CTDI_{vol}$

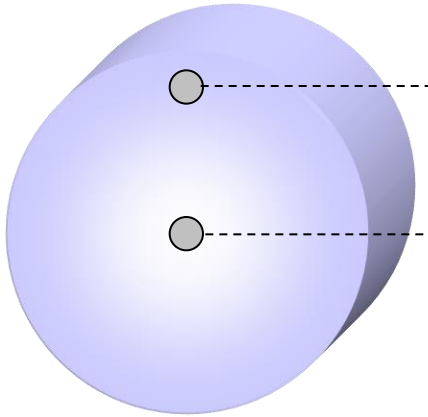
$$ {}_nCTDI_{100,w} = \frac{1}{3} \cdot {}_nCTDI_{100,c} + \frac{2}{3} \cdot {}_nCTDI_{100,p} $$

mGy

Weighted average of the central dose and peripheral dose

When pitch is taken into account: $CTDI_w$/pitch = $CTDI_{vol}$

PMMA cylinder phantom



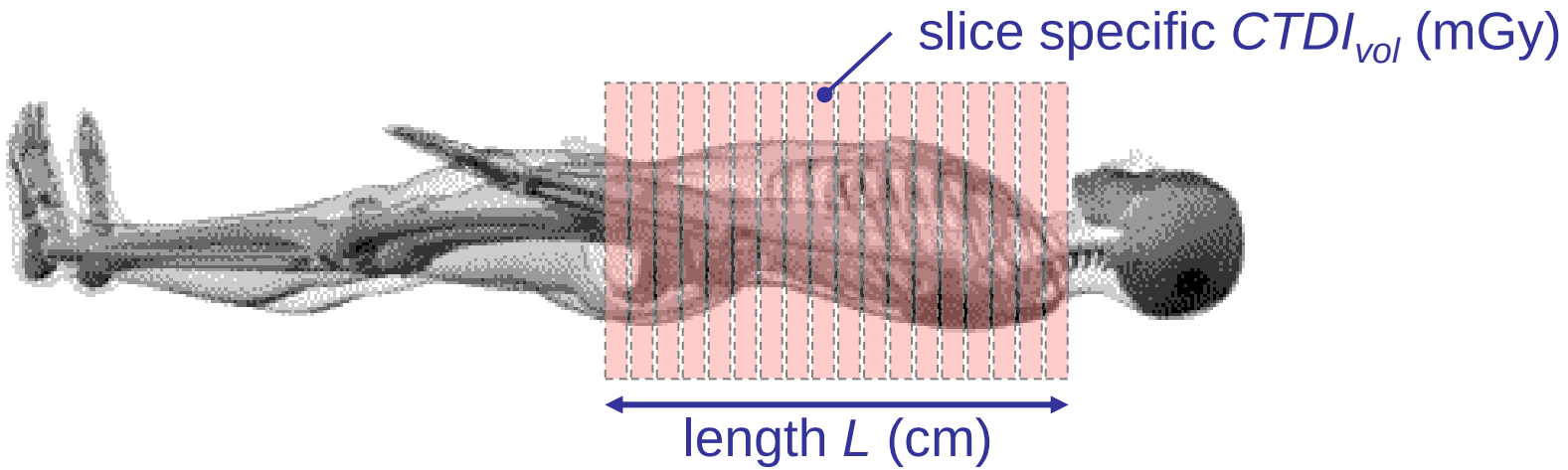
Tolerance in Finland: ± 25%

Dose length product: DLP

ICRU,IAEA: Air kerma length product: ***P_{KL} or KLP***

$$DLP = CTDI_{vol} \cdot L$$

mGy·cm



As an integral quantity, the DLP describes the cumulative dose from the entire CT examination.
~ Correlation with the effective dose.

So, how is this measured?

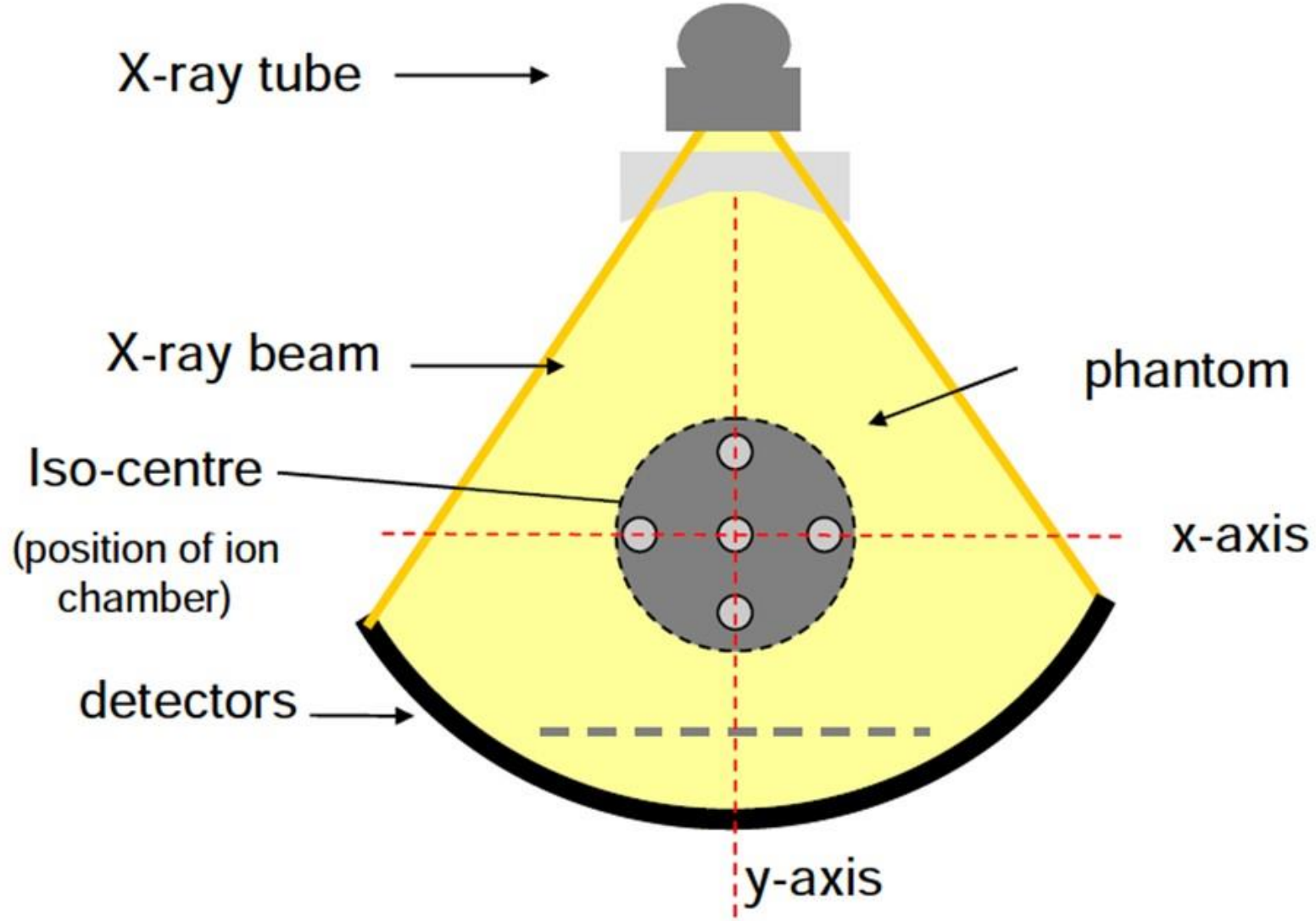
- Physical CT dose output measurements

”The CTDI”

Stuff needed: head and body phantom, and pencil chamber + electrometer

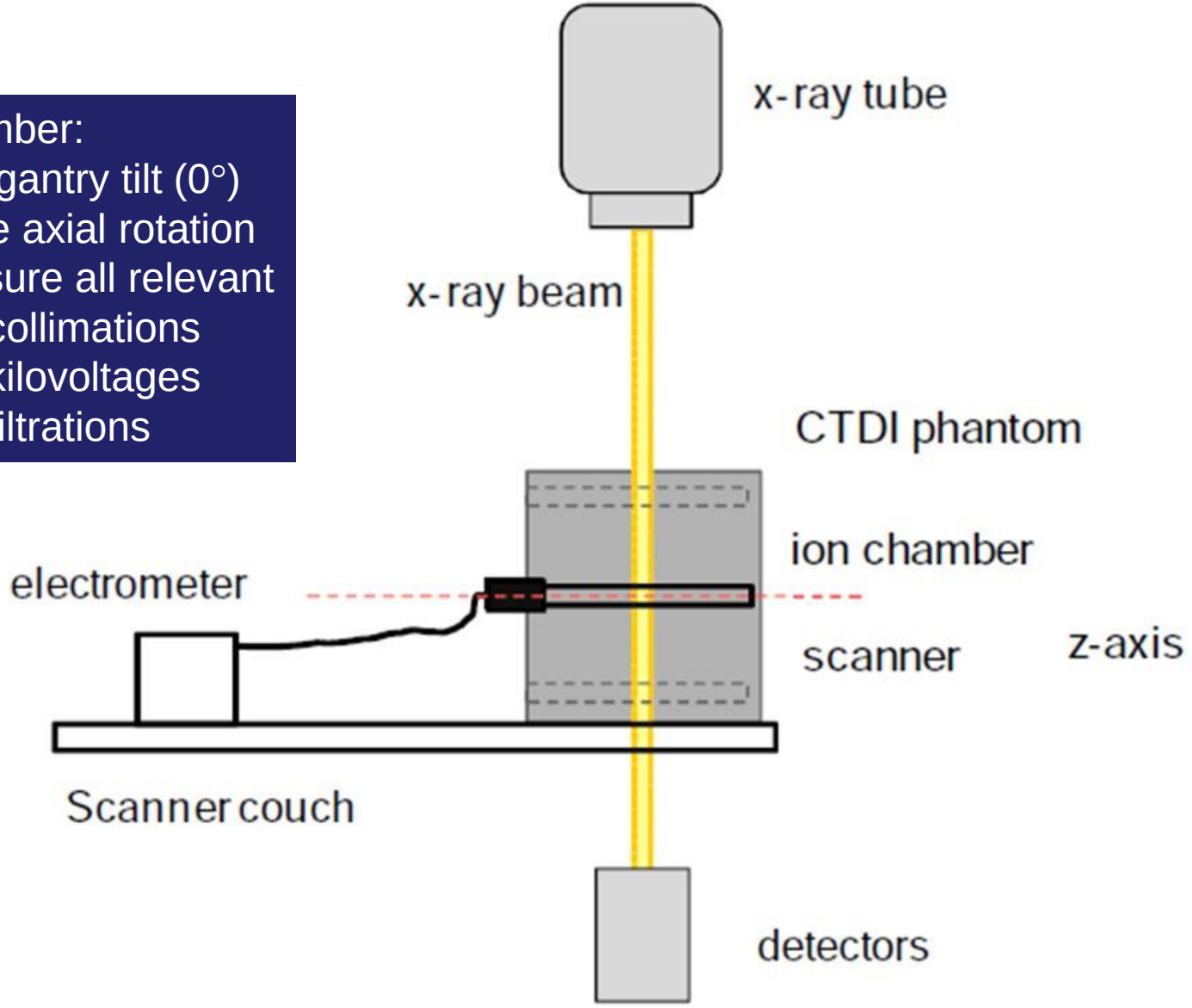
PTW

Positioning of the CTDI cylinder phantom (1)



Positioning of the CTDI cylinder phantom (2)

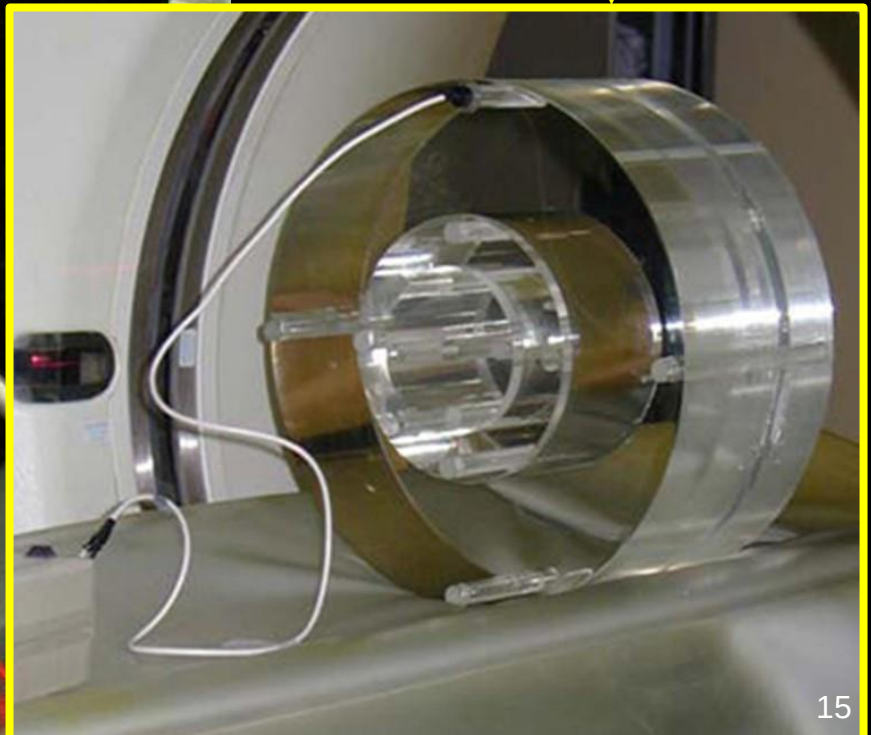
Remember:
- zero gantry tilt (0°)
- single axial rotation
- measure all relevant
  - collimations
  - kilovoltages
  - filtrations



CT dose output measurement in the standard PMMA cylinder phantom with inserted pencil-shaped ionisation chamber

∅ 32 cm to approximate reference body dimension and attenuation

∅ 16 cm to approximate reference head dimension and attenuation



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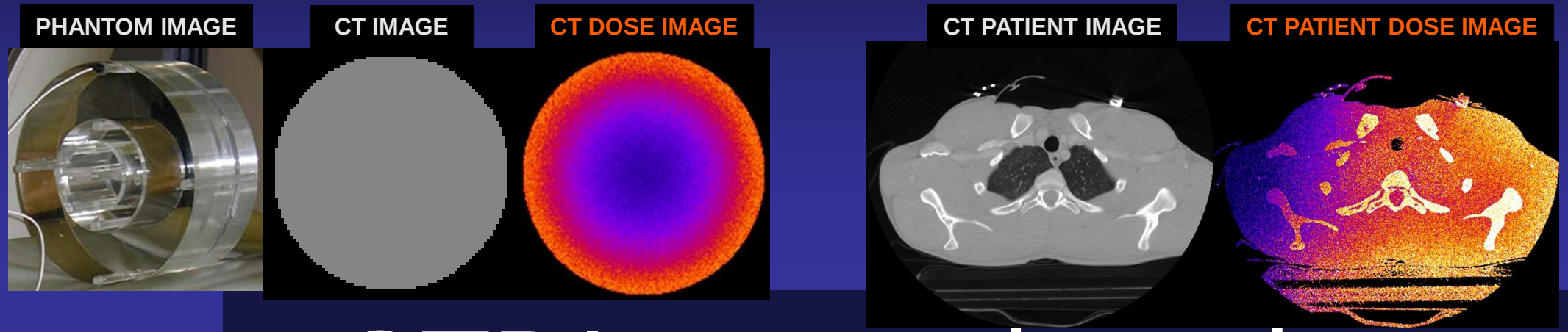
- The limitation of $CTDI_{vol}$ and DLP is that they are surrogates for patient dose, providing information about the scanner output for only a very specific standardized condition.

- CTDI phantoms are not representative of human body -



$CTDI_{vol} \neq$ patient dose

- The 100 mm integration length is not representative of clinical scan ranges

$\Rightarrow$ $CTDI_{vol}$ underestimates dose with longer range & overestimates with shorter range

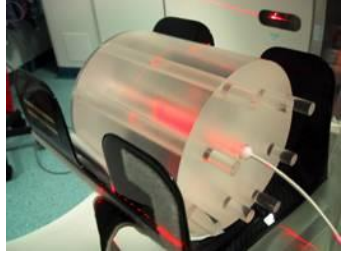
- Accurate information about patient characteristics and scan parameters is crucial to estimating patient dose in CT

McCollough 2011, AAPM RPT 220 - 2014

Measurement solution for wider beams

~scatter tails beyond the standard 100 mm z-integration length

CTDI for wider beam collimations

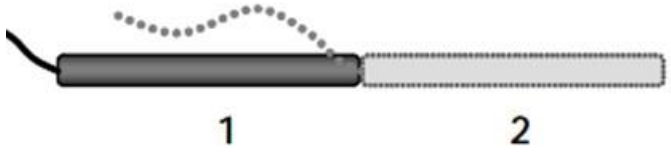


The current use of cone beam scanner technology clearly demonstrates the deficiencies of the standard CT dosimetry methodology.

The IEC/IAEA interim solution with two interpretations of the definition of $CTDI_w$ (C_w) depending on the beam width:

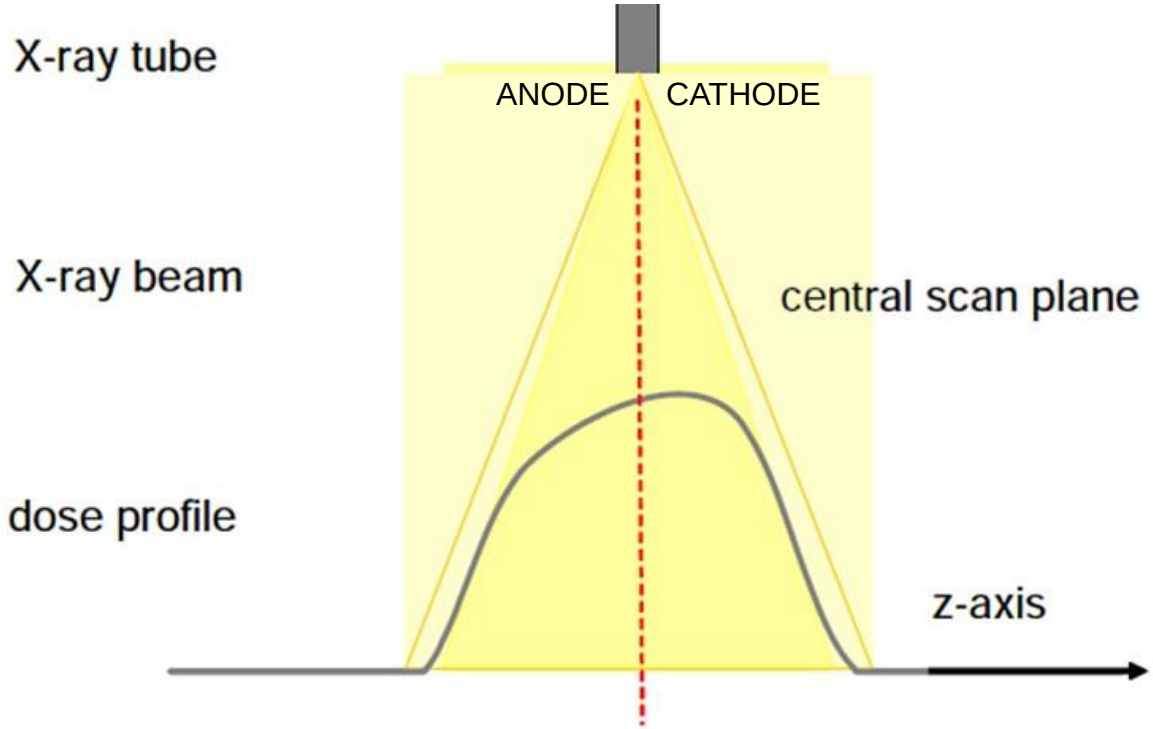
- For beams of less than 40 mm, the conventional definition is given.
- For a beam width greater than 40 mm, C_w can be written as:

$$C_{w,NT} = C_{w,Ref} \times \left(\frac{C_{a,100,NT}}{C_{a,100,Ref}} \right)$$

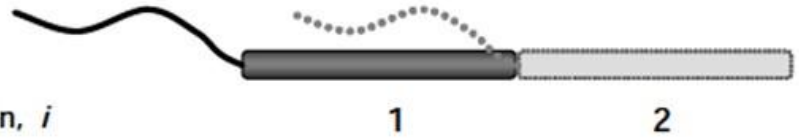


where $C_{w,NT}$ is the weighted CT air kerma index for a beam width of NT mm (if NT > 40 mm), $C_{w,Ref}$ is the weighted CT air kerma index for a reference beam width of 20 mm (or closest possible below 20 mm), and similarly, $C_{a,100,NT}$ is the CT air kerma index measured free-in-air with a 100 mm integration length chamber for a beam width of NT mm and $C_{a,100,Ref}$ is a similar quantity at the reference beam width.

Free-in-air dose measurements for wider beams



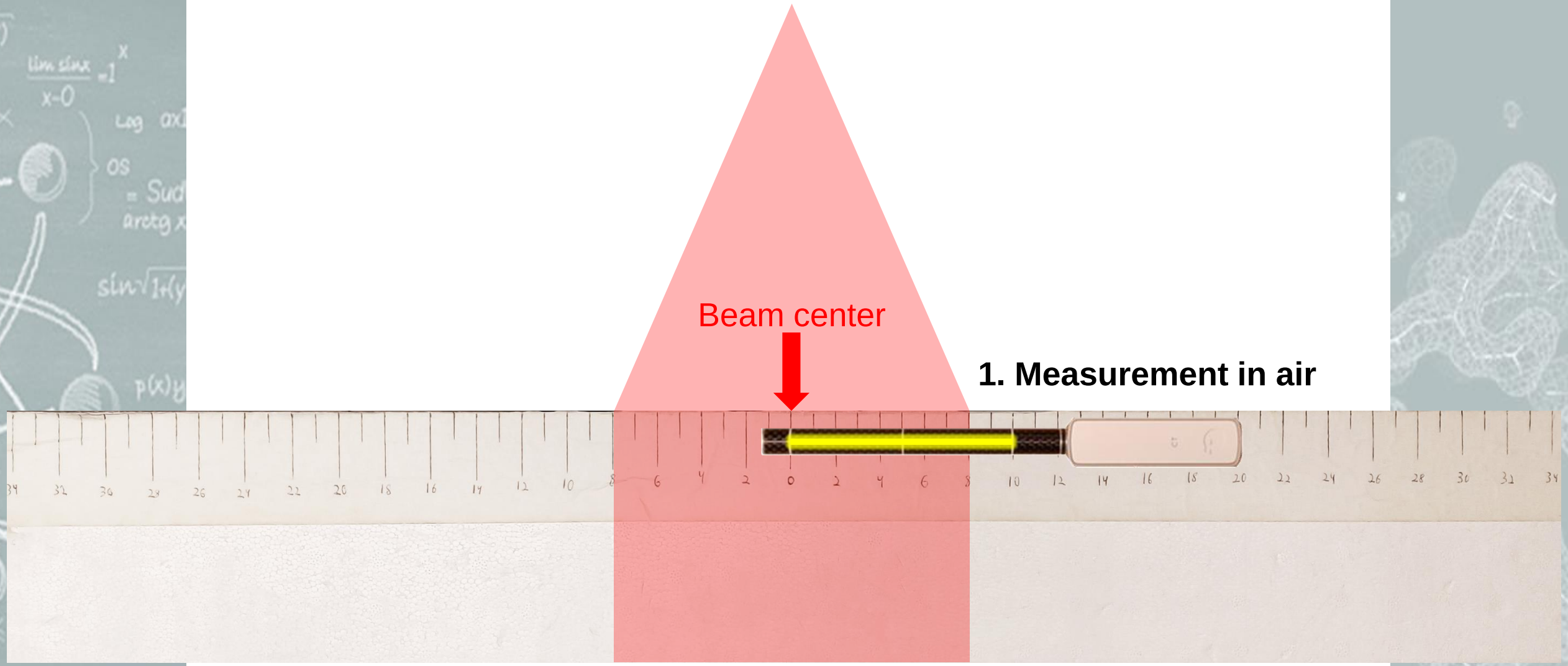
a. 100 mm ion chamber: two contiguous positions, integration length 200 mm



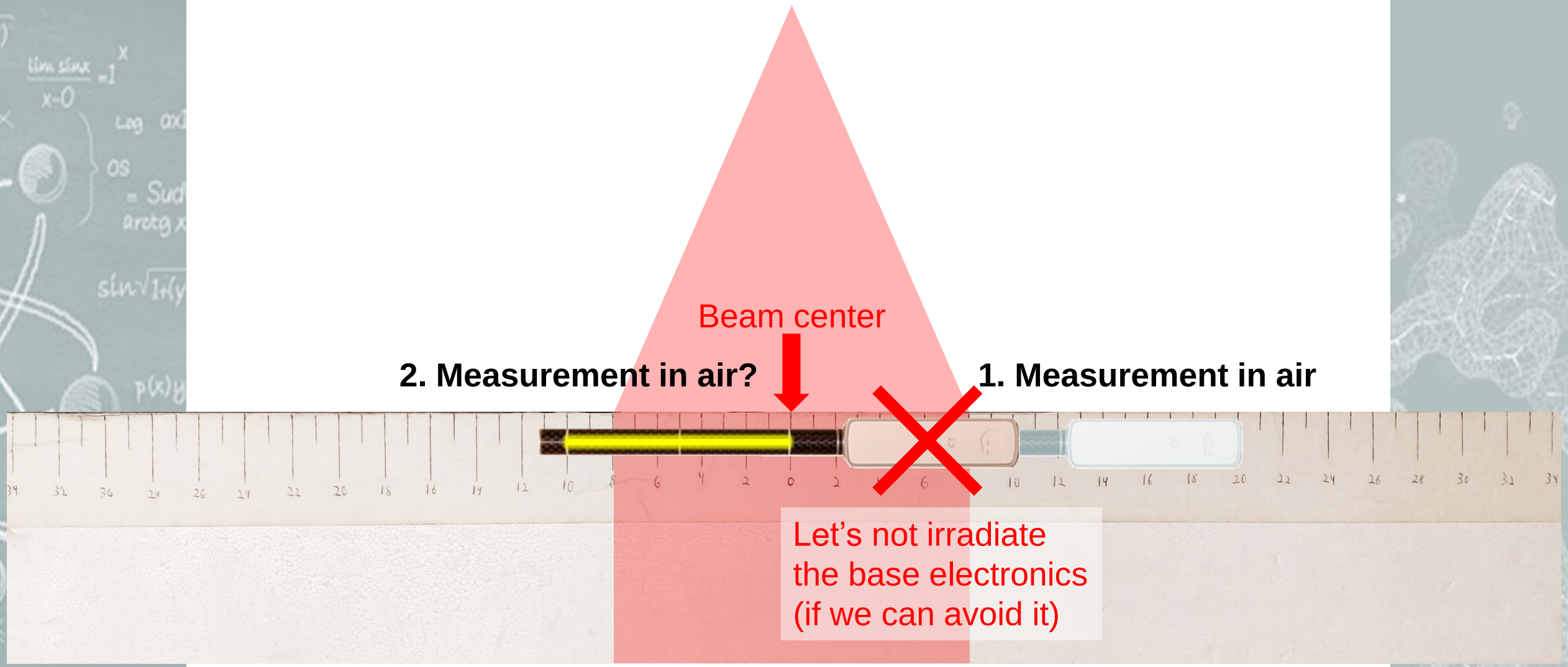
b. 100 mm ion chamber: three contiguous positions, integration length 300 mm

IAEA 2010

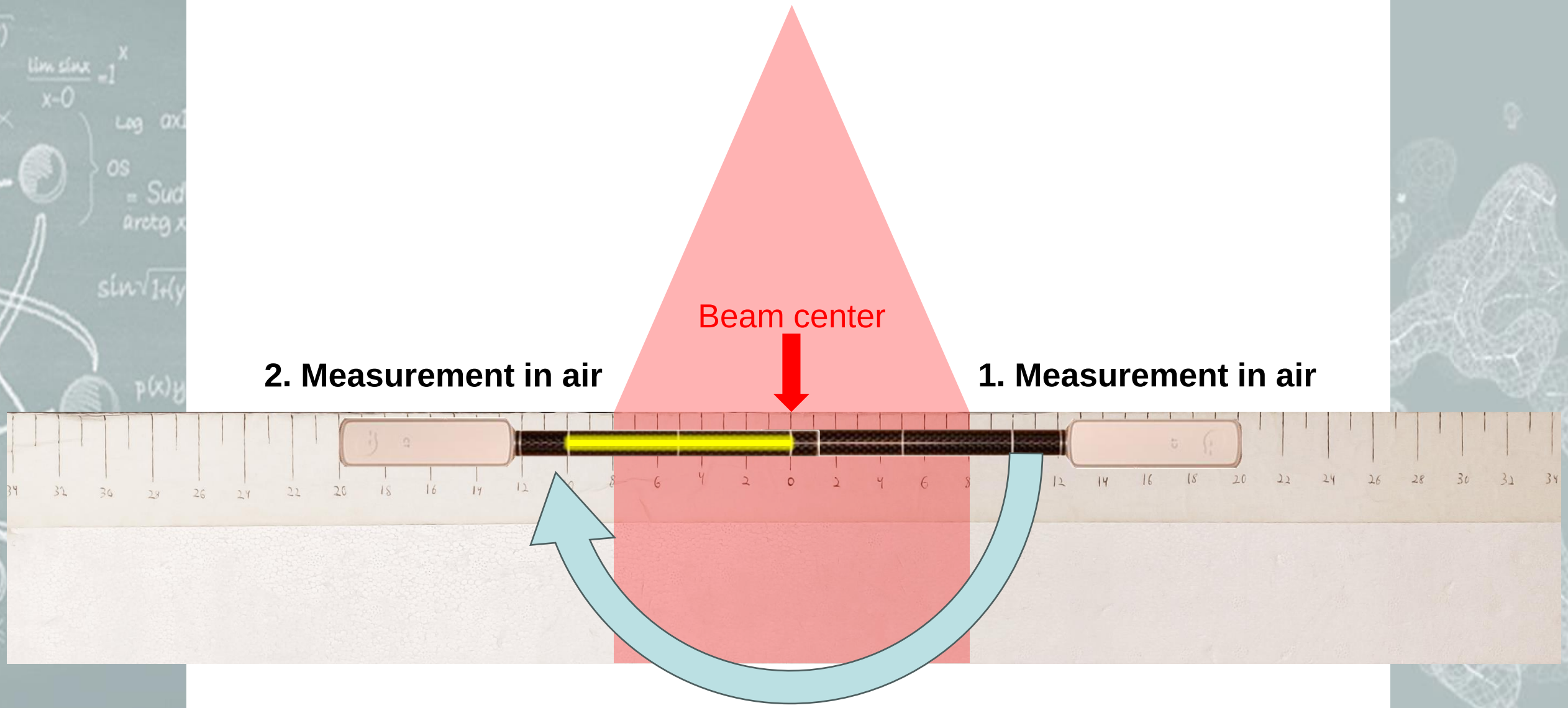
Case: Free-in-air dose measurement for 16 cm wide beam



Case: Free-in-air dose measurement for 16 cm wide beam



Case: Free-in-air dose measurement for 16 cm wide beam



Uncertainty

To ensure consistency of radiation detection, the dosimeters should be carefully calibrated in the appropriate energy ranges before they are used with patients.

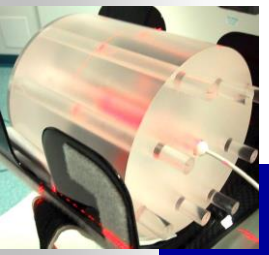
Peet and Pryor 1999, Dong 2002

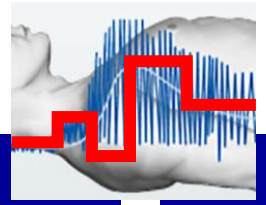
Factors contributing to the CT dose measurement uncertainty

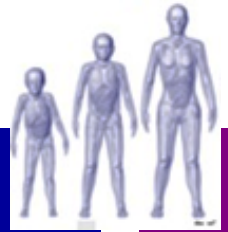
Source of uncertainty	Uncertainty ($k = 1$)(%)		
	Scenario 1	Scenario 2	Scenario 3
Measurement scenario (see Table 8.2)	6.3	3.5	2.7
Precision of reading	1.0[a]	0.6[b]	0.6[b]
Precision of tube loading indication	1.0	1.0	1.0
Precision of chamber/phantom positioning in the centre of the gantry	0.3	0.3	0.3
Uncertainty of 1 mm in phantom diameter and 0.5 mm in depth of measurement bores[c]	0.35	0.35	0.35
Uncertainty in chamber response for in phantom measurements	3.0	3.0	3.0
Relative combined standard uncertainty (k =1) for $C_{a,100}$	6.5	3.7	3.0
Relative expanded uncertainty (k = 2) for $C_{a,100}$	**13.0**	**7.4**	**6.0**
Relative combined standard uncertainty (k = 1) for C_W	7.2	4.8	4.2
Relative expanded uncertainty (k = 2) for C_W	**14.4**	**9.6**	**8.4**

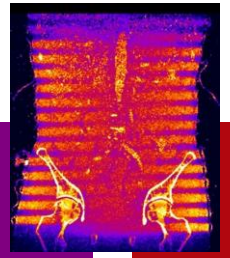
Overview of the whole range of dose quantities in CT

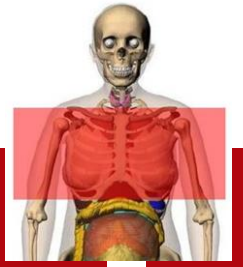
Radiation dose units in CT

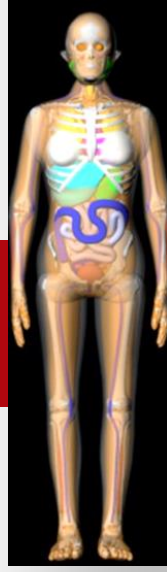












Basic parameters

- Tube voltage (kV)
- Exposure (mAs)

Effect

$CTDI_{vol}$
mGy

CT Dose Index
~ average dose to the slice in standard PMMA phantom

Scan range

- Scan length (cm)
- Number of slices

Effect

DLP
mGy·cm

Dose Length Product
~ cumulative dose in standard PMMA phantom

Patient size

- Patient diameter (cm)
- Water equivalent diameter (cm)

Effect

SSDE
mGy

Size Specific Dose Estimate
~ approximate dose to the patient in the scanned area

Organ doses

- 3D dose distribution
- Organ models

Effect

Organ dose
mGy

~ average dose to the organ

Effective dose

- Organ risk models
- Tissue weighting factors

Effect

Effective dose
mSv

~ reference radiation exposure (not physical; not to be used as a risk estimate!)

ACCURATE MEASUREMENTS

OPTIMISATION TOOL

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Radiation dose units in CT

Basic parameters	Scan range	Patient size

Exam Description: GD1CD Chest CT

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)
1	Scout	-	-	-
2	Helical	133.500-1181.000	6.04	117.11
			Total Exam DLP:	117.11

Annual measurement (as a part of technical QA)
⇒ Conformance of dose display to the actual radiation output
⇒ Patient dose data (and clinical image quality) follow-up
⇒ Application of DRLs (diagnostic reference levels) and further optimisation

factors

Effect

$CTDI_{vol}$ *mGy*

CT Dose Index
~ average dose to the slice in standard PMMA phantom

Effect

DLP *mGy·cm*

Dose Length Product
~ cumulative dose in standard PMMA phantom

Effect

SSDE *mGy*

Size Specific Dose Estimate
~ approximate dose to the patient in the scanned area

Effect

Organ dose *mGy*

~ average dose to the organ

Effect

Effective dose *mSv*

~ reference radiation exposure (not physical; not to be used as a risk estimate!)


Thank you
Kiitos
Tack