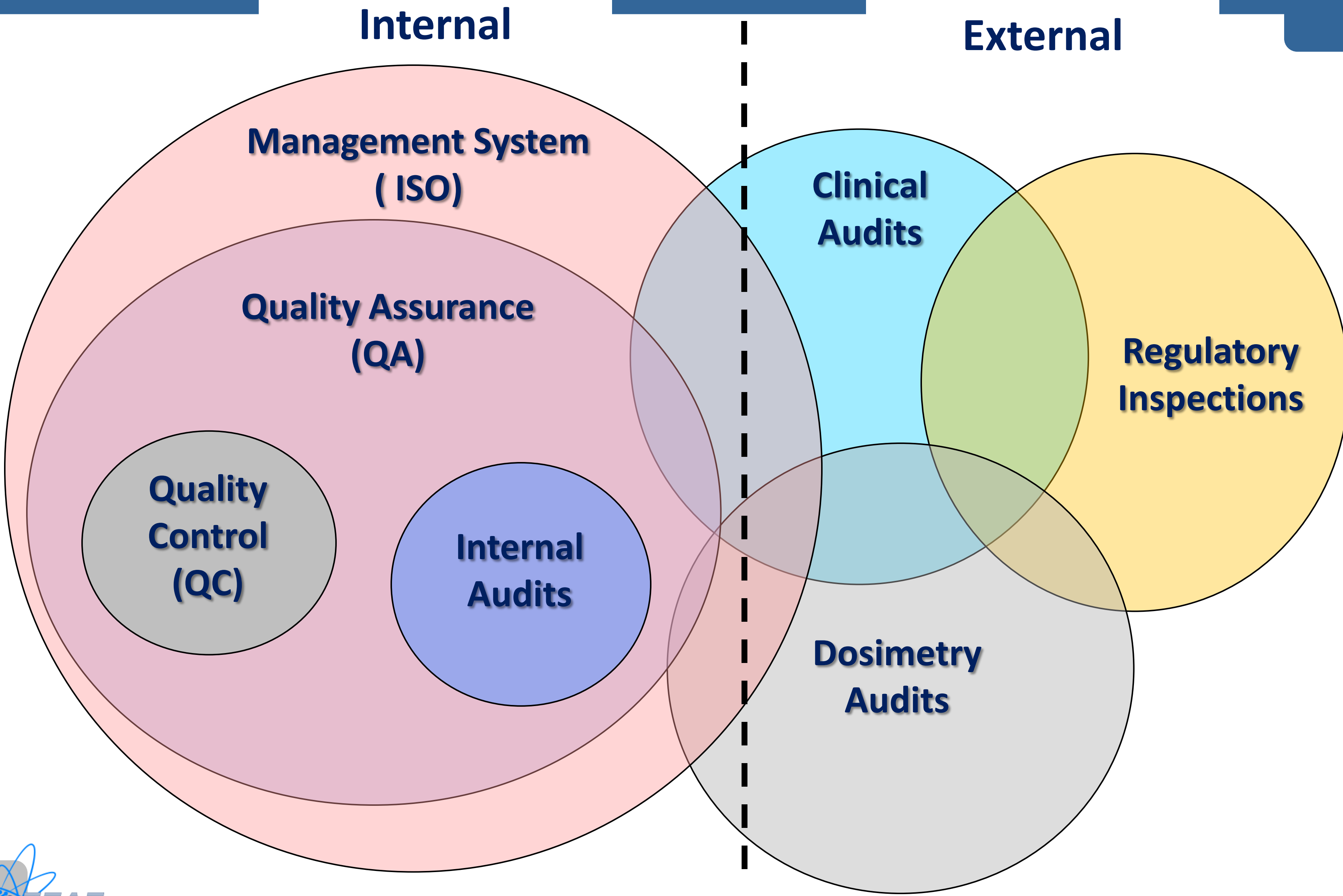
Quality Assurance of CT systems

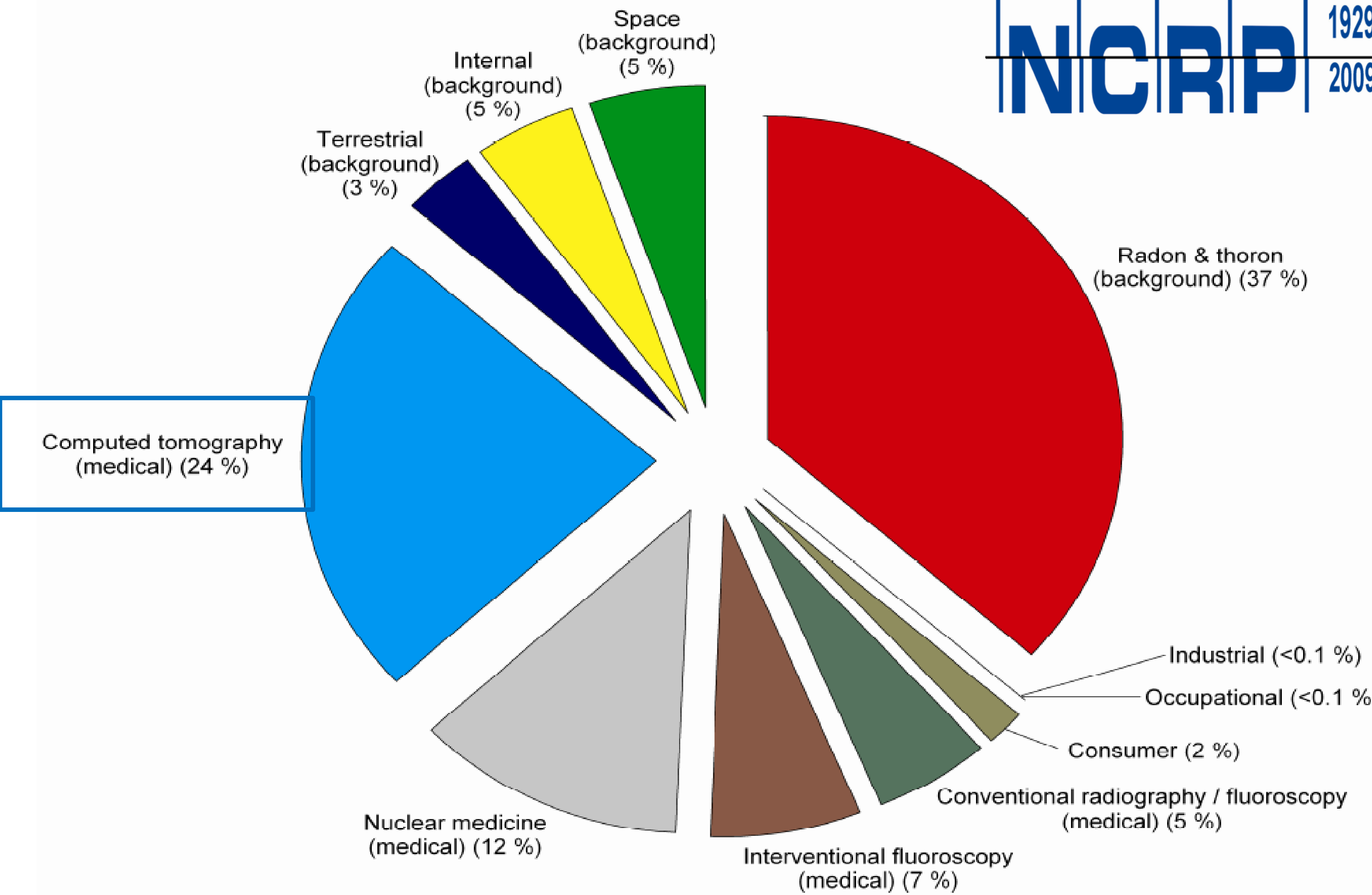
Costas J. Hourdakis
Medical Physicist, M.Sc., Ph.D.
Greek Atomic Energy Commission, EEAE

Saturday 7 February 2015, Nicosia, Cyprus

Tools for Quality



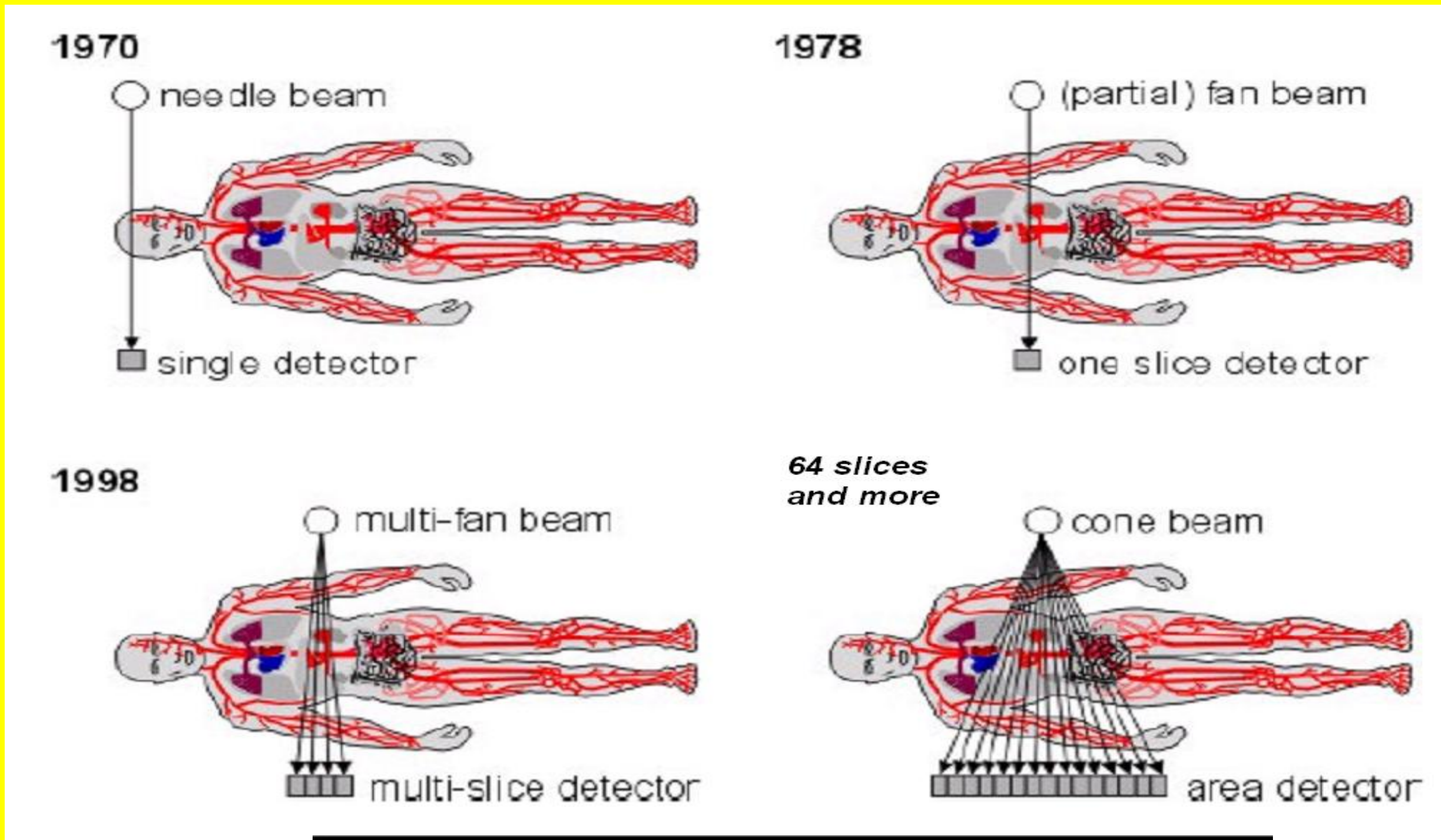
All Exposure Categories
Collective Effective Dose (percent), 2006

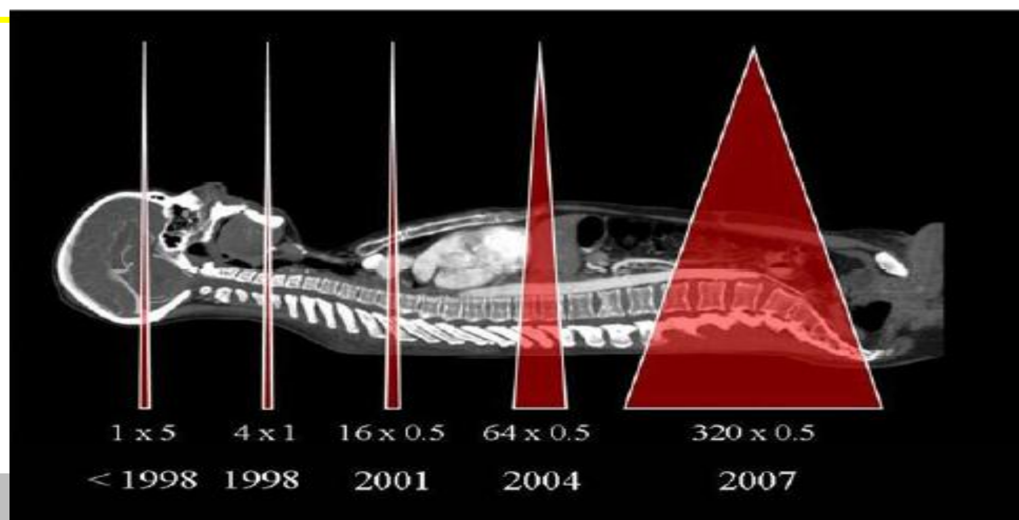


NCRP 1929 2009

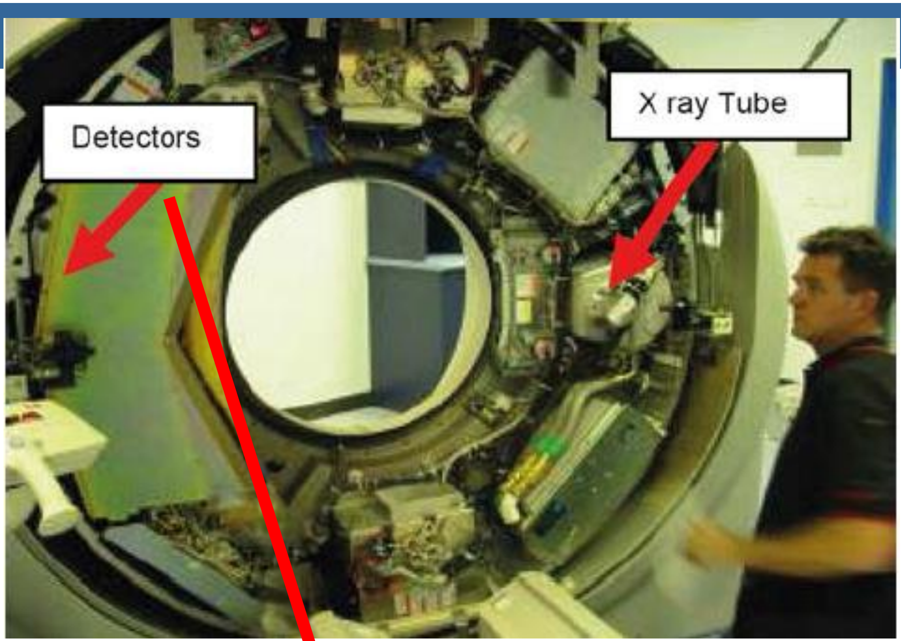
Contents

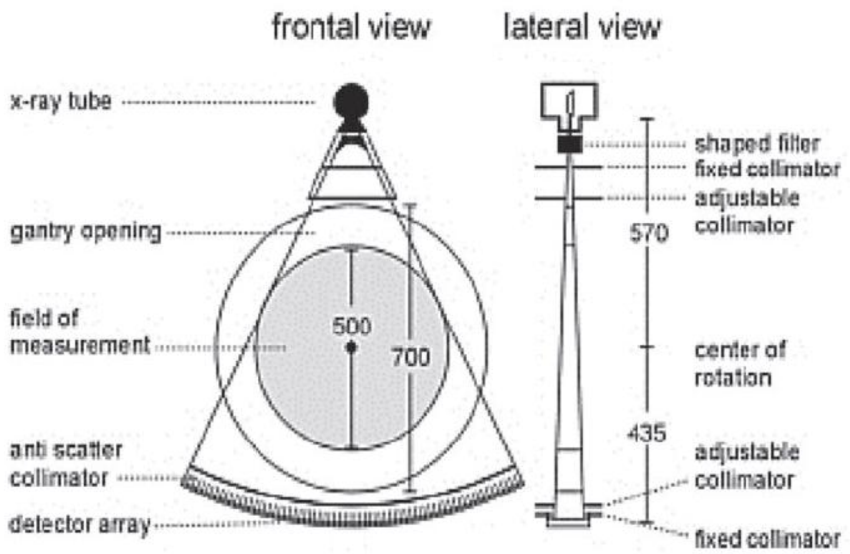
- ✓ Multi Slice – Multi detector CT scanners
  - "Problems" associated with beam widths
  - Dosimetry problems
- ✓ Quality control
  - Mechanical
  - Imaging
  - Dosimetry
- ✓ QA – Optimization

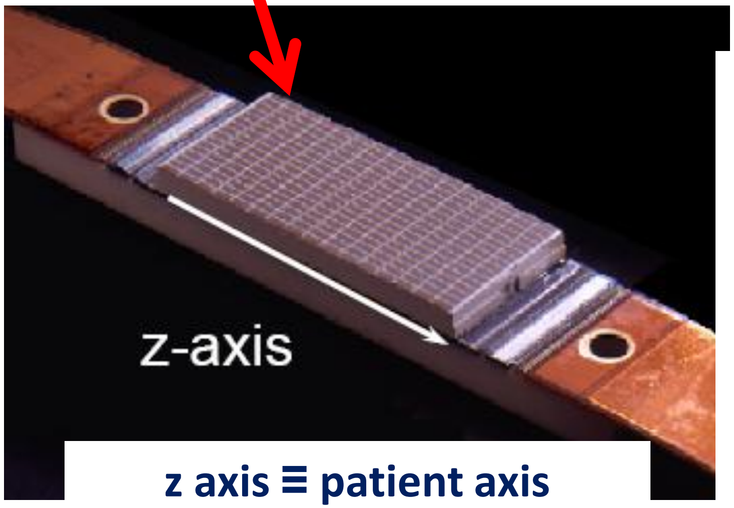

1970
needle beam
single detector
1978
(partial) fan beam
one slice detector
1998
multi-fan beam
multi-slice detector
64 slices
and more
cone beam
area detector

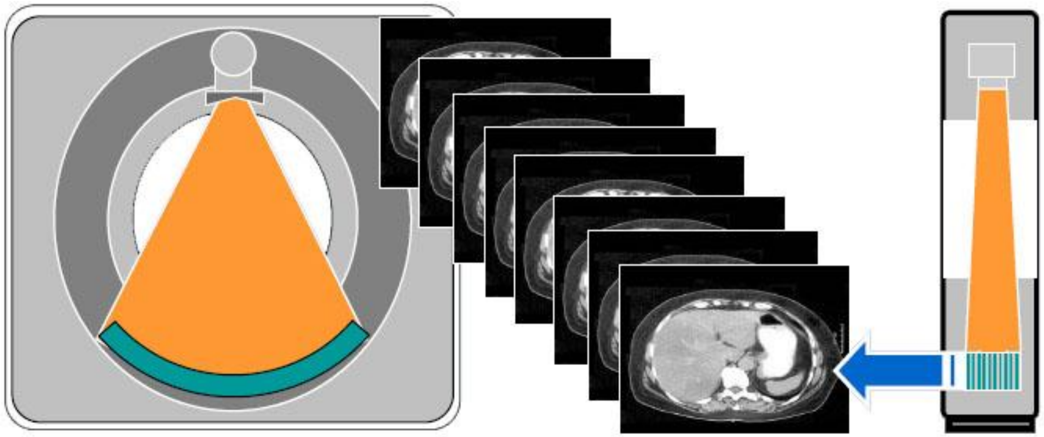

1 x 5
4 x 1
16 x 0.5
64 x 0.5
320 x 0.5
< 1998
1998
2001
2004
2007

MDCT : special characteristics







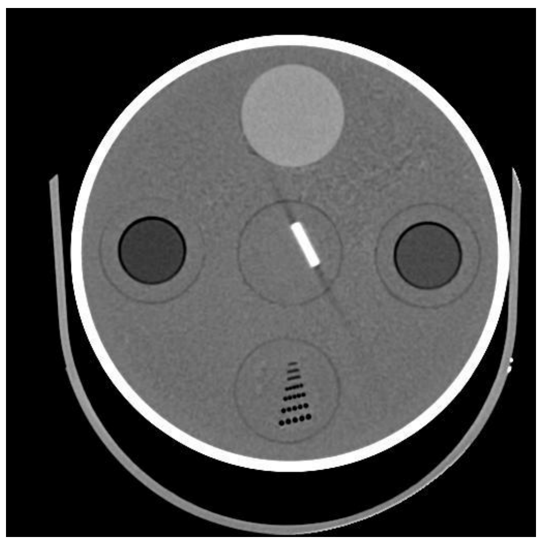


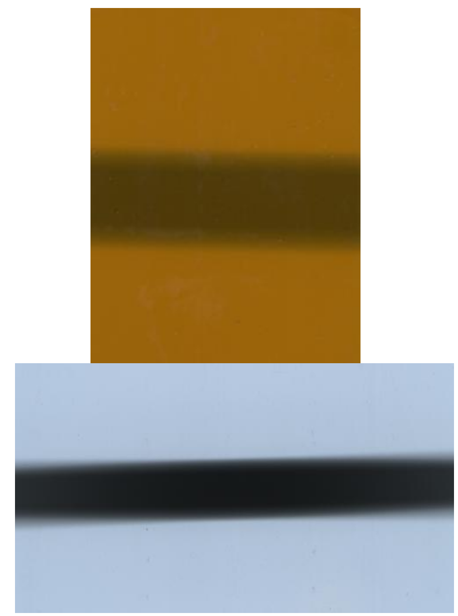
MDCT : Beam width – Slice thickness

4	x	5 mm =	20 mm

# slice per rotation, N	X	Nominal Slice **Thickness** (Reconstructed, Imaging)	=	Nominal Beam **width** (Collimation, Irradiation width)

active detectors (rows-group) on z-axis





CT Single slice ⇨ Slice thickness

MDCT : Slice width – Slice thickness

4	x	5 mm =	20 mm

slice per rotation, N X Nominal Slice **Thickness** (Reconstructed, Imaging) = Nominal Beam **width** (Collimation, Irradiation width)

Nominal Slice Thickness:

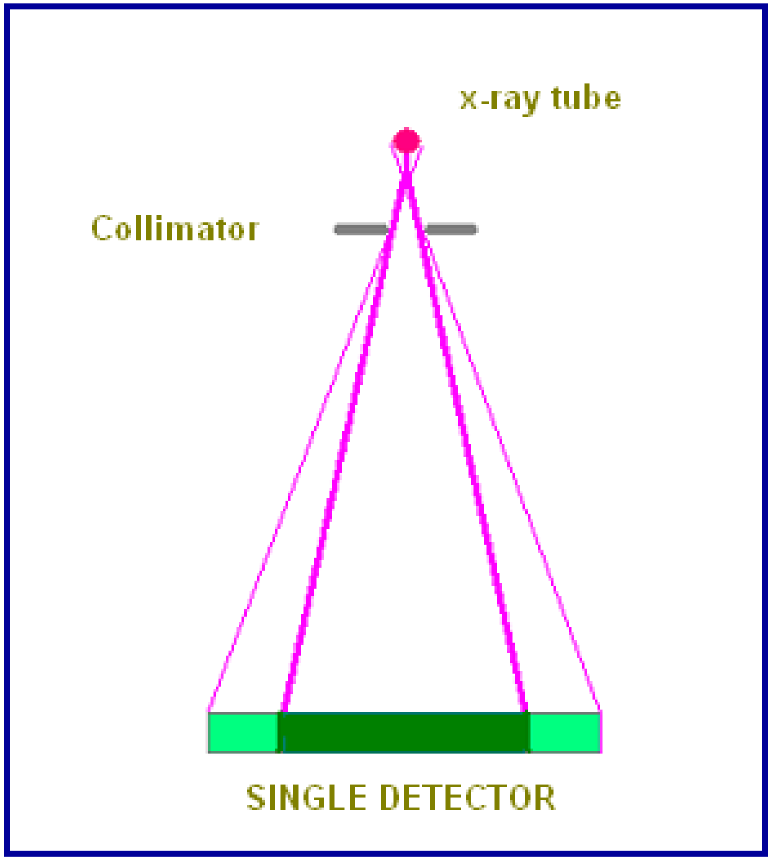
does NOT affect dose
affects image quality
does NOT affect scan time

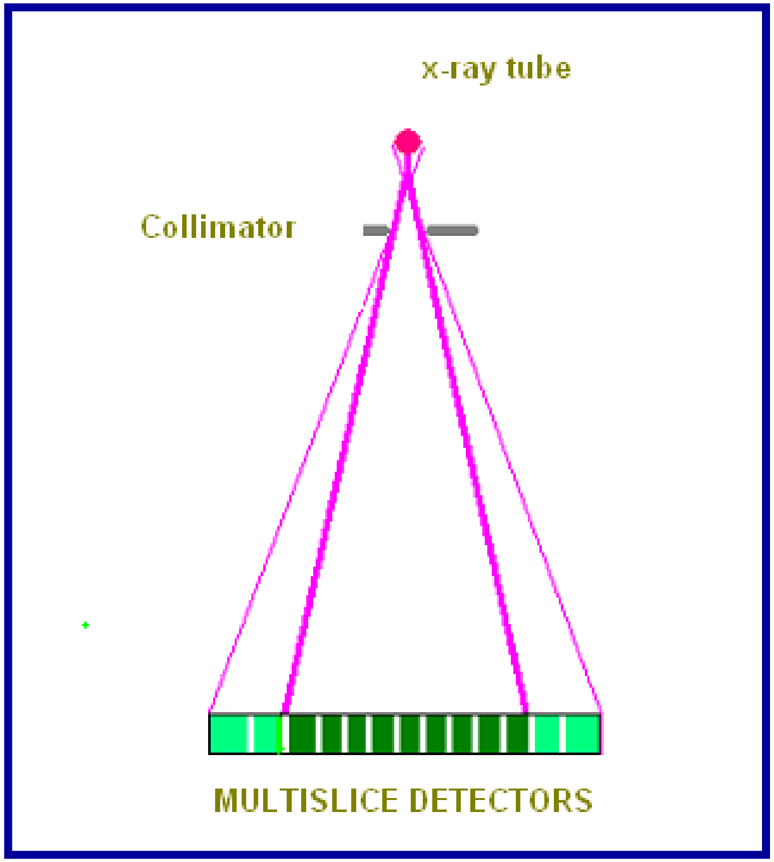
Nominal Beam width:

affects dose
dose not affect image quality
affect exam time

in principle, assuming same exposure parameters

MDCT : Overbeaming (Penumbra)



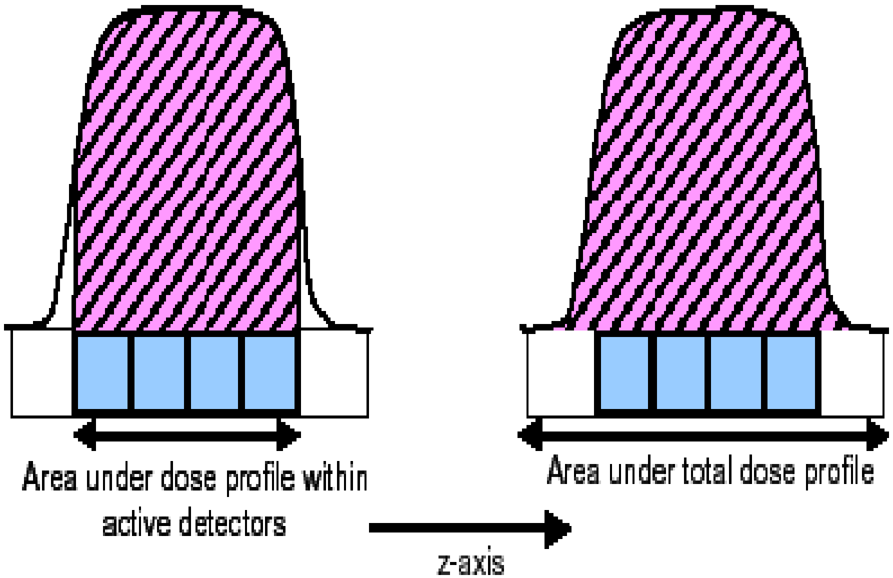


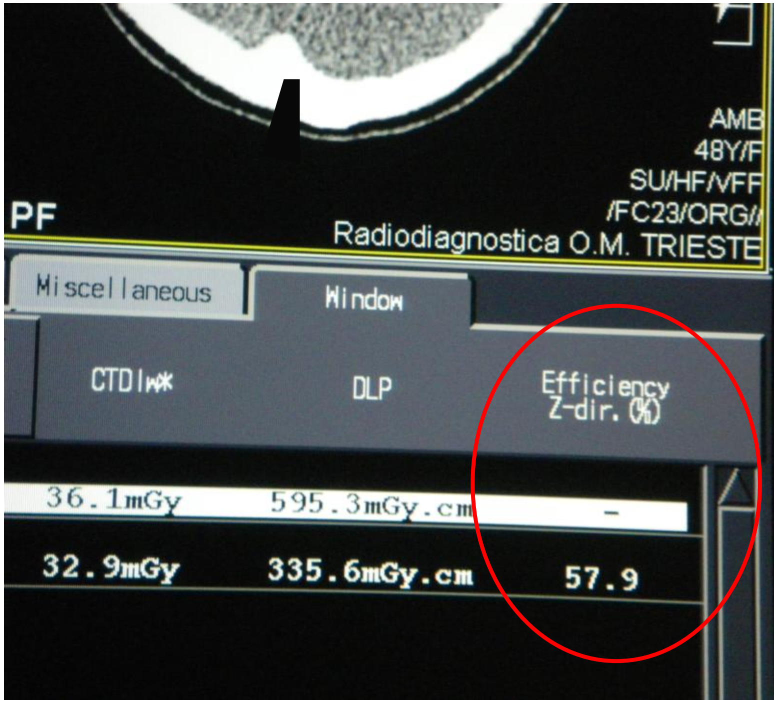
Actual X ray beam > nominal beam width

from Mario de Denaro, MP, Maggiore Hospital, Italy

MDCT : Overbeaming (Penumbra)

Z-axis geometric efficiency





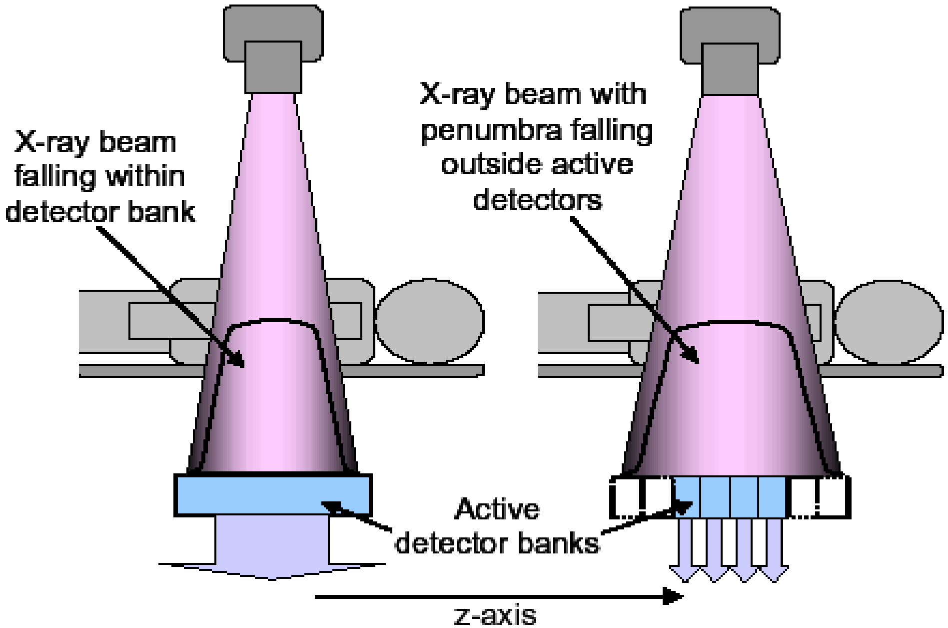
Z-axis geometric efficiency = $\frac{\text{Dose to active detectors}}{\text{Actual “true”dose profile}}$

> 70%

from Mario de Denaro, MP, Maggiore Hospital, Italy

MDCT : Overbeaming (Penumbra)

Z-axis geometric efficiency



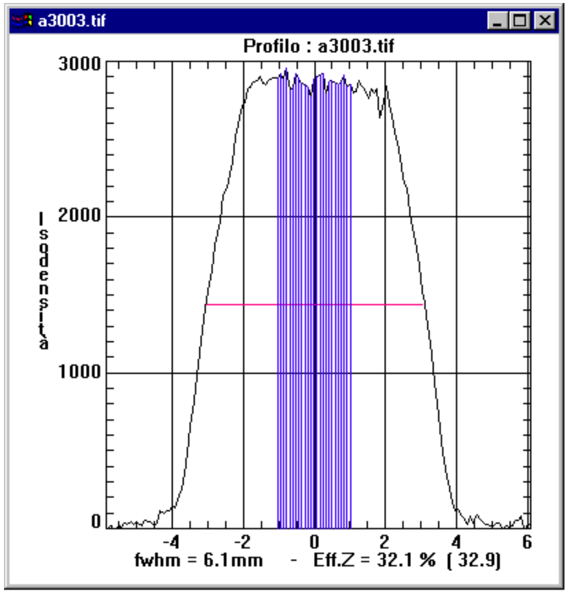
In multislice CT, due to penumbra effect, the actual x-ray beam width should be wider from nominal beam (irradiation) width, NT, by 2-3 mm → OVERBEAMING

Tip: Overbeaming has larger contribution at small beam widths

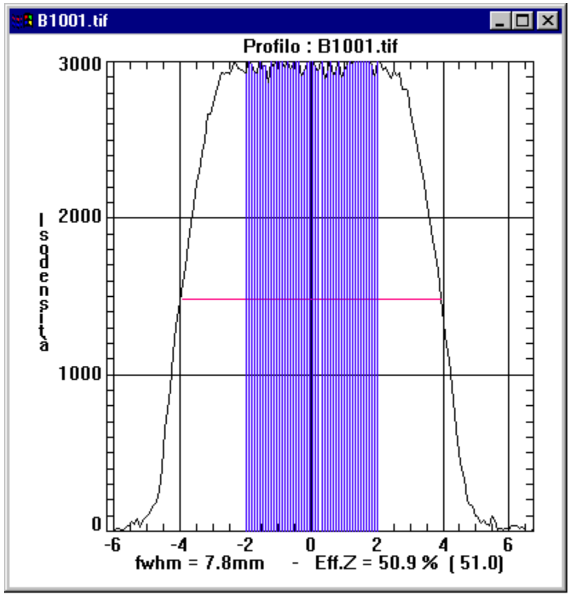
from Mario de Denaro, MP, Maggiore Hospital, Italy

MDCT : Overbeaming (Penumbra)

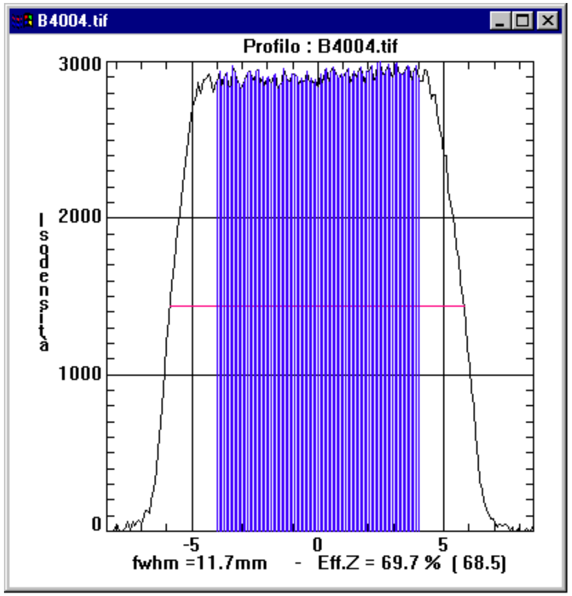
Total beam width
irradiation thikness 2 mm
Z-Efficiency = 32.1%



Total beam width
irradiation thikness 4 mm
Z-Efficiency = 50.9%

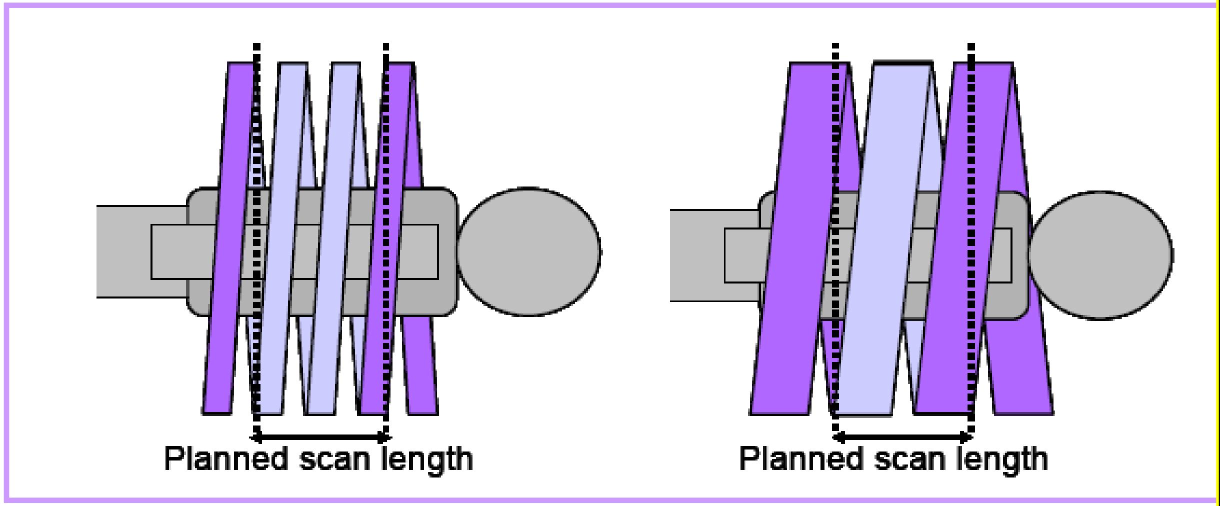


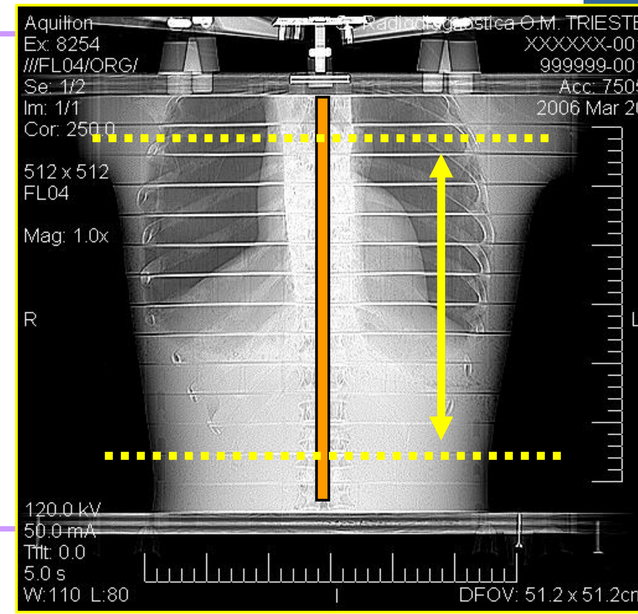
Total beam width
irradiation thikness 8 mm
Z-Efficiency = 69.7%



from Mario de Denaro, MP, Maggiore Hospital, Italy

MDCT : Overscanning





Due to image reconstruction algorithms based on interpolation, the actual scan length, must exceed the nominal planned scan length, set in CT console.

Tip : Overscanning has larger contribution at large beam widths and small scanned lengths

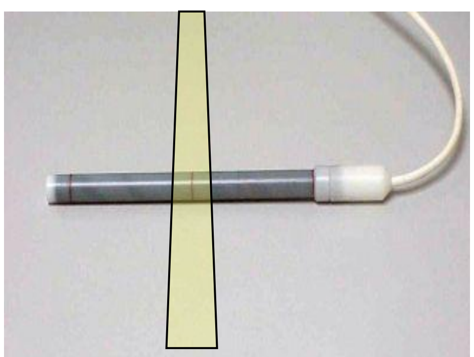
from Mario de Denaro, MP, Maggiore Hospital, Italy

MDCT : C_w , Weighted Computed Tomography Dose Index

$$C_W = \frac{1}{3}\left(C_{\mathrm{PMMA},100,c} + 2\ C_{\mathrm{PMMA},100,p}\right) \qquad \mathrm{mGy}$$

C_w, Weighted Computed Tomography Dose Index :

- measured with single axial scan only
- Measured on axis of scanner using pencil ionisation chamber
- Calculated as integral of air kerma along chamber divided by nominal slice width



mGy

$$C_{a,100} = \frac{P_{KL}}{NT} = \frac{1}{NT}\overline{M} N_{P_{KL},Q_0} k_Q k_{TP}$$

$$C_{PMMA,100,c} = \frac{P_{KL}}{NT} = \frac{1}{NT}\overline{M}_c \, N_{P_{KL},Q_0} k_Q \, k_{TP}$$

$$C_{PMMA,100,p} = \frac{P_{KL}}{NT} = \frac{1}{NT}\overline{M}_p \, N_{P_{KL},Q_0} k_Q \, k_{TP}$$

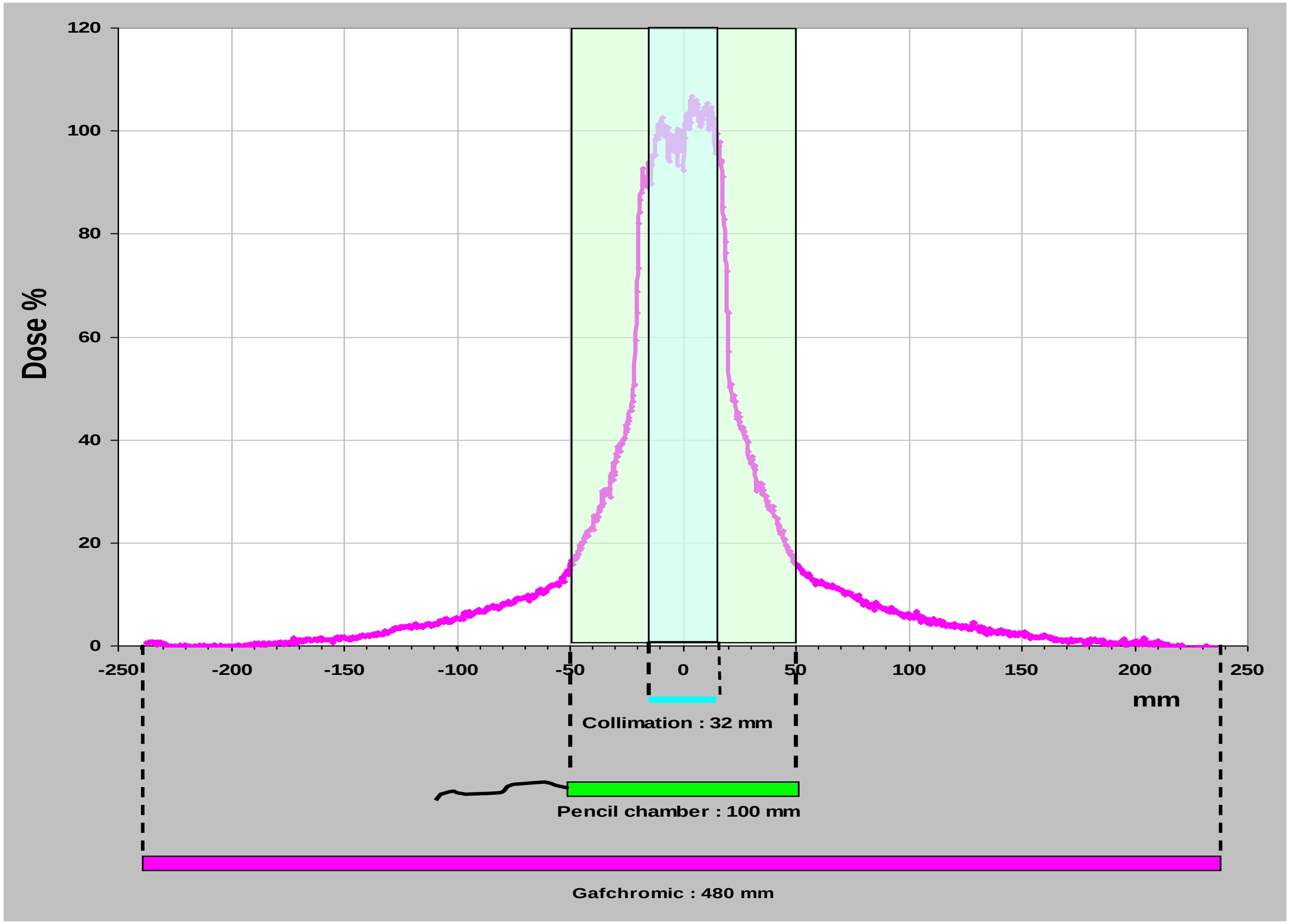
$$C_W = \frac{1}{3}\left(C_{PMMA,100,c} + 2\ C_{PMMA,100,p}\right)$$

normalized

$${}_nC_W = \frac{C_w}{P_{It}}$$

mGy/mAs

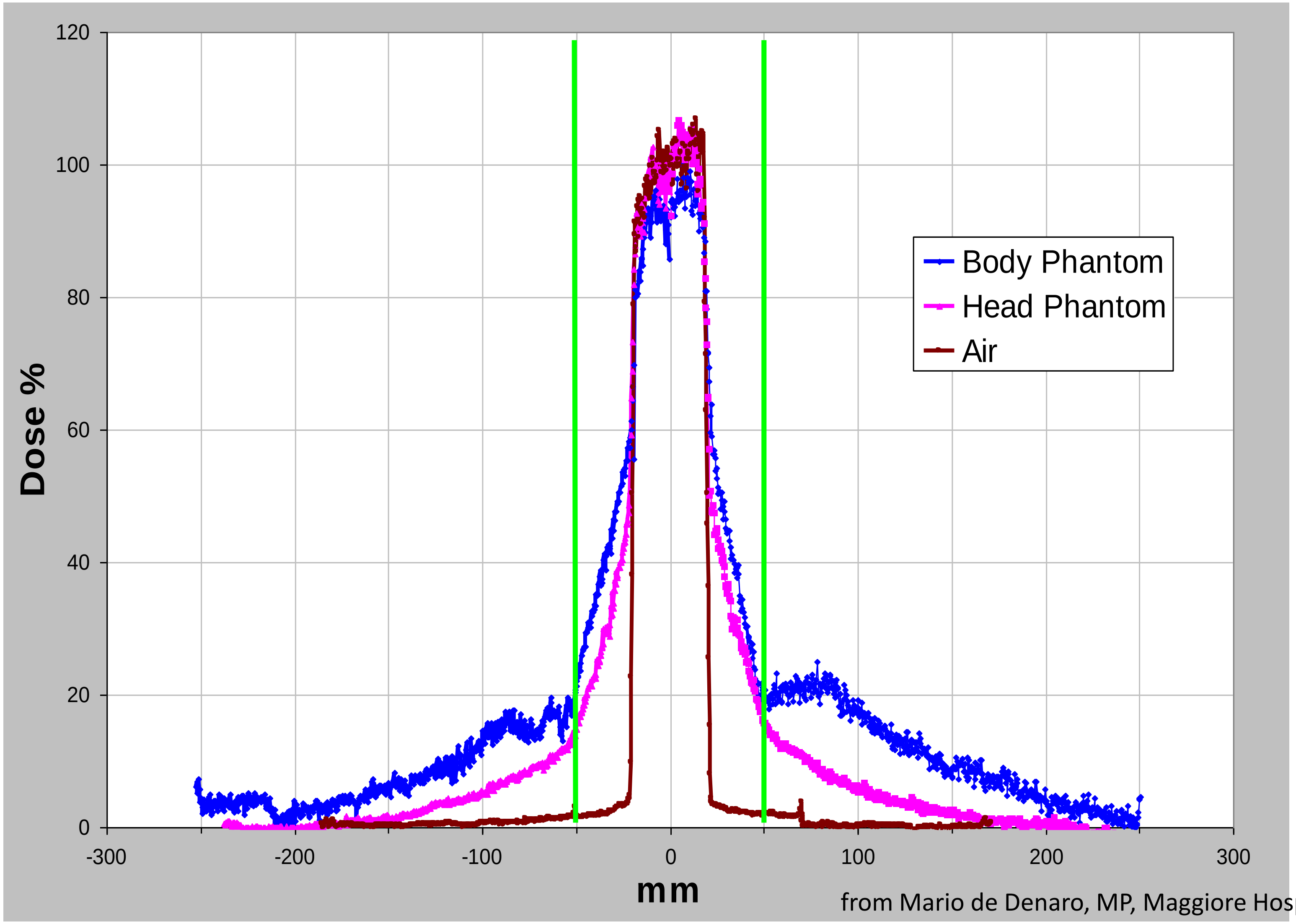
MDCT : C_w , Weighted Computed Tomography Dose Index



In MDCT : underestimation of $CTDI_w$

from Mario de Denaro, MP, Maggiore Hospital, Italy

MDCT : C_w , Weighted Computed Tomography Dose Index



from Mario de Denaro, MP, Maggiore Hospital, Italy

MDCT : C_w , Weighted Computed Tomography Dose Index

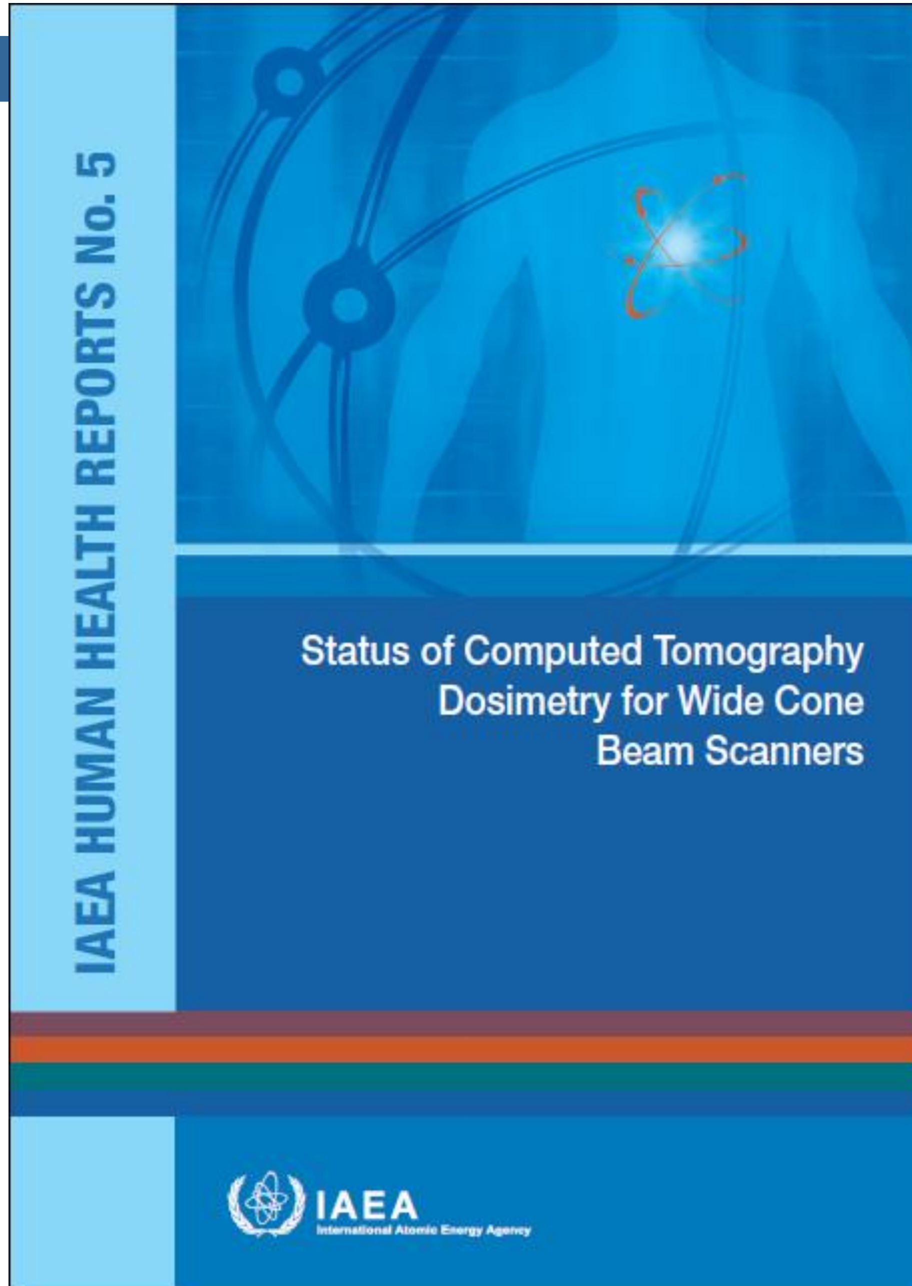
IEC Approach (IEC Part 2-44 ed. 3.0 Amend. 1, 2010)

For beam widths, NT ≤ 40 mm: the conventional method C_w still applies

For beam widths, NT > 40 mm

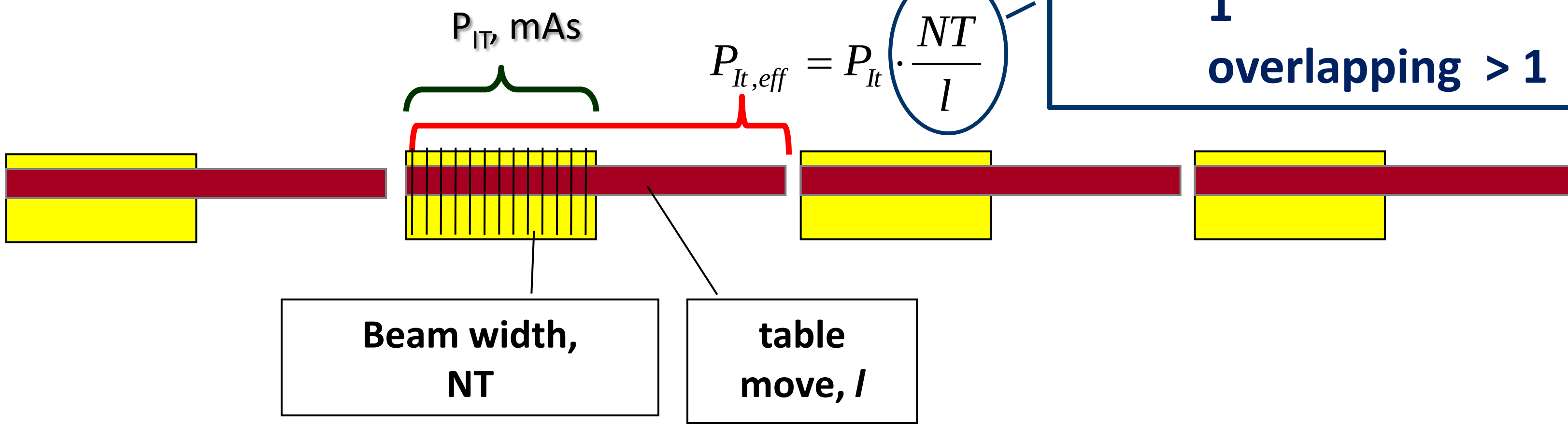
$$C_{w,NT} = C_{w,Ref} \times \left(\frac{C_{a,100,NT}}{C_{a,100,Ref}} \right)$$

Reference NT ≈ 20 mm


IAEA HUMAN HEALTH REPORTS No. 5
Status of Computed Tomography
Dosimetry for Wide Cone
Beam Scanners
IAEA
International Atomic Energy Agency

CT Dosimetry methodology

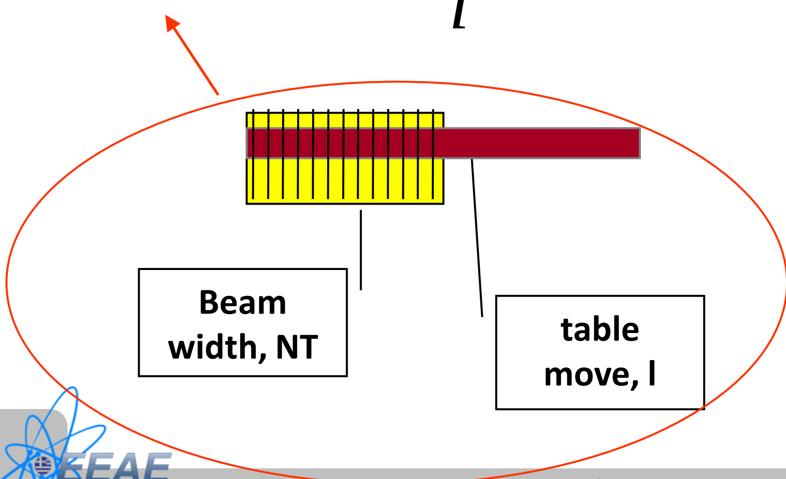
One “rotation”



$$P_{It,eff} = P_{It} \cdot \frac{NT}{l}$$

pitch : spacing < 1
1
overlapping > 1

$$C_{VOL} = C_W \frac{NT}{l}$$



N : number of slices / images in one rotation (# detectors) e.g. 16 x 0.5mm

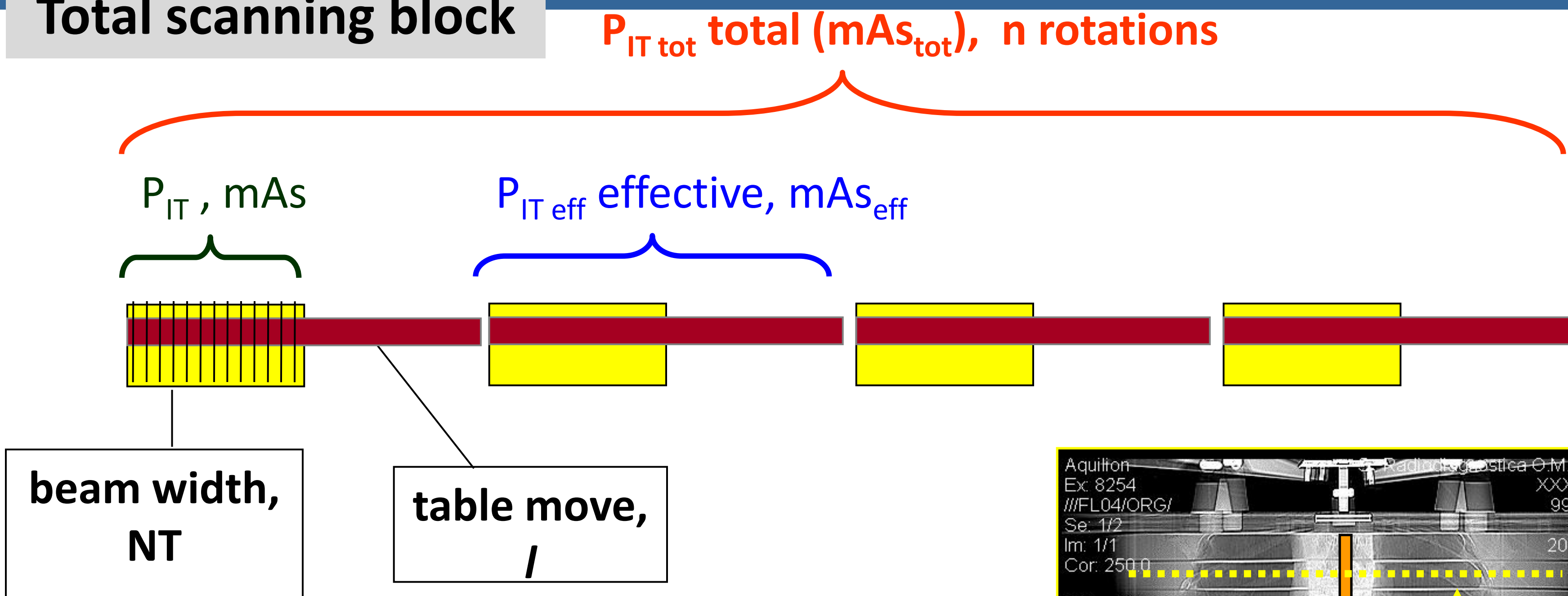
T : nominal slice thickness (reconstruction slice) e.g. 16 x 0.5mm

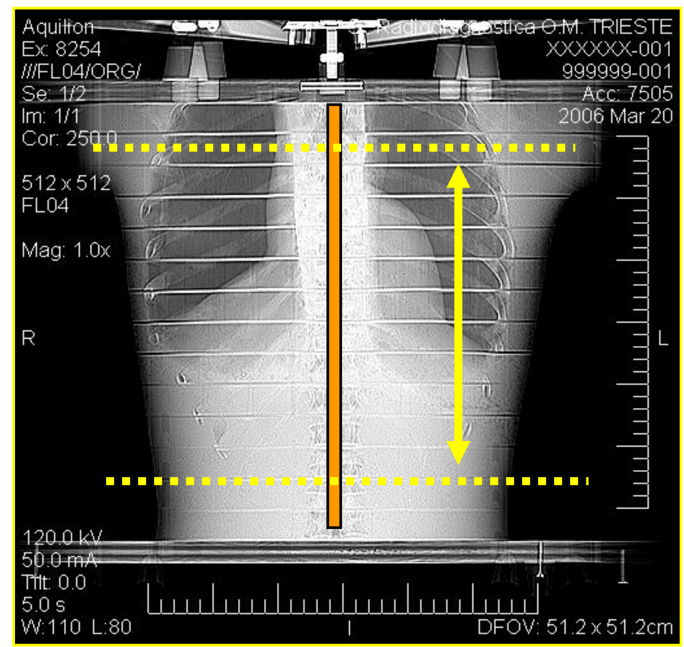
l **table movement in a single rotation, e.g. 16 mm**

***pitch* = N T / *l* = 8 / 16 = 0.5**

CT Dosimetry methodology

Total scanning block





DLP - Air Kerma – Length product, $P_{KL,CT}$

Units: mGy cm

$$P_{KL,CT} = C_{VOL} \cdot (\text{scan length})$$

$$P_{KL,CT} = C_{VOL} \cdot n \cdot l$$

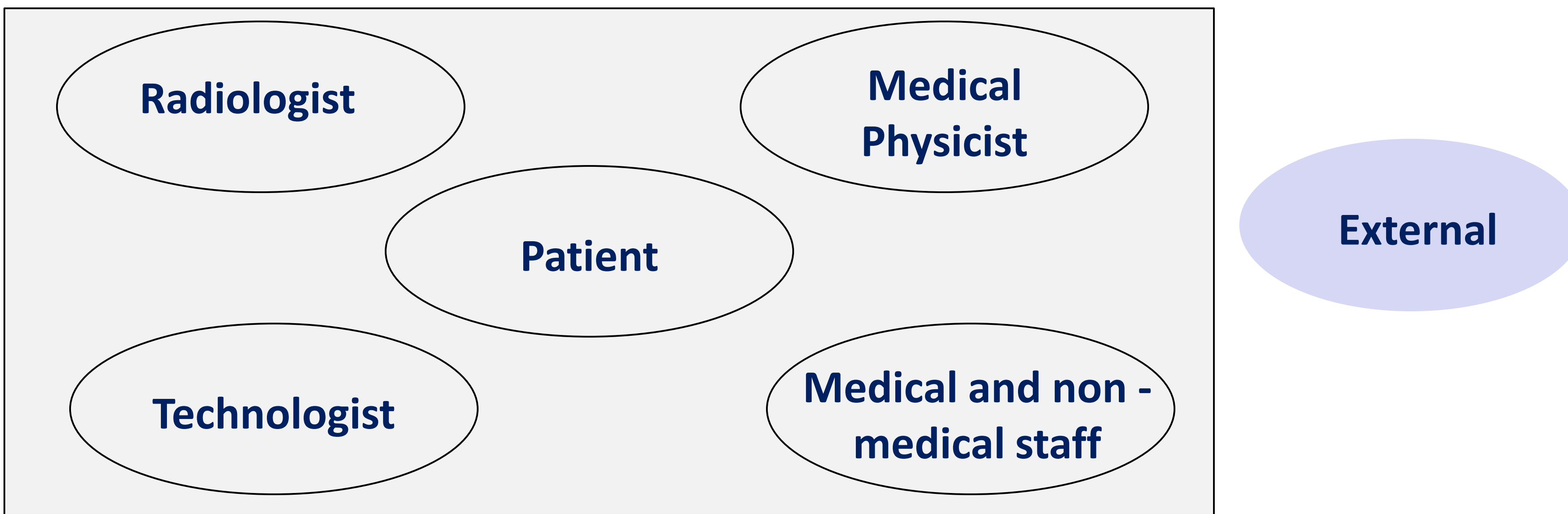
$$P_{KL,CT} = {}_nC_{VOL} \cdot P_{It\ tot} \cdot l$$

$$P_{KL,CT} = {}_nC_{W} \cdot P_{It\ eff} \cdot l$$

QA - QC

Quality assurance (QA) : planned and systematic actions necessary to provide confidence that a department, including x-ray systems, will perform satisfactorily, will provide high quality services, while specified requirements will be fulfilled.

Quality Control (QC) : Part of quality assurance intended to verify that CT systems and components correspond to predetermined requirements .



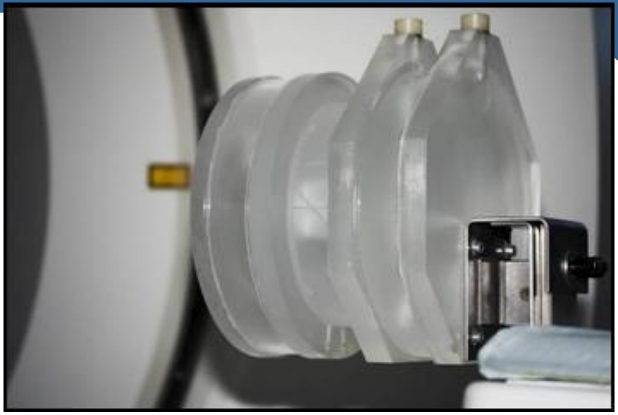
Quality Control

- Parameter
- QC instrumentation
- Measurement protocol – procedure
- Acceptance limits – criteria
- Frequency

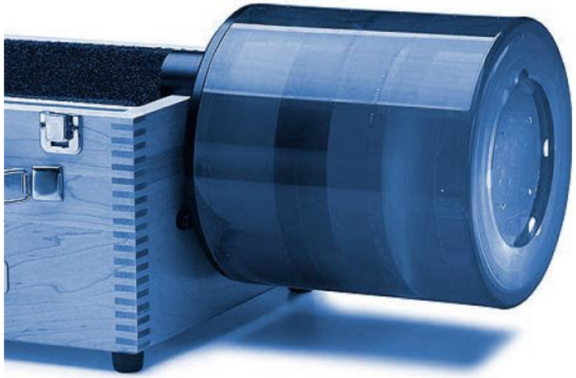
ΠΡΩΤΟΚΟΛΛΟ ΠΕΡΙΟΔΙΚΩΝ ΕΛΕΓΧΩΝ ΠΟΙΟΤΗΤΑΣ ΑΞΟΝΙΚΟΥ ΤΟΜΟΓΡΑΦΟΥ

ΠΑΡΑΜΕΤΡΟΣ	ΕΠΕΞΗΓΗΣΕΙΣ ΠΑΡΑΜΕΤΡΟΥ	ΟΡΓΑΝΑ ΕΛΕΓΧΟΥ	ΣΤΟΙΧΕΙΑ ΕΛΕΓΧΟΥ	ΑΠΟΔΕΚΤΑ ΟΡΙΑ	ΠΕΡΙΟΔΙΚΟΤΗΤΑ
Πάχος τομής (irradiated slice thickness)	Έλεγχος της ακρίβειας των διαστάσεων των παχών τομής	Κατάλληλο ομοίωμα με δομή για μέτρηση πάχους τομής ή film	Μέτρηση όλων των διαθέσιμων παχών τομής	Απόκλιση: ≤±0.5mm μέχρι 5mm ≤±1.0mm για μεγαλύτερα πάχη	Τριμηνιαίος
Γραμμικότητα ΑΥΤ	Έλεγχος της γραμμικής μεταβολής των ΑΥΤ με τους γραμμικούς συντελεστές εξασθένησης	Κατάλληλο ομοίωμα με τρεις τουλάχιστον περιοχές διαφορετικής πυκνότητας, επιπρόσθετα του νερού και του αέρα	Μέτρηση των ΑΥΤ για τρεις τουλάχιστον περιοχές διαφορετικής σύστασης του ομοιώματος & πάχος τομής 10mm	r≥0.95 (Συντελεστής συσχετισμού ονομαστικής και μετρούμενης τιμής)	Τριμηνιαίος
Ακρίβεια μετρούμενων διαστάσεων	Έλεγχος της ακρίβειας μέτρησης διαστάσεων στις τομογραφικές εικόνες	Κατάλληλο ομοίωμα γνωστών διαστάσεων με δομές γνωστών διαστάσεων	Λήψη με τομή πάχους:10mm Μέτρηση διαστάσεων ομοιώματος, δομών	Απόκλιση ≤±1mm	Ετήσιος
Ψευδοεικόνες	Έλεγχος για την ύπαρξη ψευδοεικόνων	Κατάλληλο ομοίωμα με δομές από υλικά υψηλού ατομικού αριθμού	Λήψη με τομή πάχους:10mm Έλεγχος της εικόνας για την ύπαρξη ψευδοεικόνων		Τριμηνιαίος

Instrumentation: Phantoms



Manufacturer's phantom



Catphan

(www.phantomlab.com)

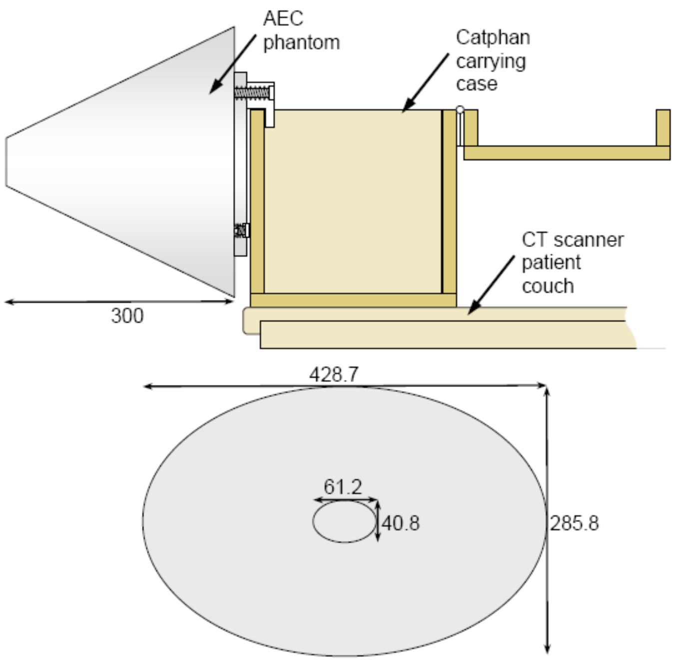
Gammex RMI 461

(www.gammex.com)

Instrumentation: Phantoms

ImPACT AEC phantom

The ImPACT AEC phantom from the side, mounted on a Catphan box, and viewed from the 'front' and 'rear', dimensions in mm



Thorax phantom (CIRS Model)

Dosimetry phantom

- ✓ Cylindrical PMMA phantoms with holes for pencil chamber
  - 32 cm body phantom
  - 16 cm head phantom

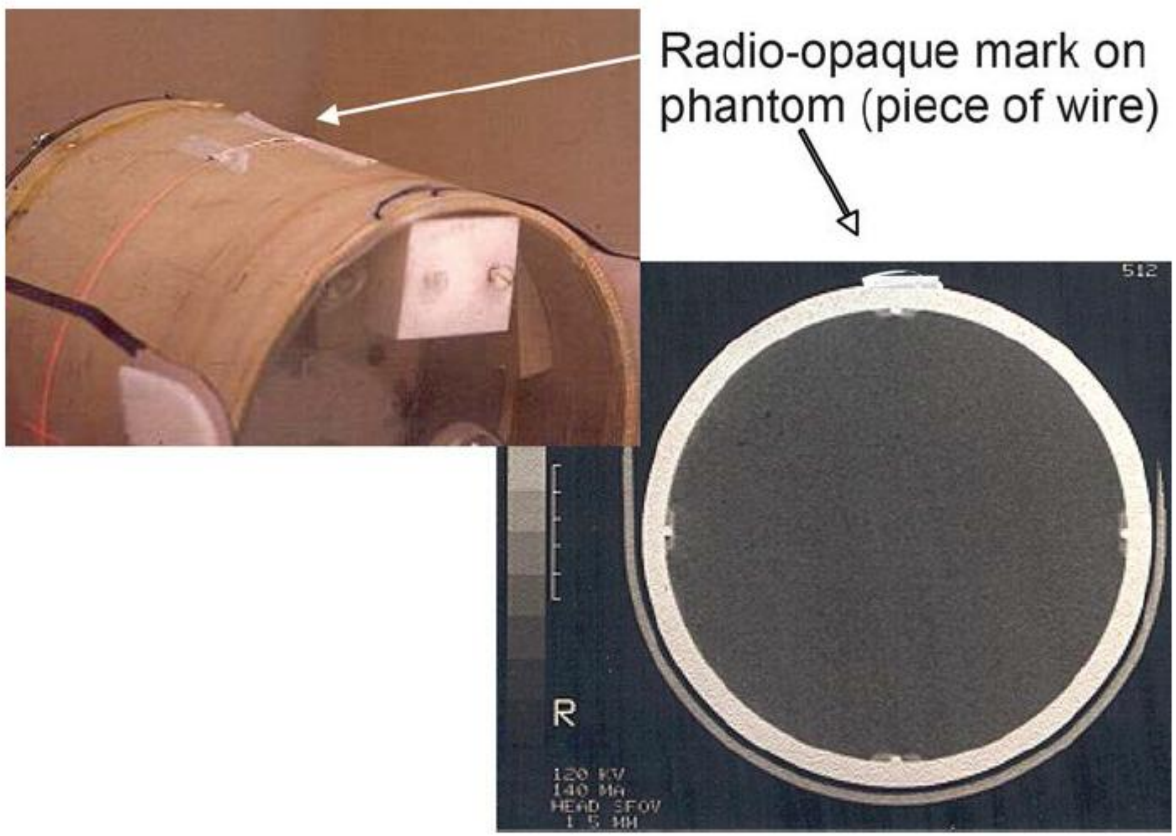
QC

-**Mechanical Performance**

-**Image quality**

-**Dosimetry**

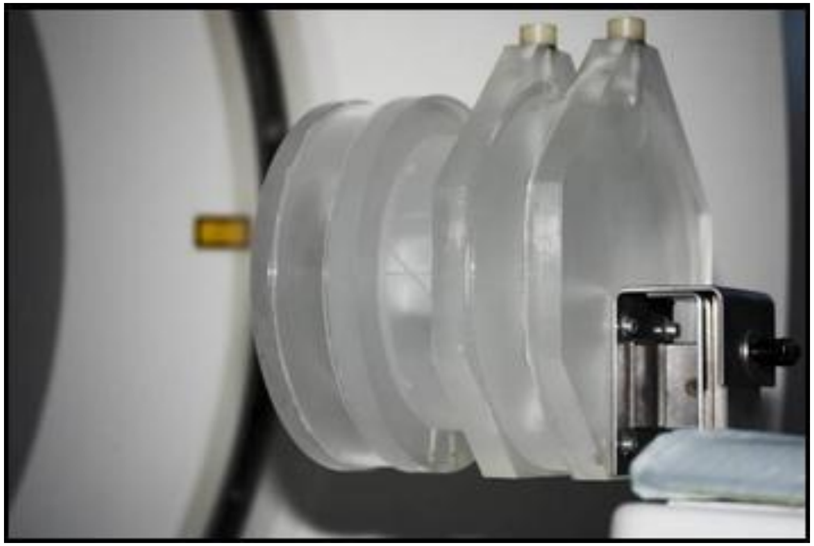
CT Light Alignment with scan plane

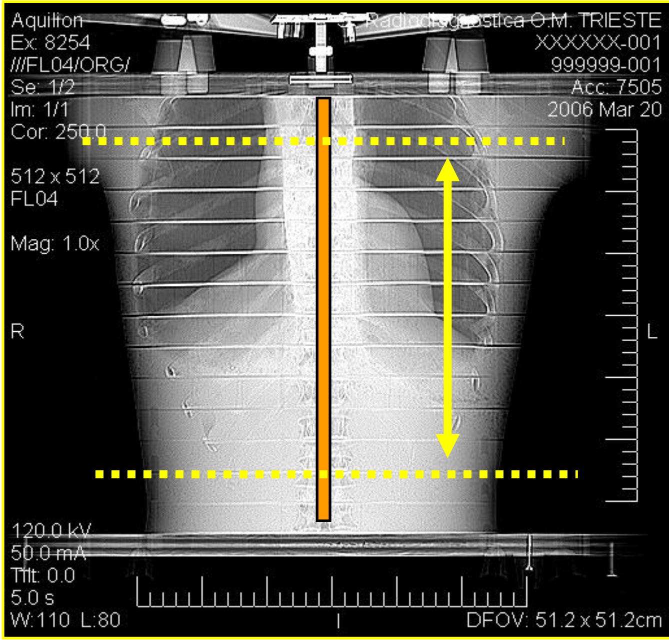


Acceptance limits : ± 5 mm
Frequency : Monthly

QC : Mechanical Performance

SPR accuracy (scan projection radiograph, scanogram, scoutview)





Acceptance limits : ± 2 mm

Frequency : Monthly

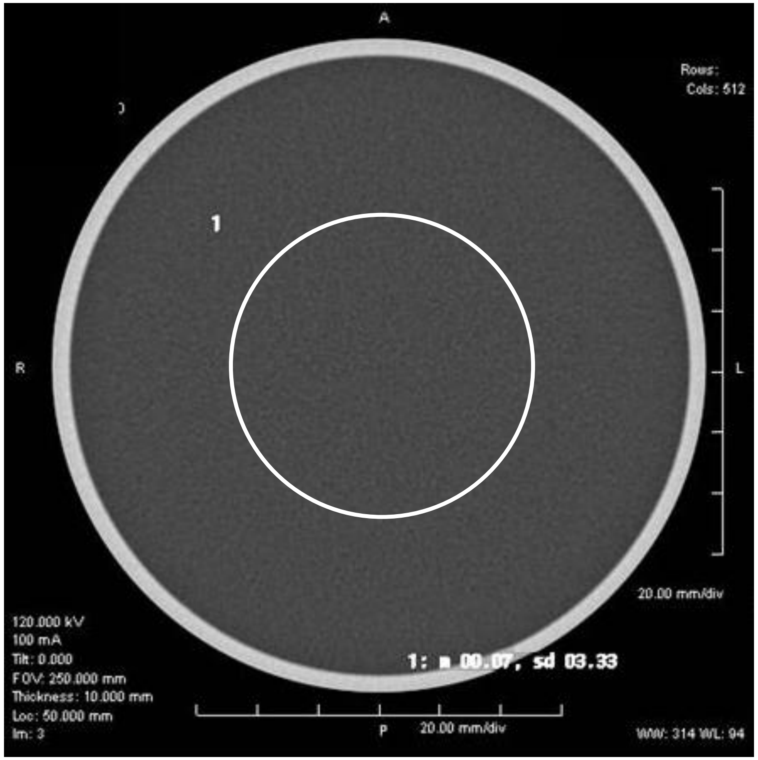
QC : Image quality

Image Noise

Noise is assessed using cylindrical phantoms, which are either filled with water or made of a tissue equivalent material

Once an axial image of the phantom has been acquired, a region of interest (ROI) is placed in the center of the image (about 40% of phantom diameter)

Noise is expressed as the Standard Deviation of CT numbers in the ROI



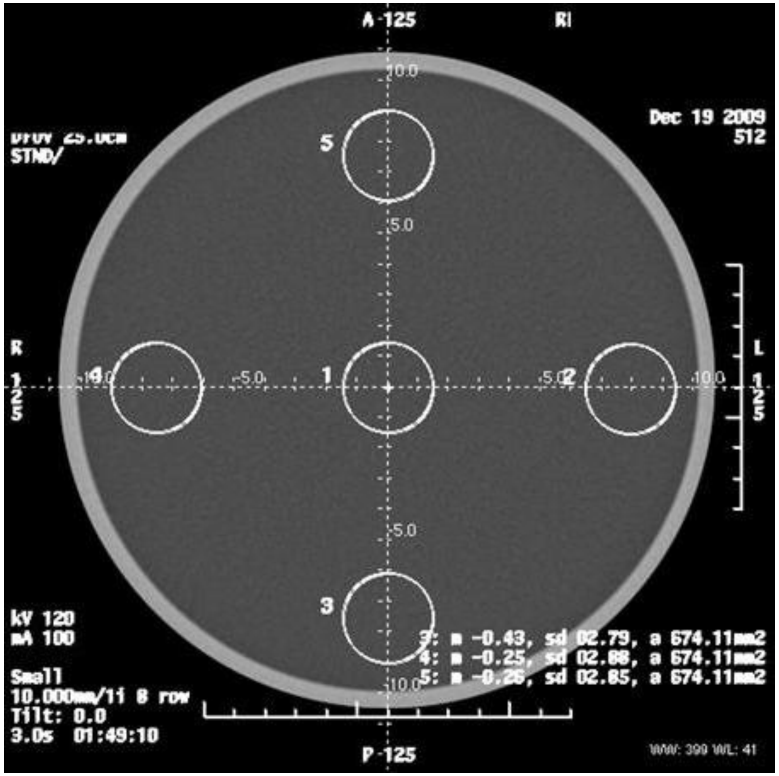
Acceptance limits : ± 25 % from baseline OR SD = 0.5%

Frequency : Monthly

Image Uniformity

CT number uniformity can be assessed by placing five ROIs (N, E, S, W and center) at positions near the edge of the image and the centre of a uniform phantom

Uniformity is measured as the absolute difference of CT numbers between the centrally placed ROI with each of four ROIs placed on the edge.



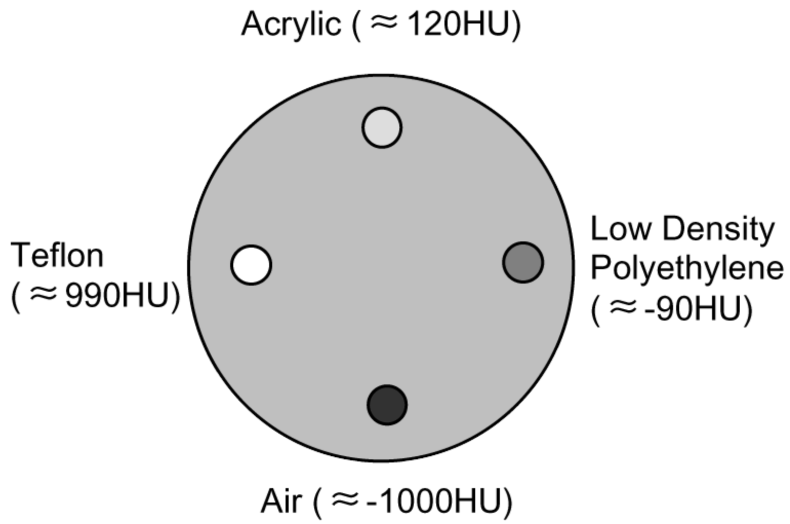
Acceptance limits : ± 10 HU

Frequency : Monthly

CT number accuracy

To ensure that CT number values comply with the manufacturer's specifications for defined acquisition parameters and phantoms

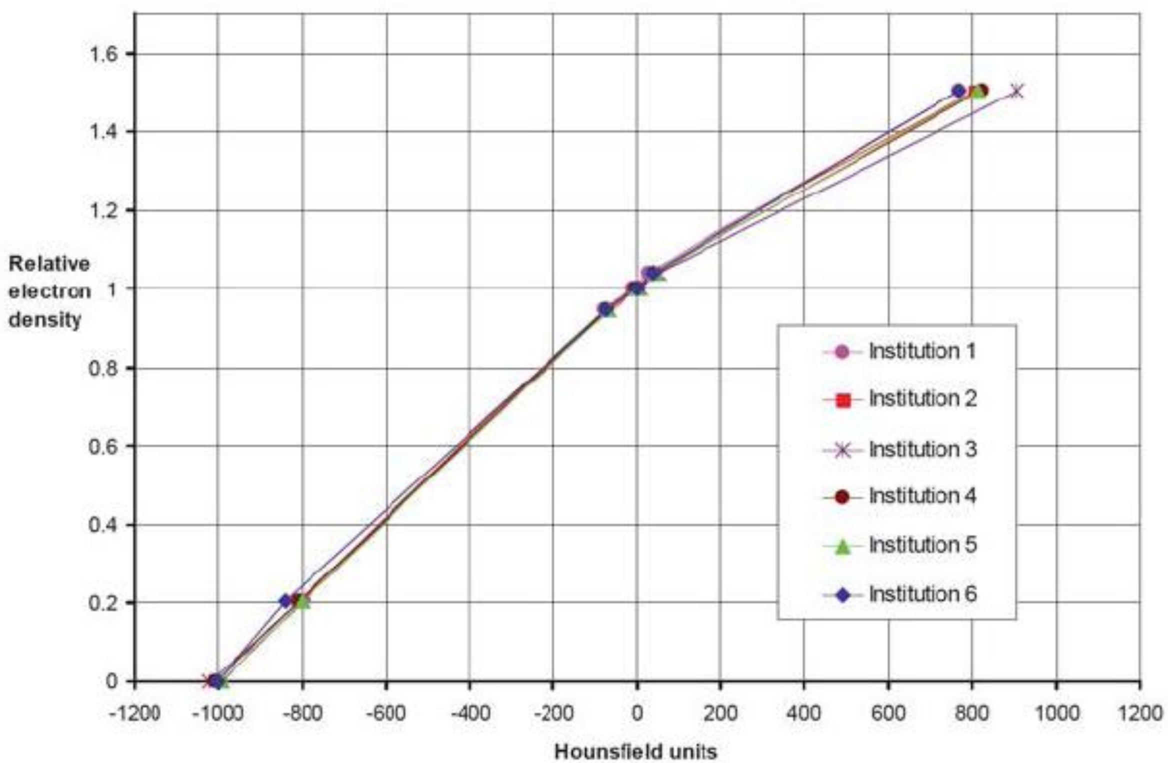
Phantoms with inserts of various materials with known CT numbers are appropriate, along with the measurements of water (0) and air (-1000)



Acceptance limits : ± 5 HU from baseline, water 0 ± 20 HU, air -1000 ± 30 HU
Frequency : Monthly

QC : Image quality

CT number accuracy



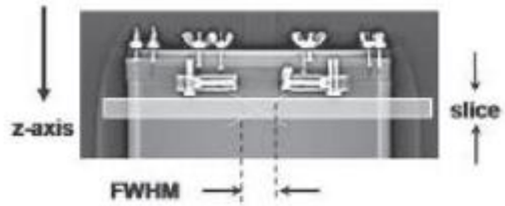
Acceptance limits : ± 5 HU from baseline,
water 0 ± 20 HU, air -1000 ± 30 HU
Frequency : Monthly

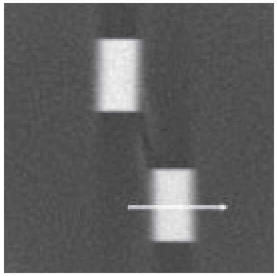
Slice thickness accuracy

To ensure that the displayed image represents a specified thickness of tissue

A ramp test object in the phantom is used

Calculation formula depends on the phantom type (inclination of the ramp)





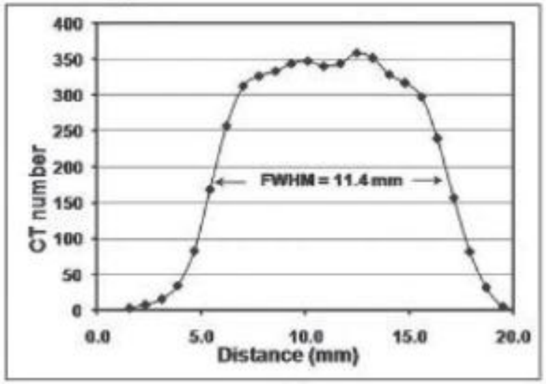
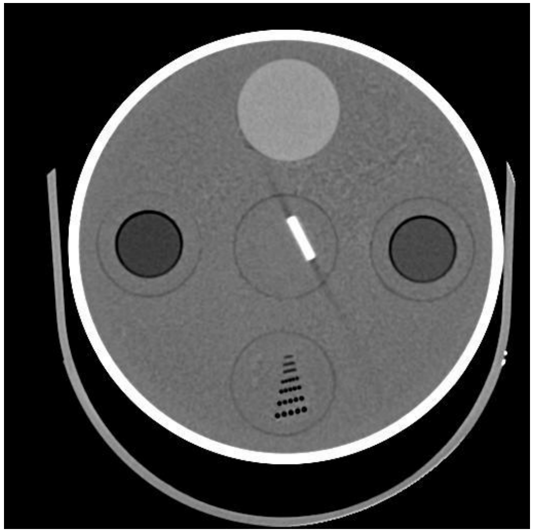


Image slice width

= FWHM × tan (θ)

= 11.4 × tan (30)

= 6.5 mm



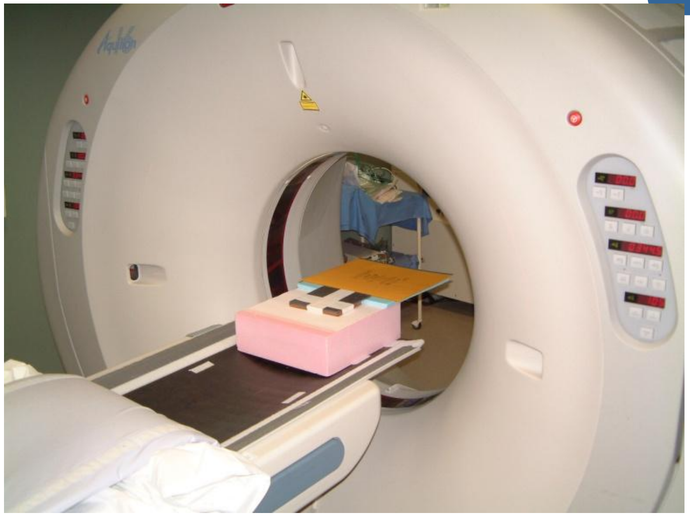
Nominal slice width (mm)	Acceptable
≤1	<nominal + 0.5 mm
>1 and ≤2	±50%
>2	±1 mm

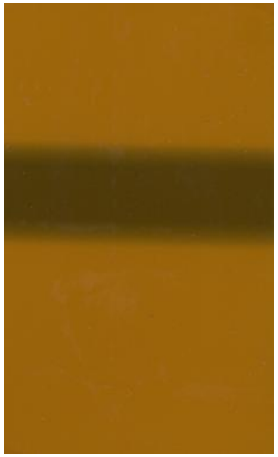
Frequency : Annually

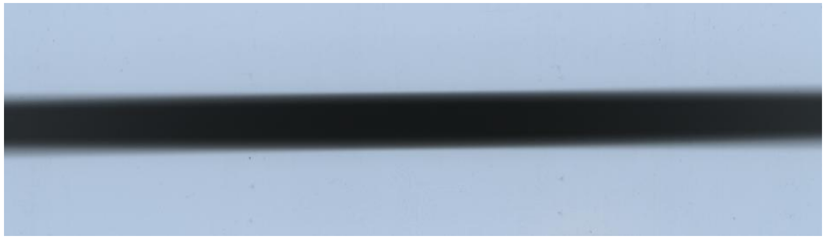
Beam width (NT) accuracy

To determine the collimator settings

To evaluate the extend of the over-beaming





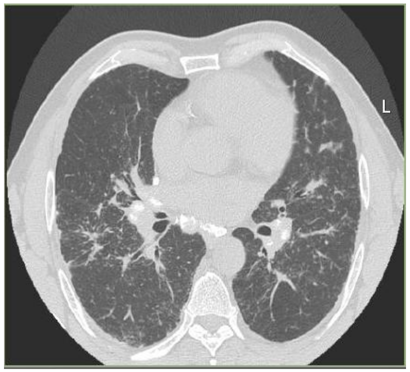


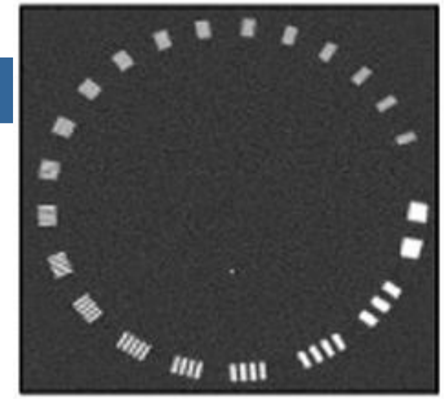
Acceptance limits : according to manufacturer

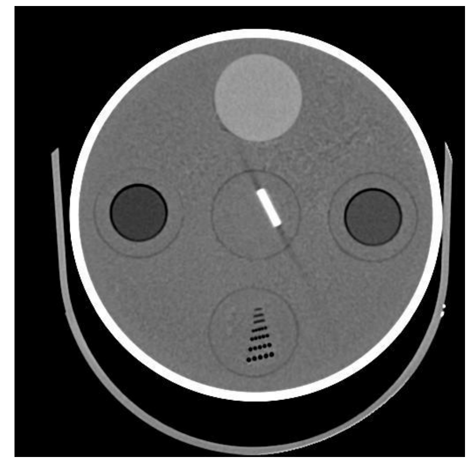
Frequency : Annually

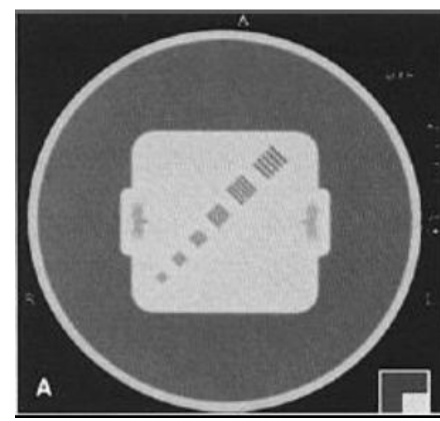
QC : Image quality

Spatial resolution – High contrast









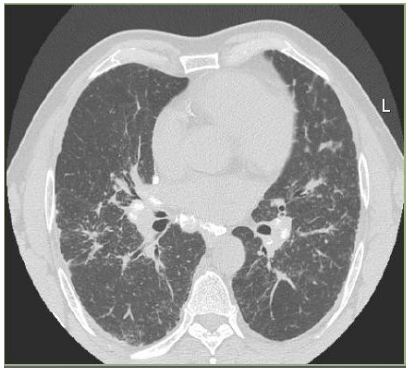
- analysis or visual assessment of images of a resolution bar phantom
-

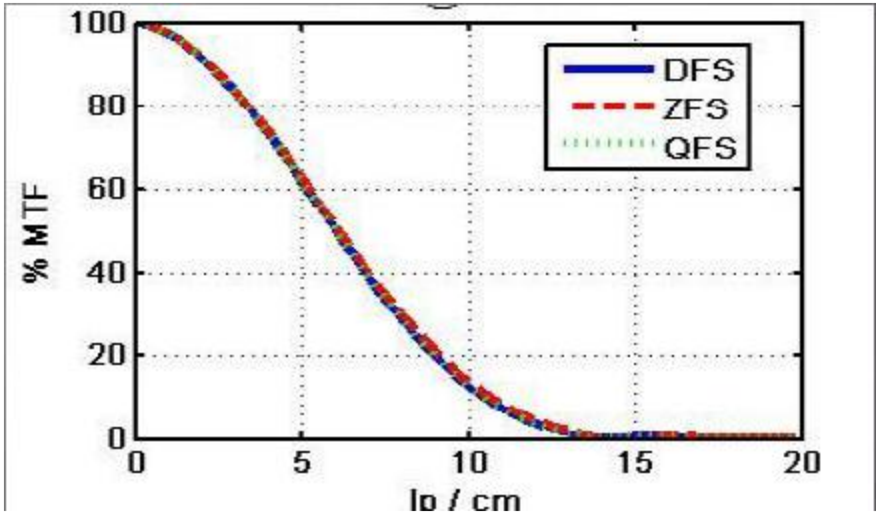
Acceptance limits : according to manufacturer

Frequency : Annually

QC : Image quality

Spatial resolution – High contrast





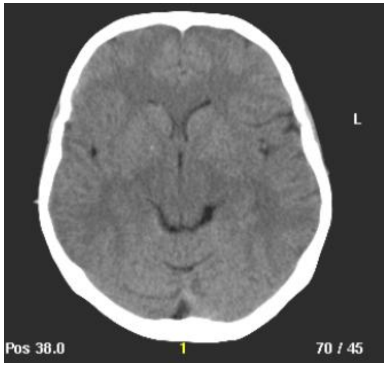
• **Point spread function (PSF), modulation transfer function (MTF).** The resolution is quoted as the spatial frequency (in line pairs/cm) at which the modulation falls to 50%, 10% or 2% MTF

Acceptance limits : according to manufacturer

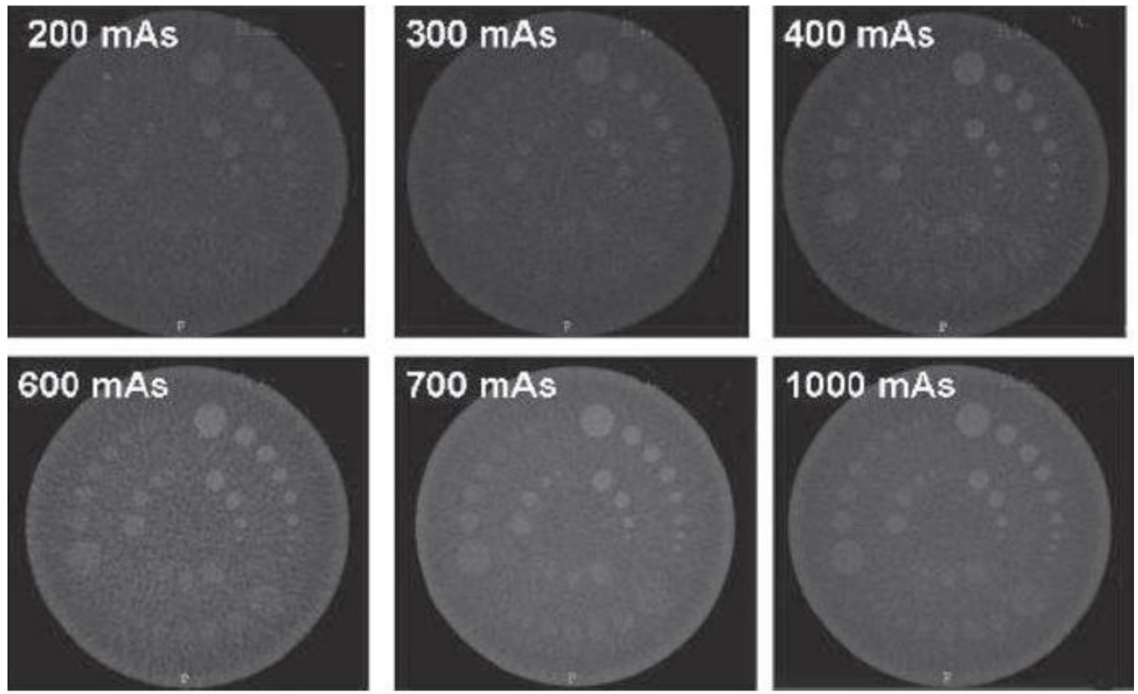
Frequency : Annually

QC : Image quality

Low contrast resolution



soft tissue

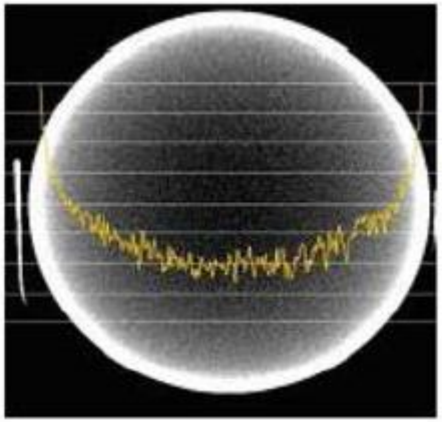


minimum diameter of a visible hole of a given contrast detail e.g. 0.3%.

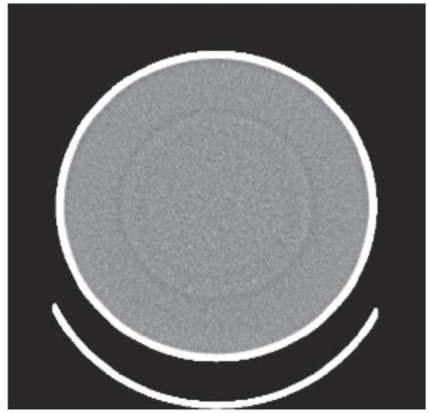
Acceptance limits : according to manufacturer

Frequency : Annually

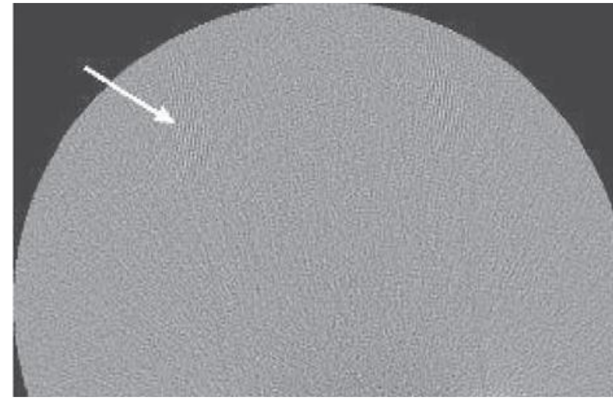
Image artifacts



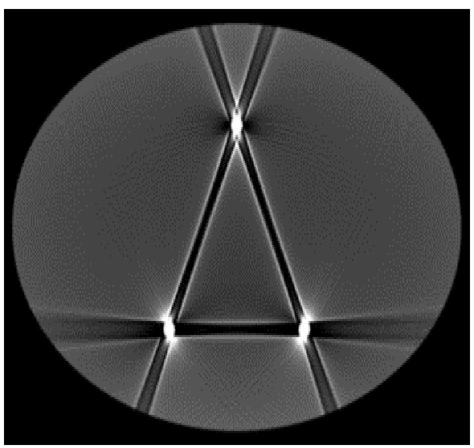
Beam hardening artifacts

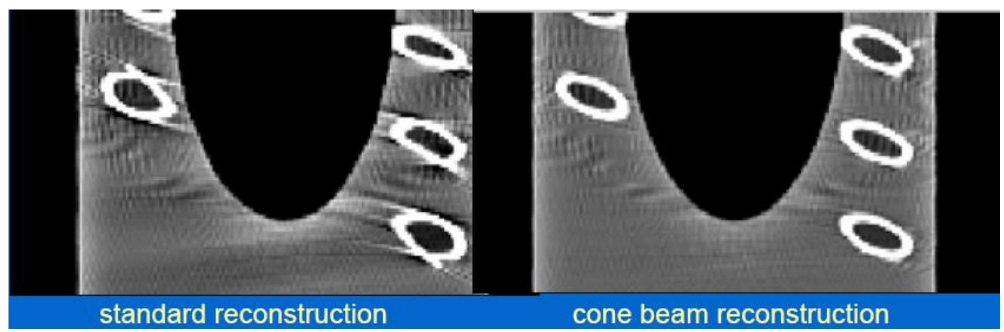


Ring artifacts



Aliasing artifacts





in MDCT

Cone beam artifacts

QC : Dosimetry

Measurement of C_a, C_w, C_{vol}

To determine the baselines (commissioning)

To check the performance of exposure - dosimetry, regularly

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

$$_{n}C_{VOL} = {}_{n}C_{W} \frac{NT}{l}$$

Acceptance limits : ± 20% from manufacturer

Frequency : Annually

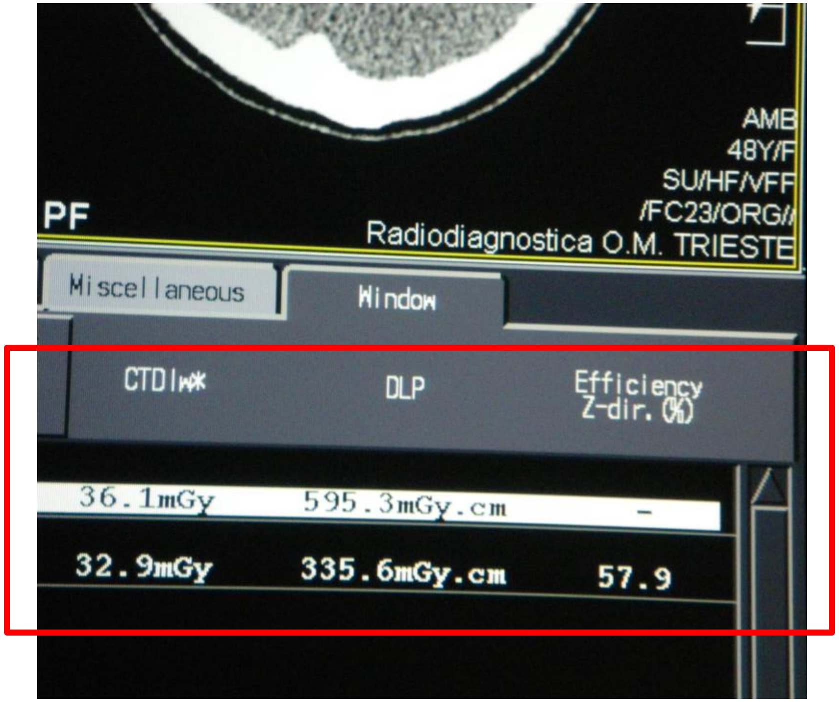
Verification of DICOM data

Scan of phantom or patient

$$ {}_nC_{VOL} = {}_nC_W \frac{NT}{l} $$

$$ P_{KL,CT} = l\ {}_nC_{VOL}\ P_{It\text{-}tot} $$

$$ P_{KL,CT} = l\ {}_nC_w\ P_{It\text{-}eff} $$



$$ P_{It,eff} = P_{It-tot} \cdot \frac{NT}{l} $$

Acceptance limits : ± 20% deviation

Frequency : Annually

QC : Dosimetry

Current modulation - AEC

Scan of phantom

$$ {}_{n}C_{VOL} = {}_{n}C_{W}\,\frac{NT}{l} $$

$$ P_{KL,CT} = l\,{}_{n}C_{VOL}\,P_{It\text{-}tot} $$

$$ P_{KL,CT} = l\,{}_{n}C_{w}\,P_{It\text{-}eff} $$

$$ P_{It,eff} = P_{It-tot}\cdot\frac{NT}{l} $$

Acceptance limits : ± 20% deviation

Frequency : Annually

OPTIMIZATION OF CLINICAL PRACTICE

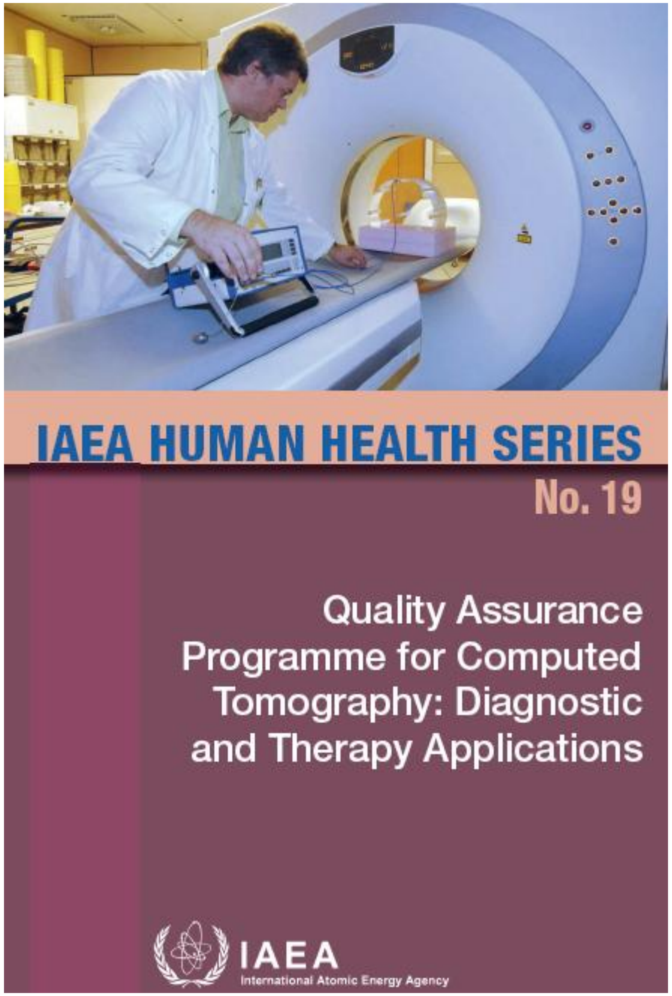


TABLE 2. EFFECT OF SCAN PARAMETERS ON IMAGE QUALITY AND DOSE[a]

Parameter	Noise	Spatial resolution		Dose
		Imaged slice width	Tomographic plane	
Current (mA)	✓			✓
Rotation time[b,c]	✓		✓	✓
Voltage (kV)	✓			✓
Focal spot selection[c,d]	(✓)	✓	✓	(✓)
Nominal imaged slice width	✓	✓		
Pitch	✓	✓		✓
Total X ray beam collimation	(✓)[e]	(✓)[e]		✓
Detector group width	✓	✓		
Scan volume				✓
x–y reconstruction kernel	✓		✓	
z axis interpolation algorithm	✓	✓		

[a] When an individual parameter is varied while all other scan factors are kept constant.
[b] If the sampling frequency is dependent on rotation time, then spatial resolution will be affected.
[c] The focal spot size has a direct impact on spatial resolution, through penumbral effects.
[d] Small amount of change to noise and dose with focal spot size.
[e] Single slice, dual slice.

OPTIMIZATION OF CLINICAL PRACTICE

✓Optimal scanning block size

- Restrict the scanned volume to the minimum necessary
- One large block is better than multiple smaller contiguous blocks to minimize over-ranging (e.g. thorax-abdomen)
- Adjust beam parameters to one body region (e.g. chest)
- Head and body filters

✓Optimal collimation settings : widest beam width (collimation) to reduce over beaming (16x1.5mm instead of 16x0.75mm)

✓ Axial vs spiral techniques (e.g. axial for head)

✓ Use of tube current modulation (AEC)

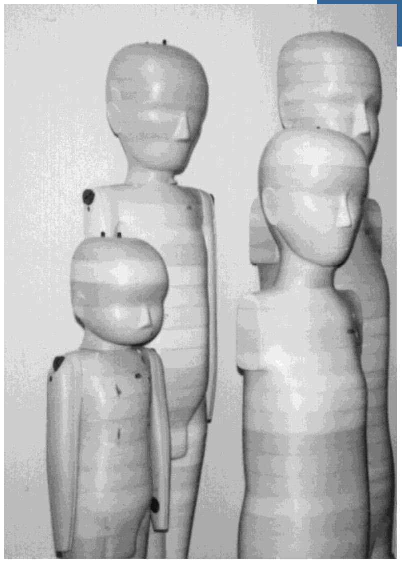
✓ Optimization for children – Special protocols

OPTIMIZATION for CHILDREN

CT protocols for children - mAs reduction factor (RF)

CTs without AEC

Abdomen baseline:	kV	mA	Time (s)	Pitch abdomen	Pitch thorax
	fill in	fill in	fill in	fill in	fill in
		Abdomen		Thorax	
PA thickness (cm)	Approx. age	mAs reduction factor (RF)	Estimated mAs = BL x RF	mAs reduction factor (RF)	Estimated mAs = BL x RF
9	newborn	0.43		0.42	
12	1 yr	0.51		0.49	
14	5 yr	0.59		0.57	
16	10 yr	0.66		0.64	
19	15 yr	0.76		0.73	
22	small adult	0.90		0.82	
25	medium adult	1.00	fill in	0.91	
31	large adult	1.27		1.16	



Head baseline:	kV	mA	Time (s)	Pitch	Filter
	fill in	fill in	fill in	fill in	fill in
		Head			
PA thickness (cm)	Approx. age	mAs reduction factor (RF)	Estimated mAs = BL x RF		
12	newborn	0.74			
16	2 yr	0.86			
17	6 yr	0.93			
19	medium adult	1.00	fill in		

Limitations
- quantum noise
- performance e.g. bow tie filter
- CT models

- Establishment of baseline techniques for an adult head and abdomen CT
- Apply RF
- Establishment of baseline techniques for children CT

costas.hourdakis@eeae.gr

QA – other elements

- ✓ **Human resources**
  - Qualification
  - Responsibilities & duties
  - Continuous training
- ✓ **Radiation Protection**
  - Radiation surveys
  - Personal dosimetry
- ✓ **Patient information**
- ✓ **Servicing & maintenance of equipment**
- ✓ **Recording keeping and log-books**

QA – other elements

✓Recording and reporting of accidents

“Any unintended *event, including operating errors, equipment failures* and other mishaps, the consequences or potential consequences of which are not negligible from the point of view of *protection or safety.” IAEA Glossary*

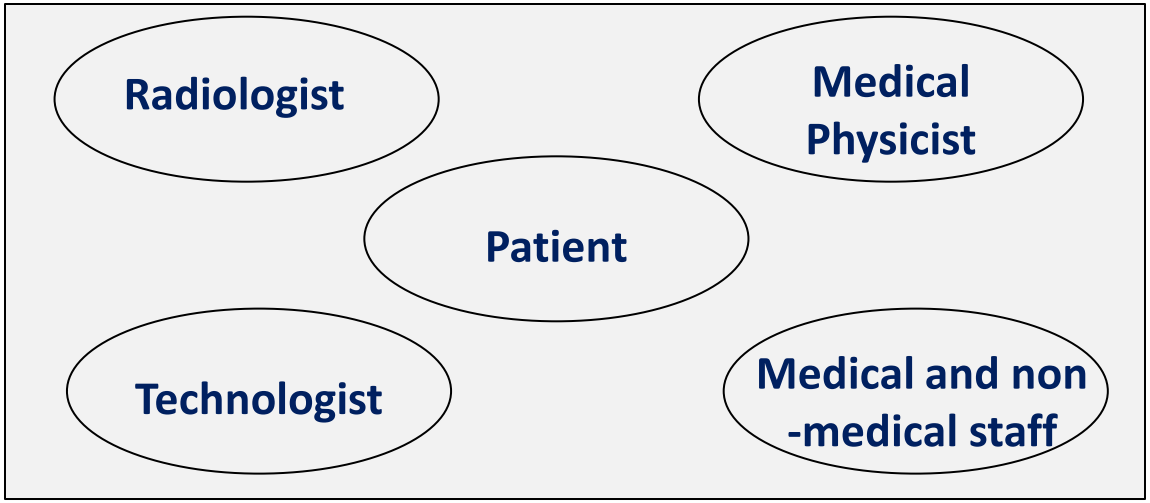
Perfusion studies of the head by MDCT and DSA
Imanishi et al. Eur Radiol. 2005 Jan;15(1):41-6

Lessons learnt

Dissemination of knowledge – experience – lessons learnt

QA – other elements

✓Cooperation of staff



Internal

Management
Technician servise

External

Suppliers
Service Co.
Insurance fund.

- Availability of equipment for QC & measurements
- Examination protocols : Image quality & Dose
- Pediatric examination
- Local DRLs
- Risk assesment

Conclusions

- ✓QA is the most important tool for improving and maintain quality
- ✓Know your scanner...!!! especially MDCT
- ✓ Establishment of examination protocols
- ✓ Children need special attention & personalized procedures
- ✓ Cooperation between staff, management and external bodies

All QA routes lead to QUALITY

I thank you for your attention

costas.hourdakis@eeae.gr