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Dosimetry for CT 2: Multi Slice Technology

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Joint ICTP-IAEA Advanced School on Dosimetry in Diagnostic Radiology: and its Clinical Implementation

11 – 15 May 2009 - Miramare, Trieste, Italy

DOSIMETRY FOR CT :

Multi slice technology

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Ospedali Riuniti di Trieste

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Introduction : C, P ⟺ CTDI, DLP

For a large number of years, Computed Tomography Dose Index (CTDI) has been used. Recent publications point out the experimental difficulty in determining the dose to air, especially in the vicinity of an interface, and that, in reality, **the quantity measured by instruments is air kerma**.

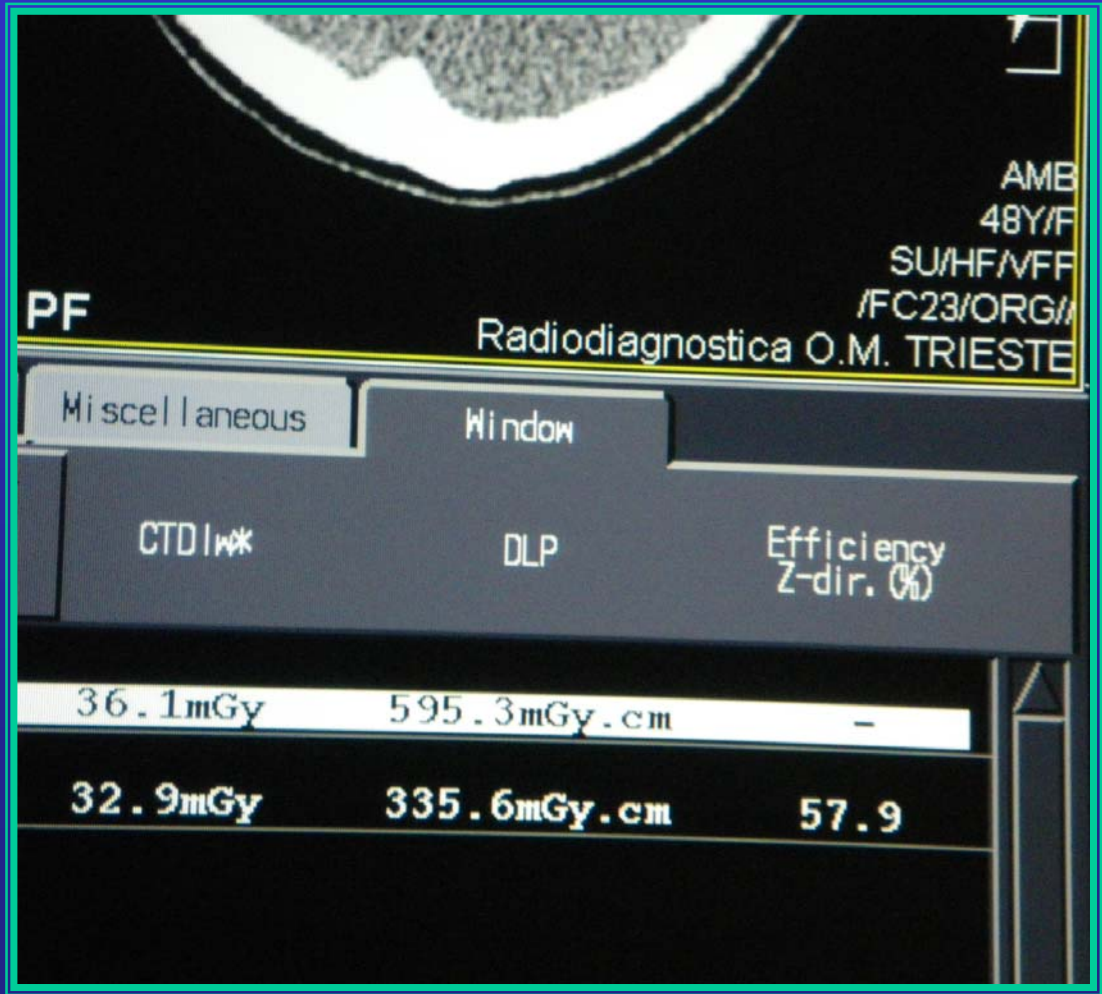
For these reasons recent publications recommend the use of air kerma rather than absorbed dose to air, and consequently,

Computed Tomography Dose Index (CTDI) is to be replaced in future by the Computed Tomography Air Kerma Index (C_a).

However, most publications still use quantities in terms of CTDI.
The use of the new quantity does not change the method to determine organ doses from the conversion coefficients, nor their numerical values.

Dose values displayed on the CT console

CTDI (C) DLP (P) Z-axis Geometric Efficency



Dose in Multislice Scanner

?????? Dose increase or decrease ??????

Decrement ➔ Introduction of dose reduction algorithm
Current modulation techniques

Increment ➔ Geometric parameters
Geometric efficency

Introduction of new clinical applications
Cardio CT, Functional perfusion, Trauma, ..

Dose in Multislice Scanner

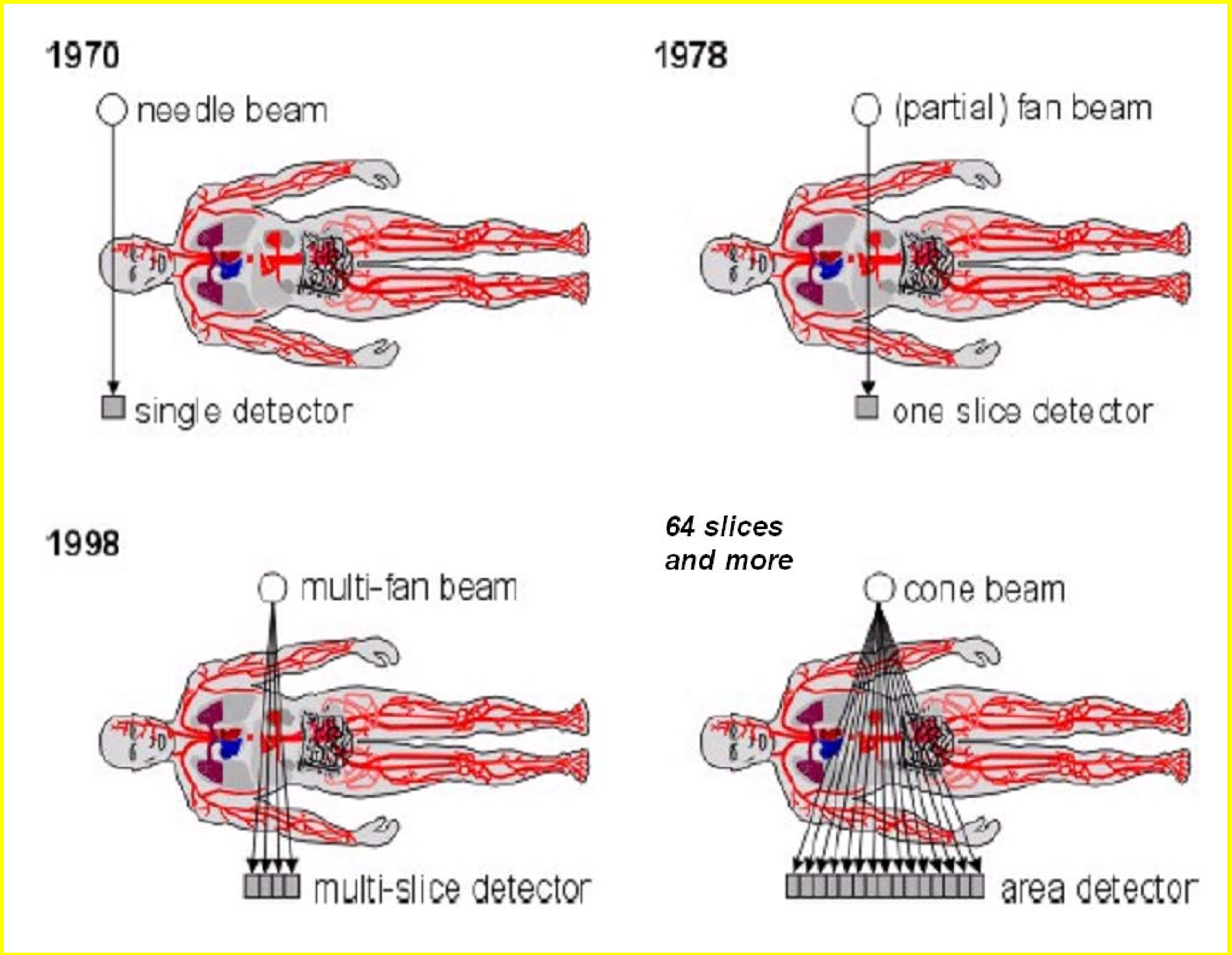
?????? Measurment is still reliable ??????

$CTDI_w$ MEASUREMENT :

The increment of the beam width make
the pencil chamber lenght inadequate

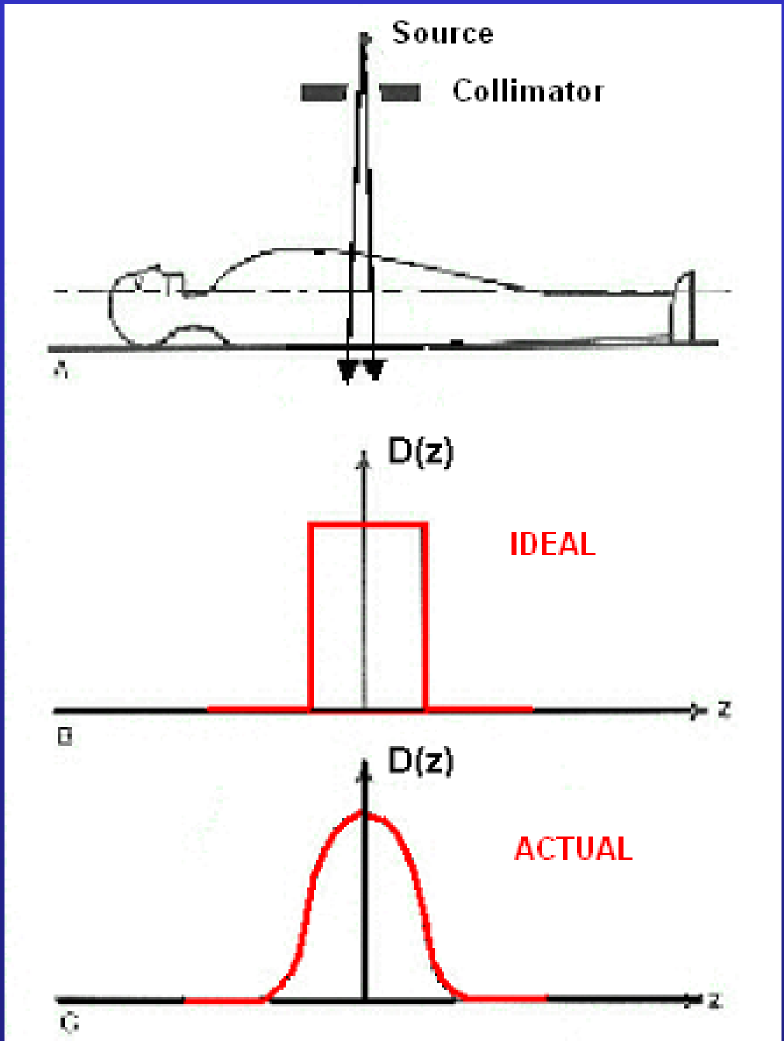
David J. Brenner:
Is it time to retire the CTDI for CT quality assurance and dose optimization?
Medical Physics, Vol. 32, No. 10, October 2005

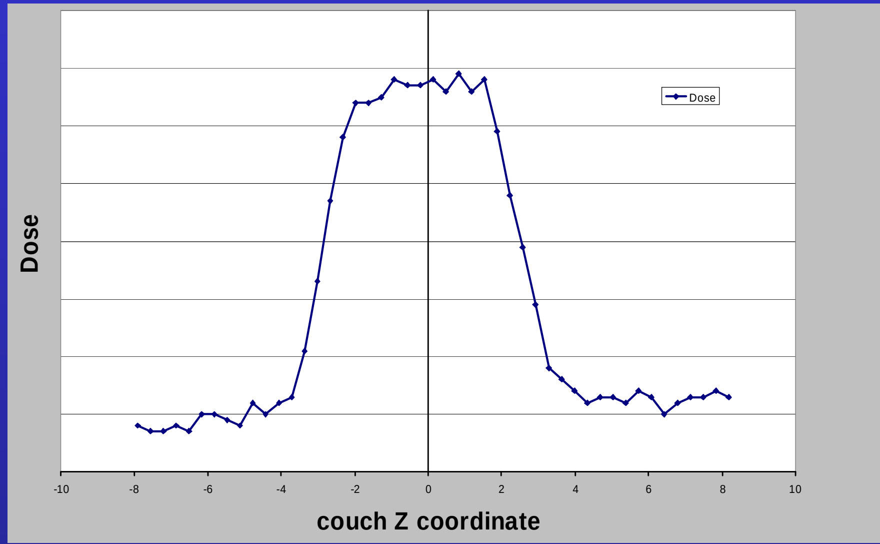
Multi slice technology
Increasingly collimation width



Dose profile

DOSE PROFILE





Measured

Multi slice technology

Geometric parameters affecting the dose

- X ray beam width
- Overbeaming
- Overranging

X ray beam width

Single slice technology → **Slice thichness**

Multi slice technology

- **Reconstructed Slice Thickness**
  do not affect the dose to the patient
- **Acquisition Slice Thickness**
  affect the dose to the patient

Single slice thickness = T

Total number of slices = N

Acquisition Slice Thickness → Total nominal beam width

Nominal beam width = $N \cdot T$

Multi slice technology

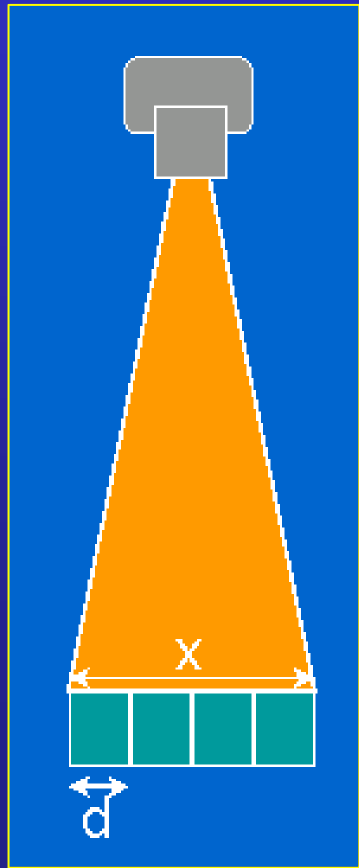
Pitch and volume CTDI

$$\textbf{PITCH} = \frac{\text{Couch movement per rotation}}{\text{Slice thickness}}$$

$$\textbf{PITCH}_{\textbf{d}} = \frac{\text{Couch movement per rotation}}{\text{Slice thickness (d)}}$$

(Helical pitch)

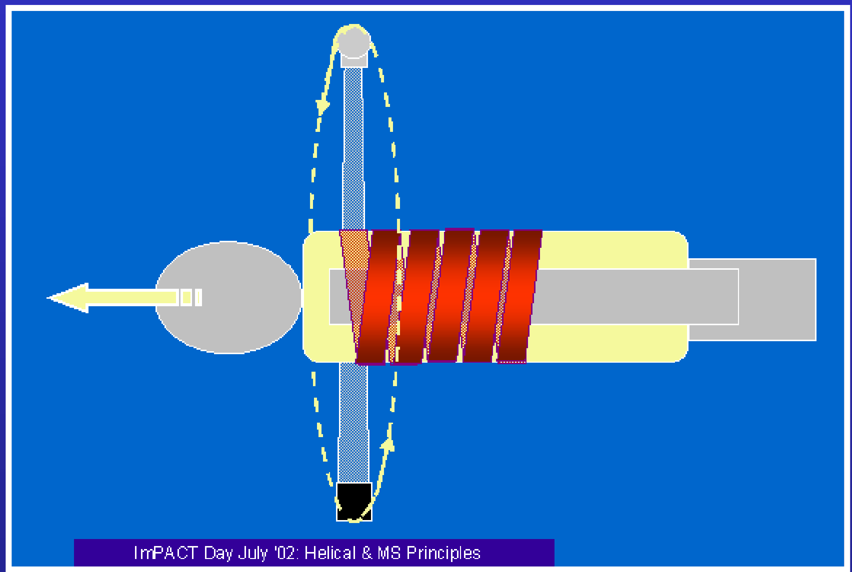
$$\textbf{PITCH}_{\textbf{x}} = \frac{\text{Couch movement per rotation}}{\text{Nominal beam width (x)}}$$

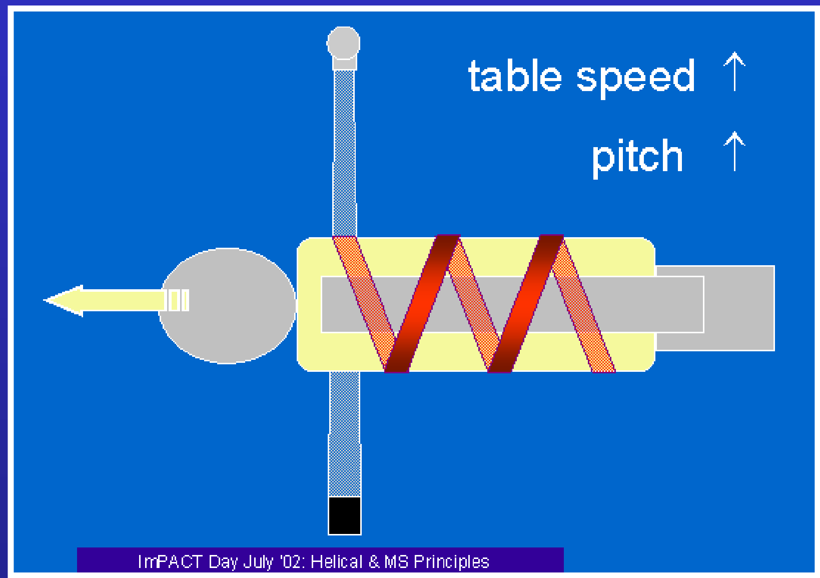


Multi slice technology

Pitch and volume CTDI

Helical (volume) acquisition



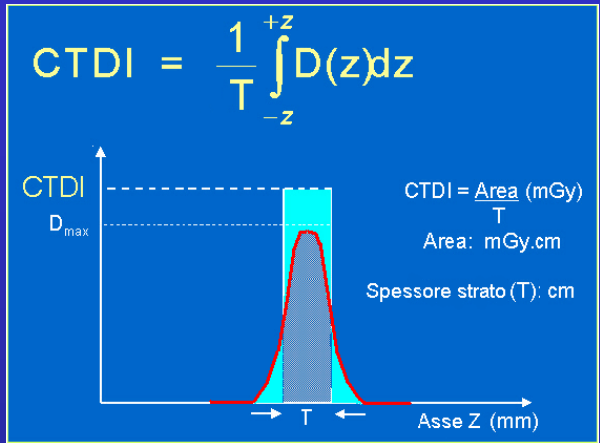


From : www.impactscan.org

Multi slice technology

Pitch and volume CTDI

Single slice scan



Helical scan

⇓

Volume CTDI

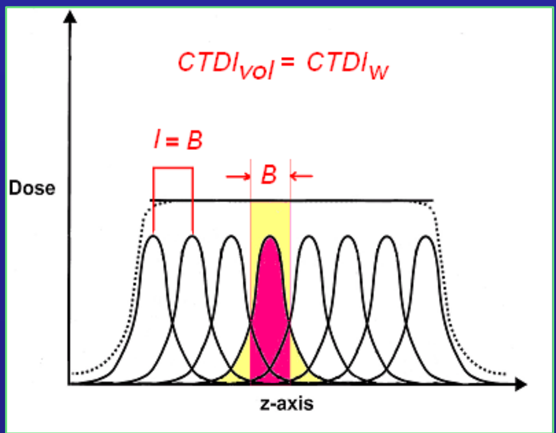
$$CTDI_{vol} = CTDI_w \ / \ Pitch$$

$$CTDI_{vol} = CTDI_w \cdot \frac{N \cdot T}{l}$$

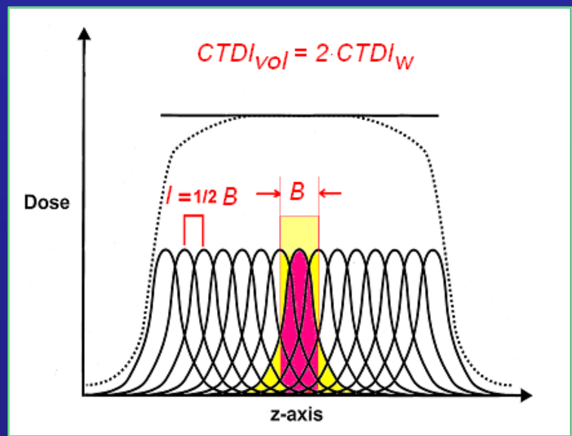
where

l = couch increment per rotation and

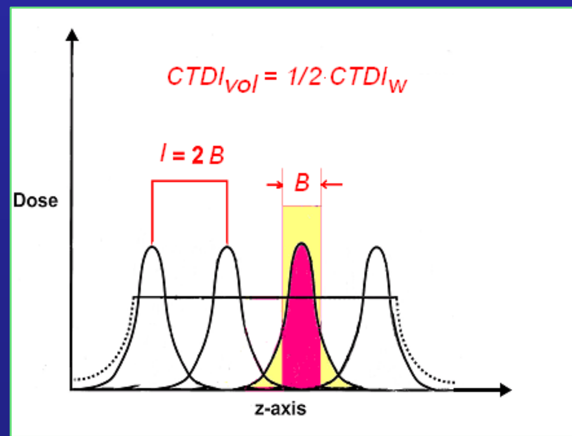
N·T = nominal beam width (B)



Pitch = 1



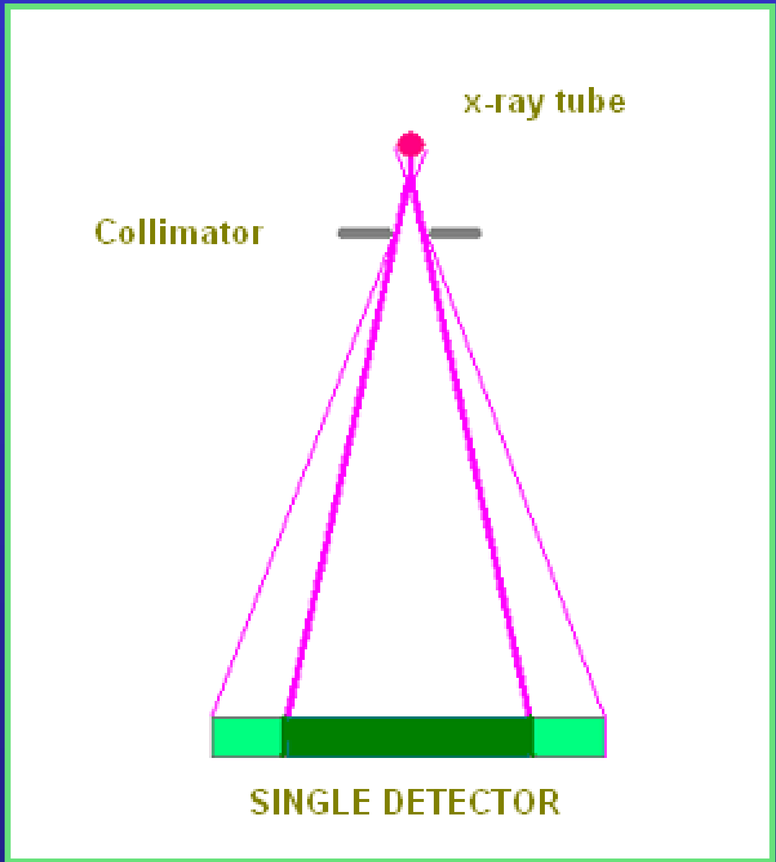
Pitch = 0.5

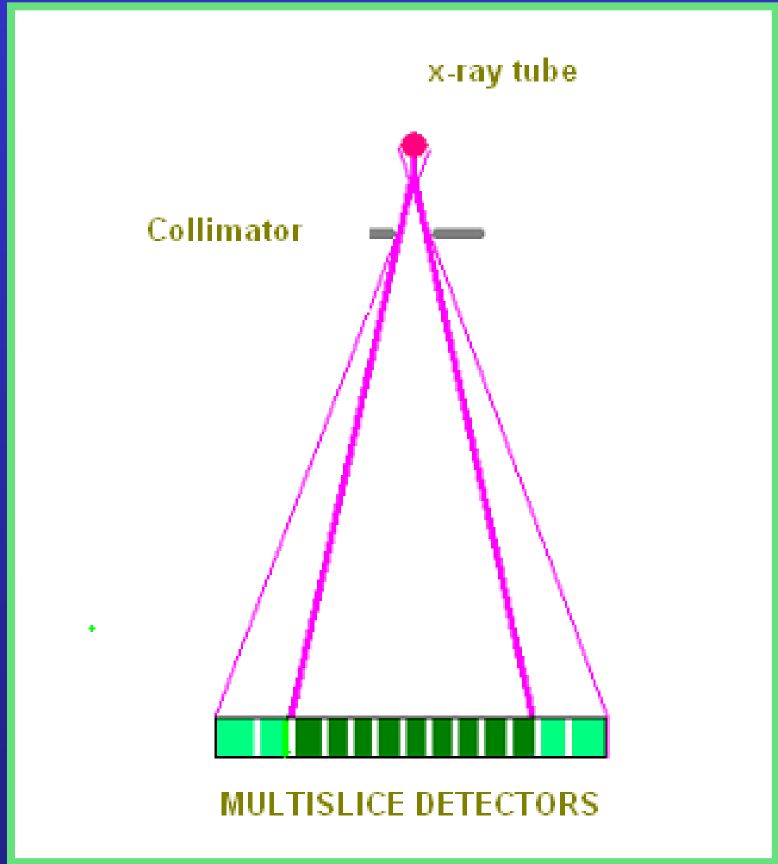


Pitch = 2

Overbeaming

Penumbra effect

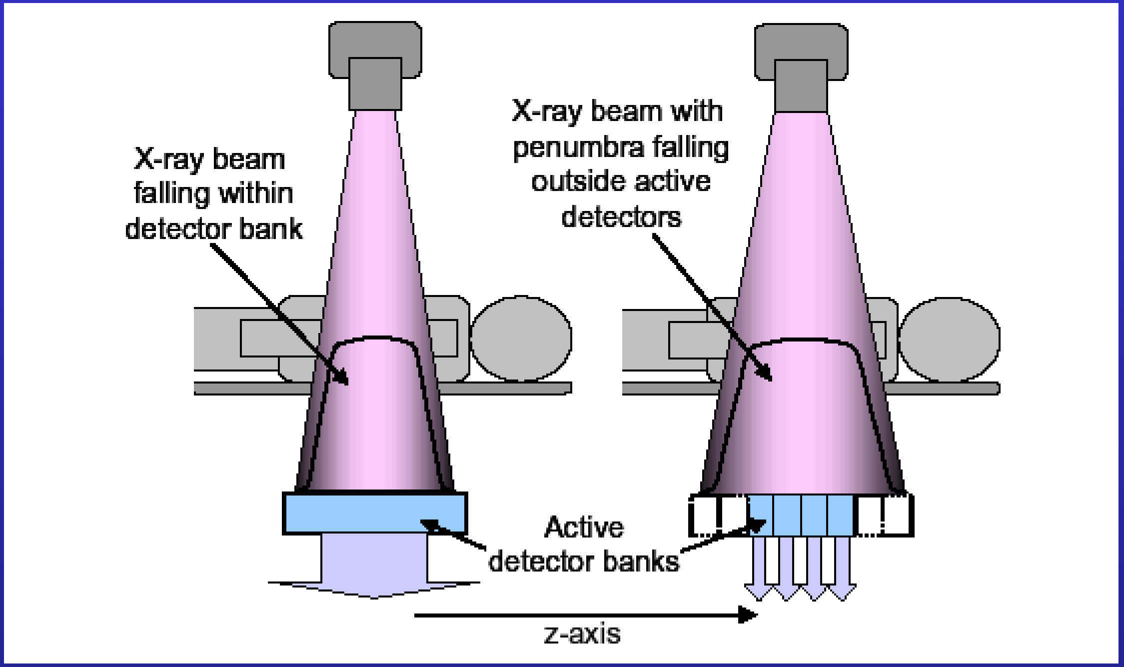




The actual width of X ray beam > nominal width

Z-axis geometric efficiency

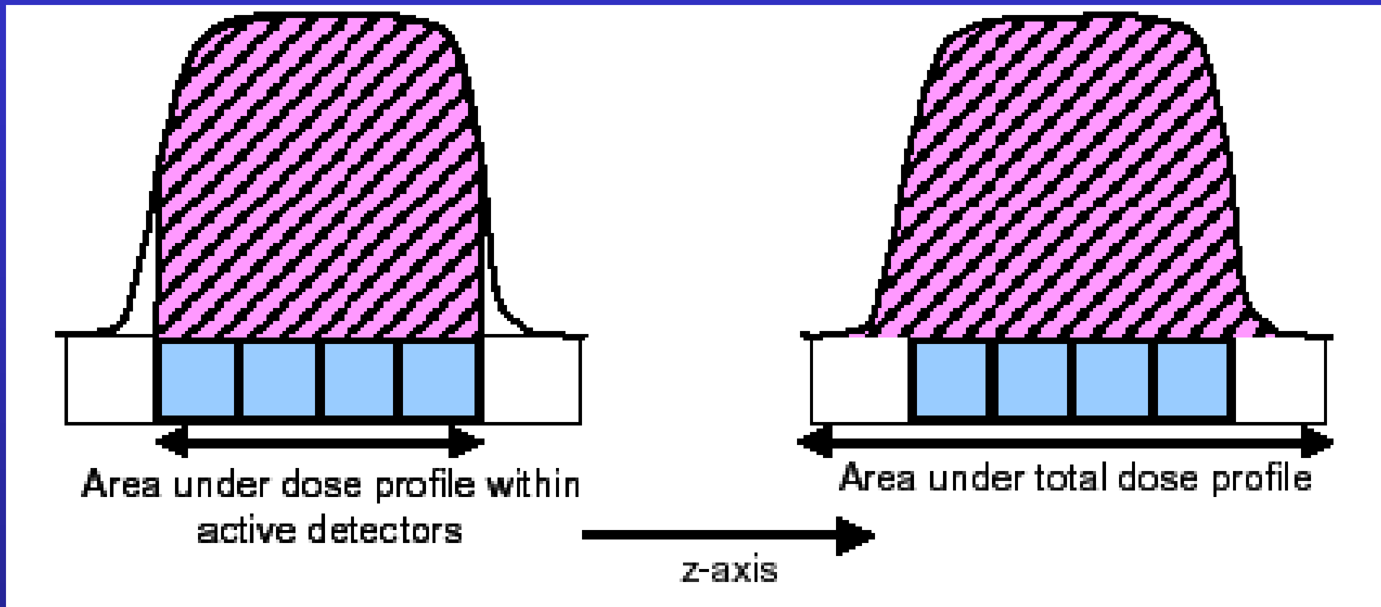
Penumbra effect



In multislice CT, due to penumbra effect, the dose profile must be 2-3 mm larger then the nominal slice thikness

OVERBEAMING

Z-axis geometric efficiency



$$\textbf{Z-axis geometric efficiency} = \frac{\text{Area under dose profile within active detectors}}{\text{Area under total dose profile}}$$

Z-axis geometric efficiency

Definitions for z-axis geometric efficiency (g.eff.)

- IEC 60601- 2- 44 Ed. 1 1999: Original definition
  - "the full width at half maximum of the sensitivity profile expressed as percentage of the full width at half maximum of the dose profile."
- IEC 60601- 2- 44 Ed. 2 Am.1 2003: New definition
  - "the integral of the dose profile along the z-direction, integrated over the range subtended by the detector elements used during acquisition, expressed as a percentage of the total integral of the dose profile in the z-direction"
- g.eff. to be displayed on scan console when less than 70%

Z-axis geometric efficiency - Measurement

Multislice CT Toshiba Aquilion 16

Polistirene support

Material (film) :

Kodak Ready Pack X-OmatV

Gafchromic XRQA

Dose profile

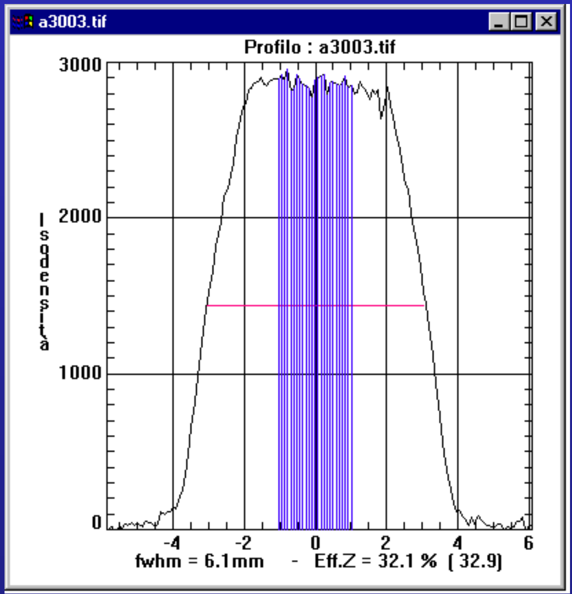
Ready Pack film (whole profile : 30 cm)

Gafchromic film (central area : 3.5x2 cm)

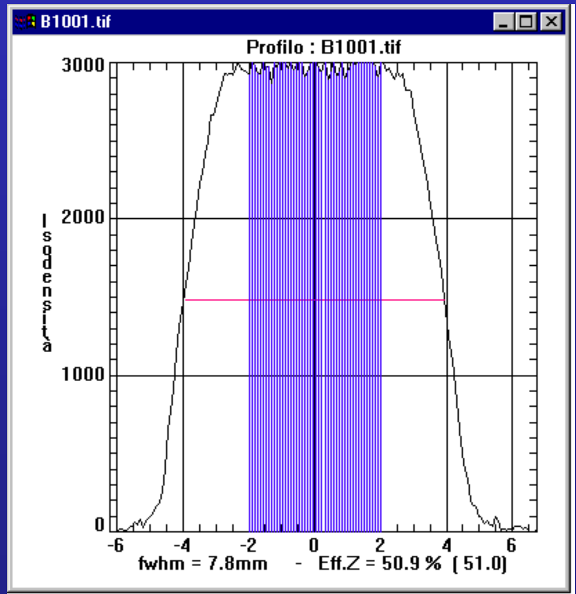
Z-axis geometric efficiency measurement

Overbeaming effect **is more evident for small thikness.**

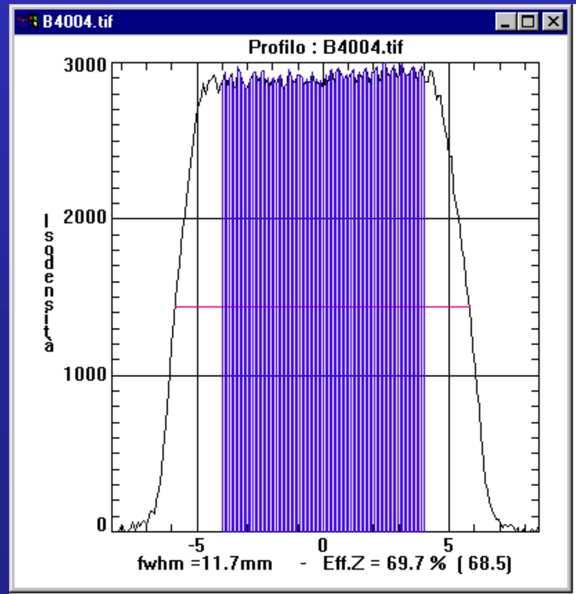
Total thikness 2 mm
Z-Efficiency = 32.1%



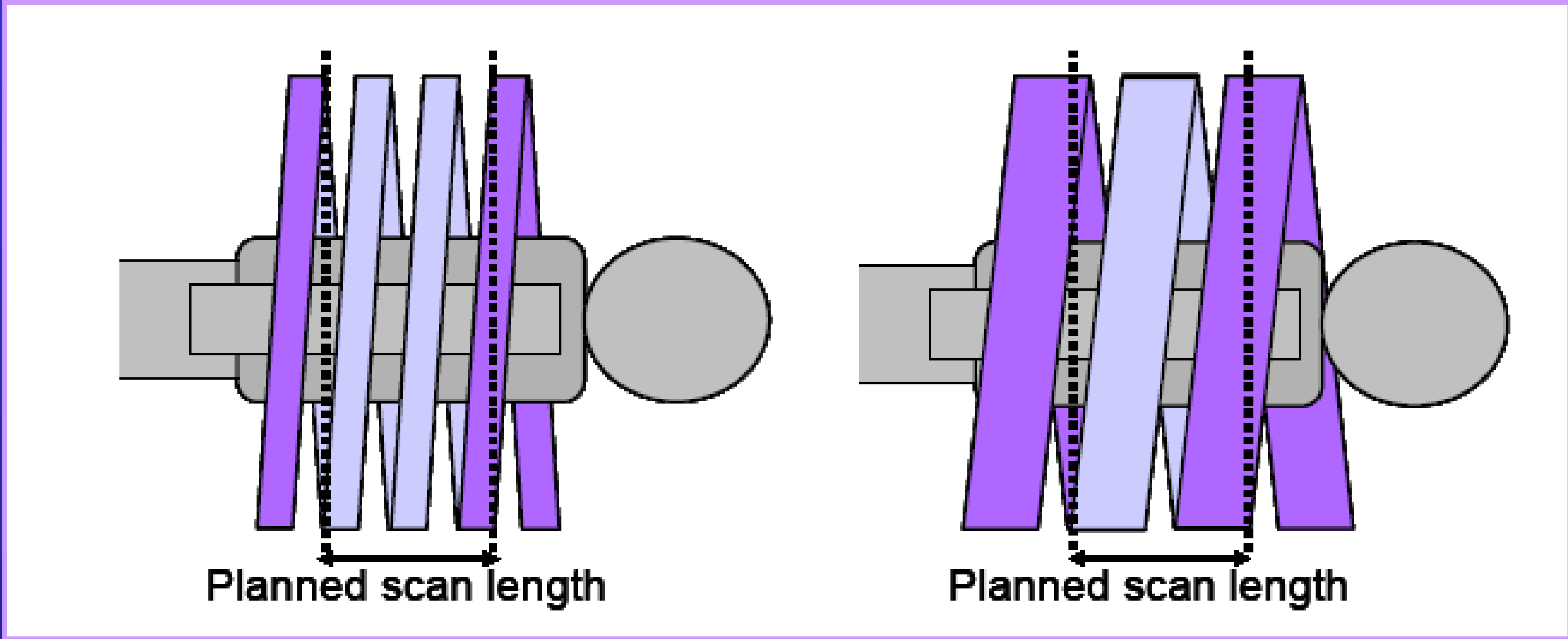
Total thikness 4 mm
Z-Efficiency = 50.9 %



Total thikness 8 mm
Z-Efficiency = 69.7 %



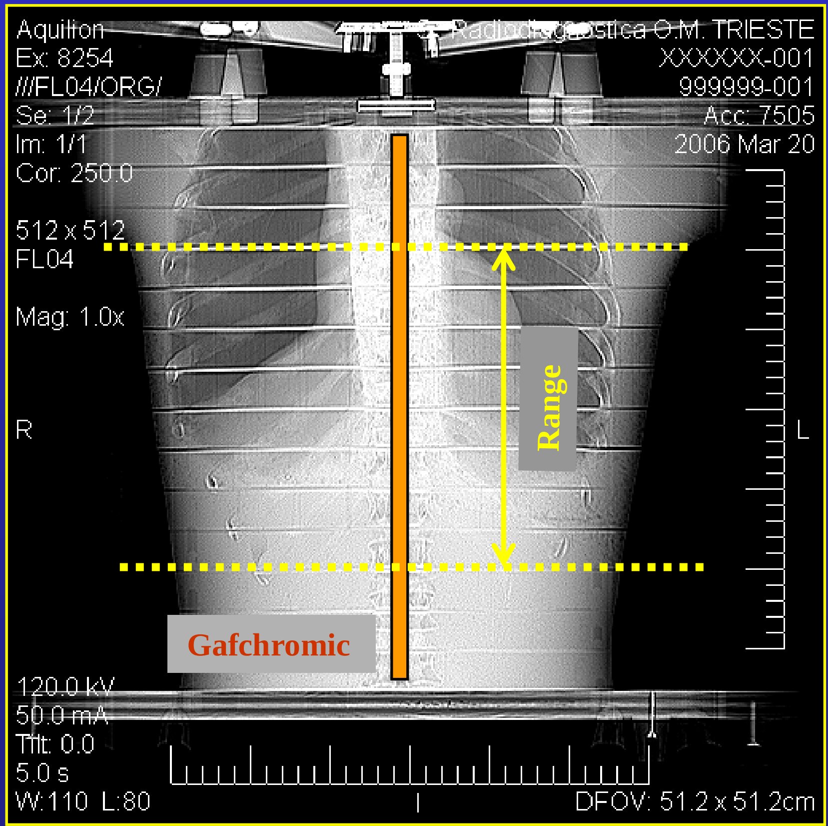
Overranging (*or overscanning*)



Due to image reconstruction algorithms based on interpolation, the actual scan range exceed the nominal range planned by the consolle.

Overbeaming and Overranging

MSCT - 64 slices and 16 slices acquisition

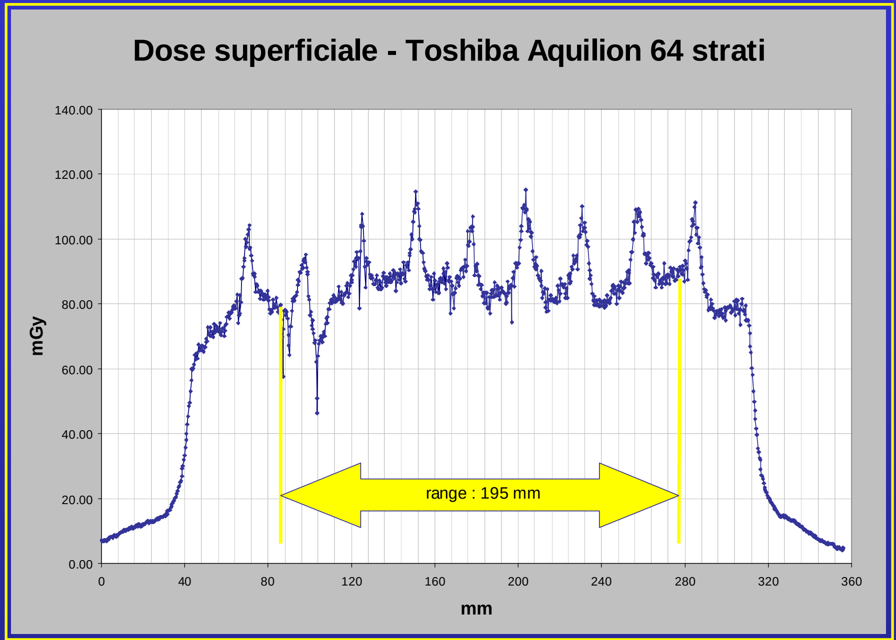


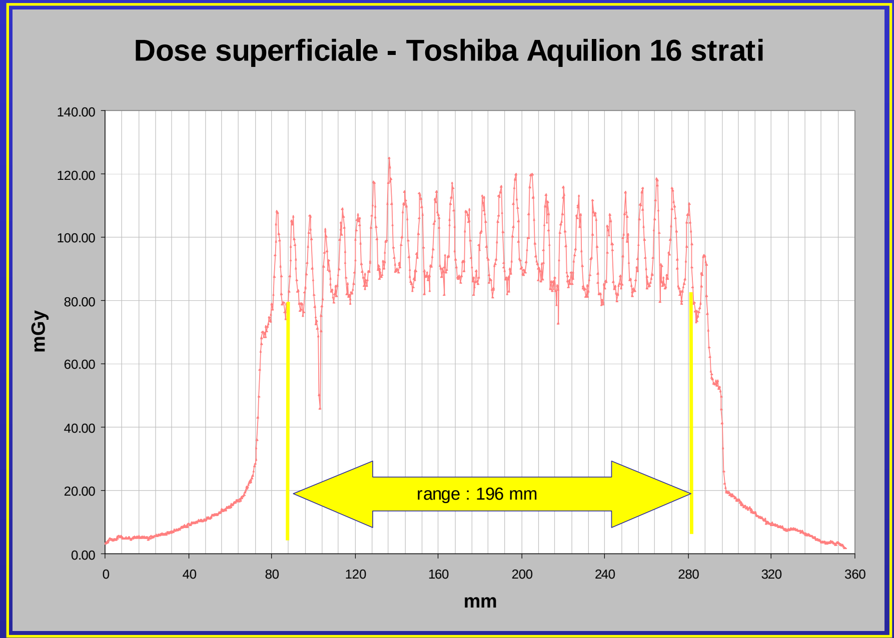
EXPERIMENTAL SET-UP

- Rando Alderson phantom
- Gafchromic strip 36x1 cm
- Same range
- Same mAs
- Different collimation

Overbeaming and Overranging

MSCT - 64 slices and 16 slices acquisition





<u>Setting</u>

Nominal range : 195 mm

Collimation : 0.5x64 mm - Pitch : 0.828

CTDIvol : 65.8 mGy - DLP : 1.66 Gy*cm

<u>Gafchromic measurement</u>

Actual range : 258 mm (+32%)

Mean surface dose : 92.2 mGy

Integral surface dose : 2.44 Gy*cm

<u>Setting</u>

Nominal range : 196 mm

Collimation : 0.5x16 mm - Pitch : 0.938

CTDIvol : 76 mGy - DLP : 1.64 Gy*cm

<u>Gafchromic measurement</u>

Actual range : 217 mm (+11%)

Mean surface dose : 100.0 mGy

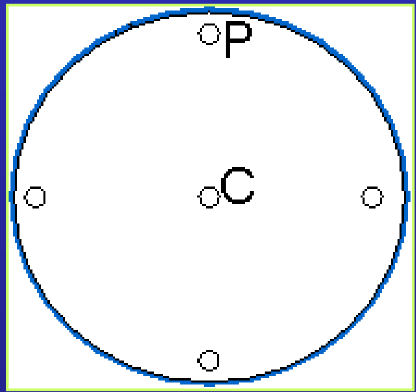
Integral surface dose : 2.18 Gy*cm

CTDI Measurement (*CTDIw*)

Perspex phantom:

Cilinder 16 cm diameter(head) thikness 14 cm
Cilinder 32 cm diameter(body) thikness 14 cm

C = Central position
P = Peripheral position (1 cm from the edge)

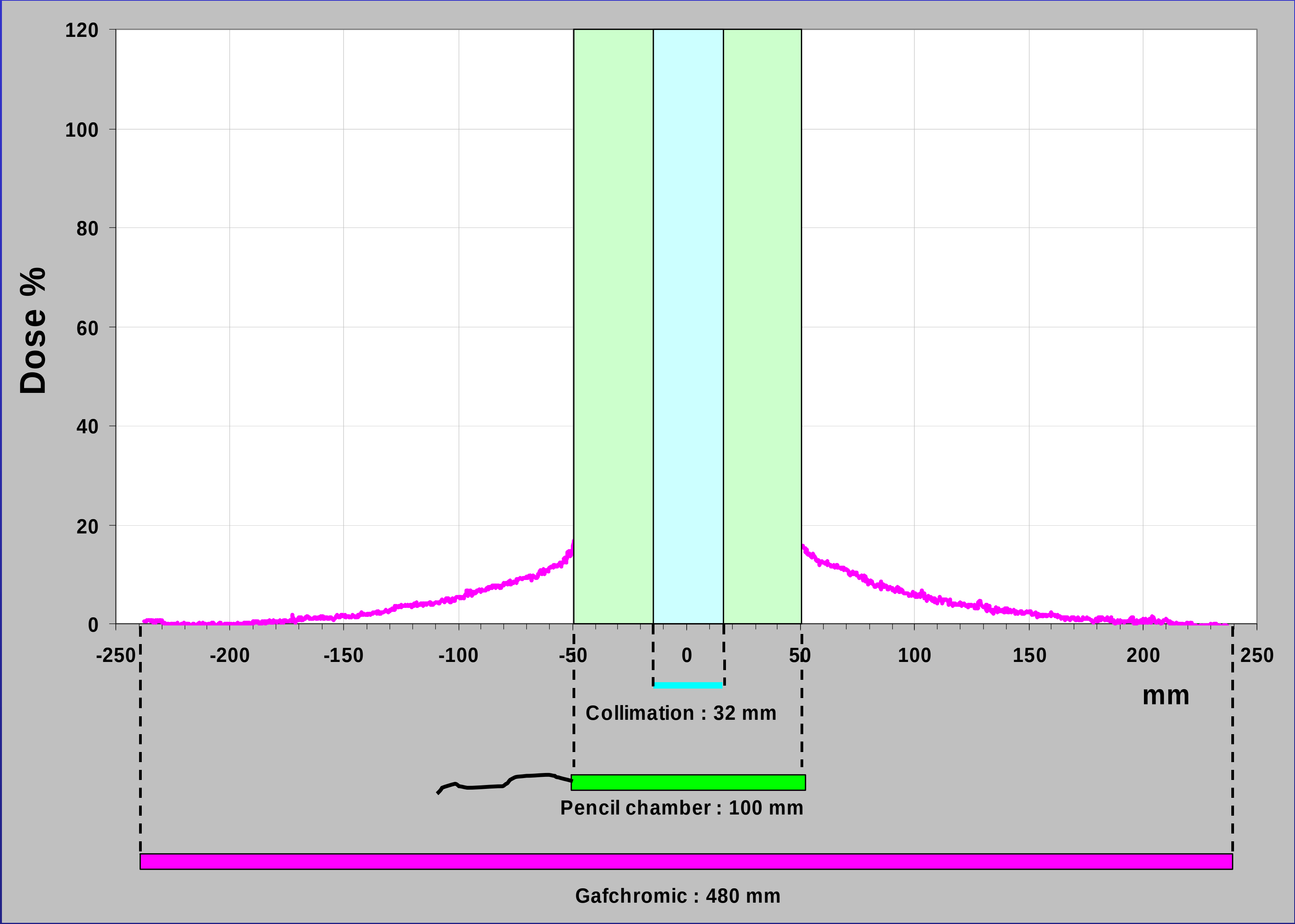


Weighted CTDI (CTDIw)

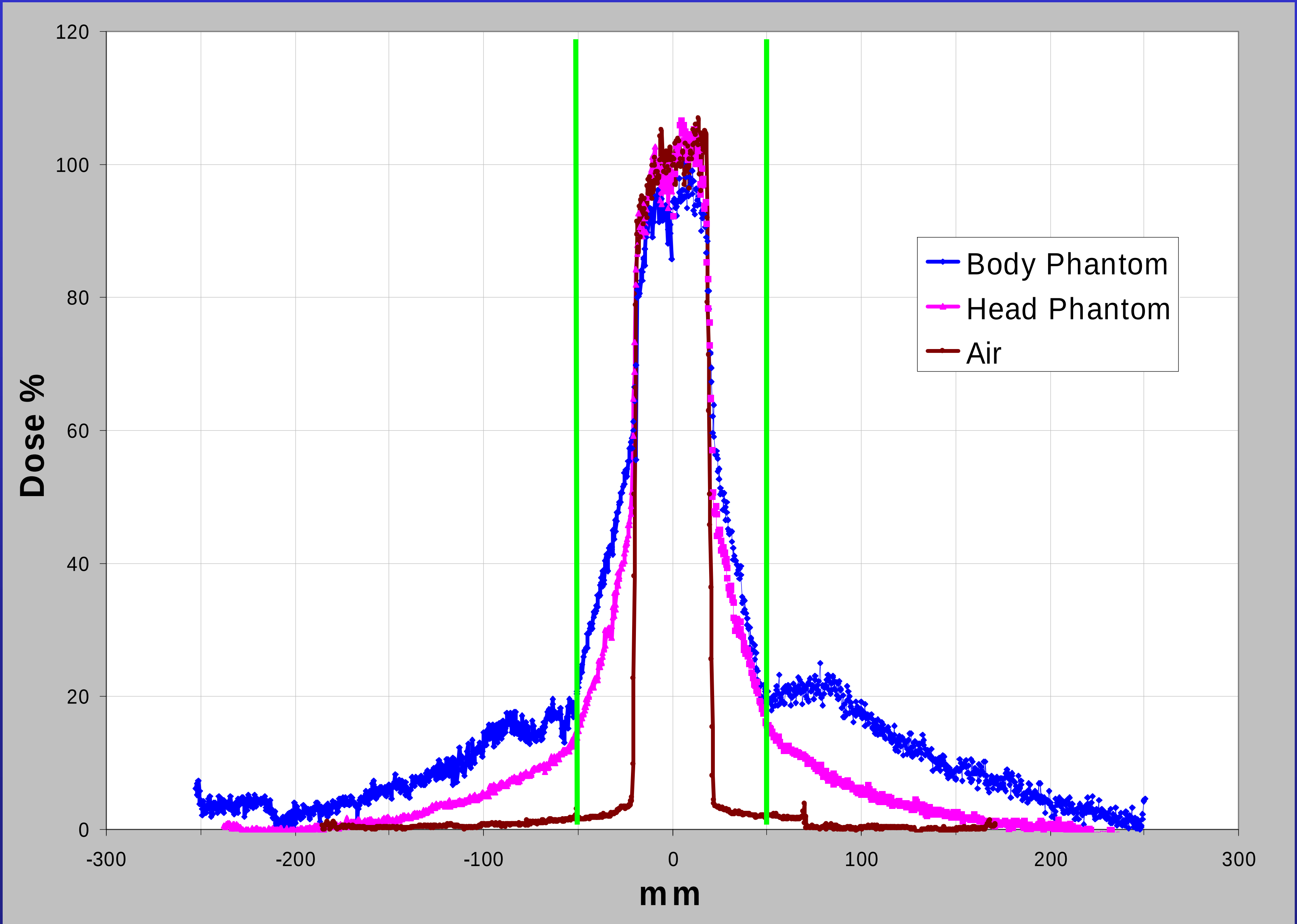
$CTDIw = 1/3\ CTDI_{center} + 2/3\ CTDI_{periphery}$

← Must be displayed in the consolle of the scanner !!

CTDI$_w$ measurement in Multi Slice



CTDI measurement in Multi Slice



Phantom factors $P_{H\ or\ B}$

As a practical alternative, estimates of $CTDI_w$ for the head or body CT dosimetry phantom may be derived from simpler measurements of CTDI made free-in-air ($CTDI_{air}$) under similar conditions of exposure

$$CTDI_w = CTDI_{air} \cdot P_{H\ or\ B} \qquad \textit{(mGy cm)}$$

(H = head, B = body)

where

$$P_H = \frac{({}_nCTDI_w)_H}{{}_nCTDI_{air}}$$

← Head Phantom factor

$$P_B = \frac{({}_nCTDI_w)_B}{{}_nCTDI_{air}}$$

← Body Phantom factor

Phantom factors $P_{H\ or\ B}$

$$P_{H\ or\ B} = {}_{n}CTDI_{w}\ /\ {}_{n}CTDI_{air}$$

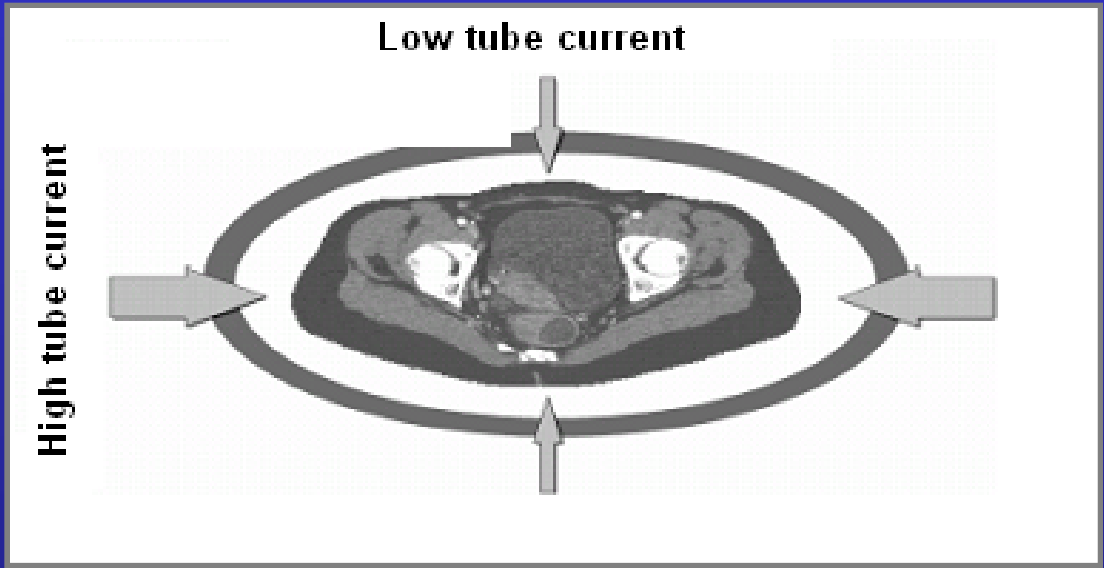
EUROPEAN GUIDELINES ON QUALITY CRITERIA FOR COMPUTED TOMOGRAPHY (EUR 16262 EN) : Chapter 2; APPENDIX I

Manufacturer	Model	${}_{n}CTDI_{air}$ mGy /mAs	PMMA Head phantom (16 cm diameter)		PMMA Body phantom (32 cm diameter)	
			${}_{n}CTDI_{w}$ mGy/mAs	P_H	${}_{n}CTDI_{w}$ mGy/mAs	P_B
Siemens	AR.HP	0.335	0.252	0.75	0.128	0.38
	Hi Q	0.195	0.161	0.83	0.093	0.48
	Plus S	0.128	0.110	0.86	0.062	0.48
		0.161	-	-	0.082	0.51
GE	Pace	0.344	0.200	0.58	0.094	0.27
	Max 640	0.258	0.158	0.61	0.064	0.25
	9800	0.204	0.143	0.70	0.063	0.31
Philips	LX	0.200	0.160	0.80	0.081	0.41
	CX/Q	0.172	0.149	0.87	0.070	0.41
	SR	0.204	0.152	0.75	0.082	0.40

Dose reduction algorithm

Current modulation in *XY* plane *(Angular modulation)*

Patient anatomy is highly asymmetric, so X-rays are much less attenuated in the anteriorposterior direction than in the lateral direction



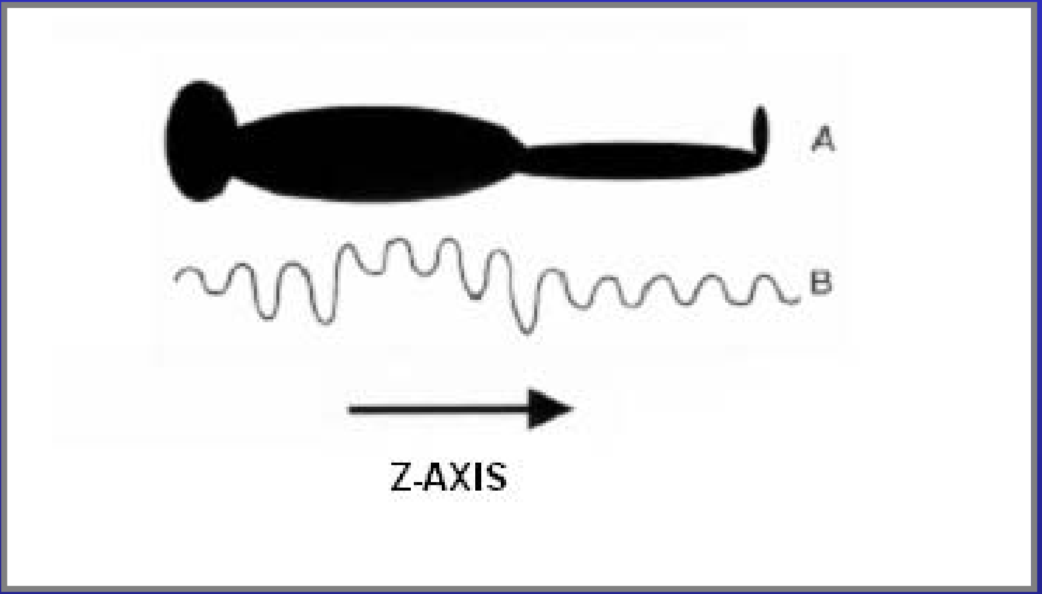
The automatic current modulation require the knowledge of the attenuation characteristic of the patient; it can be obtained in two way:

1. **data from the scanogram to evaluate the lateral dimension of the patient;**
2. **data “online” by using projection data that lag 180° from the x-ray generation angle**

Dose reduction algorithm

Current modulation along Z axis *(z-Axis modulation)*

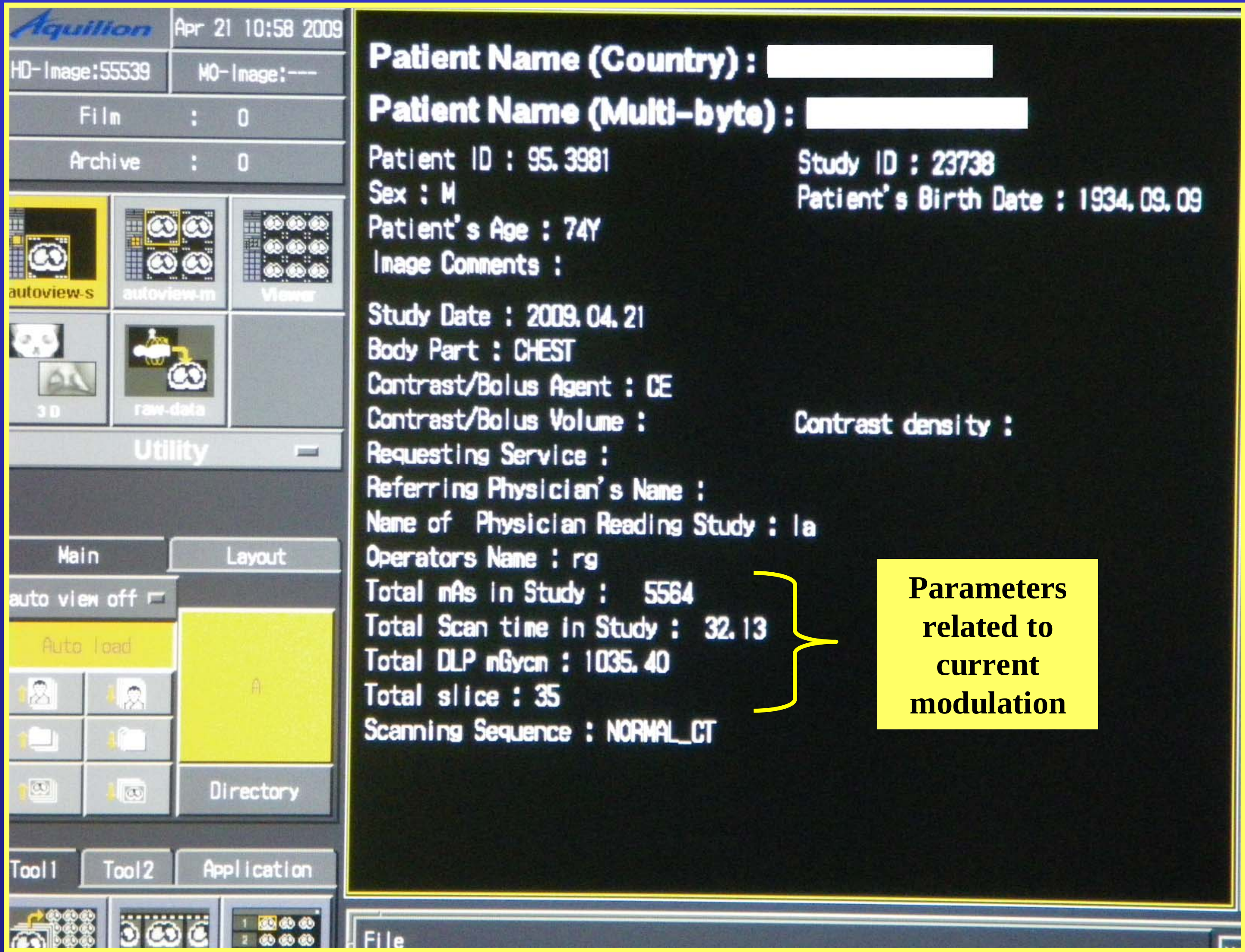
Z-Axis modulation is an attempt to render all images with similar noise, independent of patient size and anatomy



The current is modulated depending on the thikness of the different sections of the patient (es. neck correspond to a very small section compared to abdomen).

The informations for the automatic reduction are available from the scanogram.

Total scan parameters

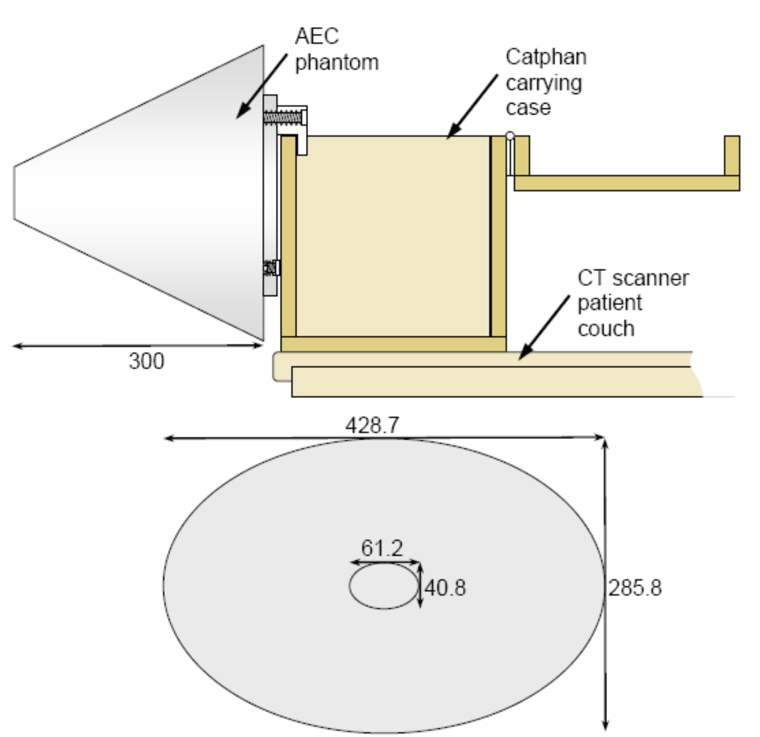


Dose reduction evaluation

From:

<u>“ImPACT Report 05016 : CT scanner automatic xposure control systems “</u>

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



EFFECTIVE DOSE IN COMPUTED TOMOGRAPHY

Dose index		Risk estimate
CTDI, DLP	? ?	EFFECTIVE DOSE

ICRP publication N.103

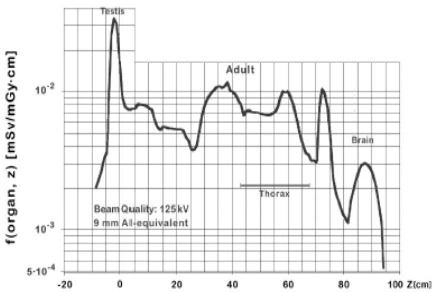
……. The assessment and interpretation of effective dose from medical exposure of patients is very problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure which is the case especially with x-ray diagnostics.

Evaluation of effective dose

Main evaluation methods

Evaluation by conversion factors	Measurement by TLD	Simulation by Montecarlo code

Evaluation by conversion factors



Coeff. di conversione DLP-dose efficace

Regione	Dose efficace normalizzata E_{dlp} (mSv mGy^{-1} cm^{-1})
Testa	0.0023
Collo	0.0054
Torace	0.017
Addome	0.015
Pelvi	0.019

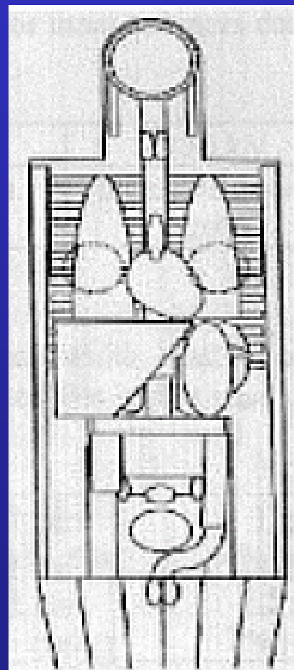
Coefficienti DLP dose efficace.

Conversion factor tables

Measurement by TLD

Antropomorphic phantom Rando Alderson

Simulation by Montecarlo code

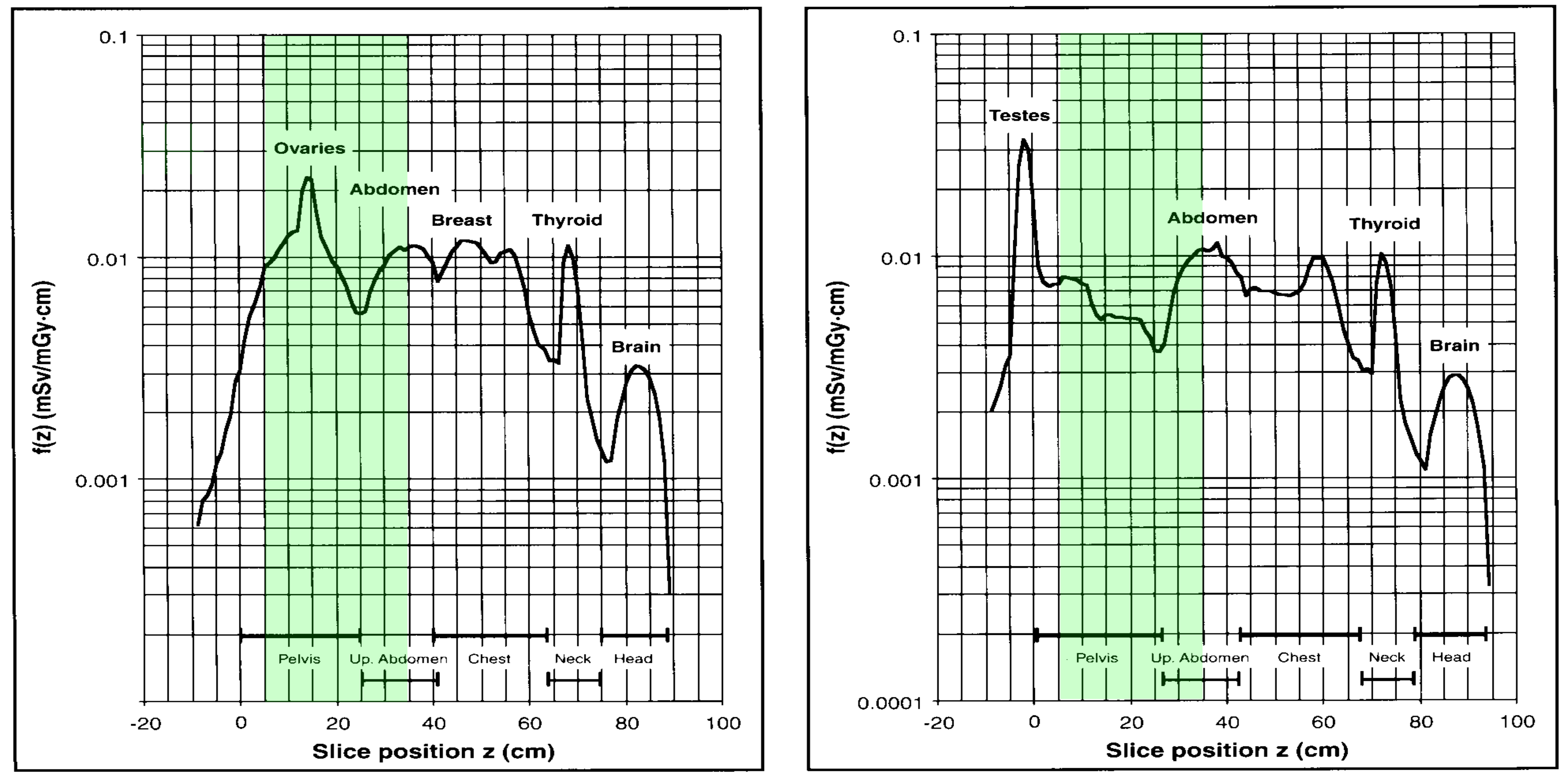


Mathematics phantom (Adam)

Evaluation of effective dose in CT based on published conversion factors

$$F = 1/p \cdot \sum_{z-}^{z+} f(z)$$

Z-, Z+ = scan limits
p = pitch



Da: Hidajat N, Schröder RJ, Vogel T e Coll : Dosisreduktion beim Patienten in der Computertomographie Fortschr Röntgenstr 165: 462-466, 1996.

Evaluation of effective dose in CT based on published conversion factors

$$E = DLP_{air} \cdot f_{mean} \cdot k_{CT}$$

E = Effective Dose

DLP_{air} = Dose Lengh Product in aria

k_{CT} = Scanner factor (**da: NRPB-R249, 1991** *)*

Mean values f_{mean} for the conversion factor (in mSv/mGy·cm)

(Da: Hidajat N, Schröder RJ, Vogel T e Coll : Dosisreduktion beim Patienten in der Computertomographie Fortschr Röntgenstr 165: 462-466, 1996.)

Body region	Adults	
	(female)	(male)
Head	0.0022	0.0020
Neck	0.0051	0.0047
Chest	0.0090	0.0068
Upper abdomen	0.010	0.0091
Pelvis (*)	0.011	0.0062
Entire abdomen (*)	0.010	0.0072

(*) without direct irradiation of gonads of male patients

Measurement by TLD

Thermoluminescence detectors LiF (TLD 100) size 1x1x6 mm

- *Intestine*
- *Kidney*
- *Pancreas*
- *Uterus*
- *Pelvis*
- *Skin*
- *Bladder*
- *Ovaries*
- *Testes*

Evaluation of effective dose in CT based on Montecarlo code

Program CT Dose

Developed by: ***National Institute of Radiation Hygiene - Denmark***

Download dal sito : www.mta.au.dk

Input

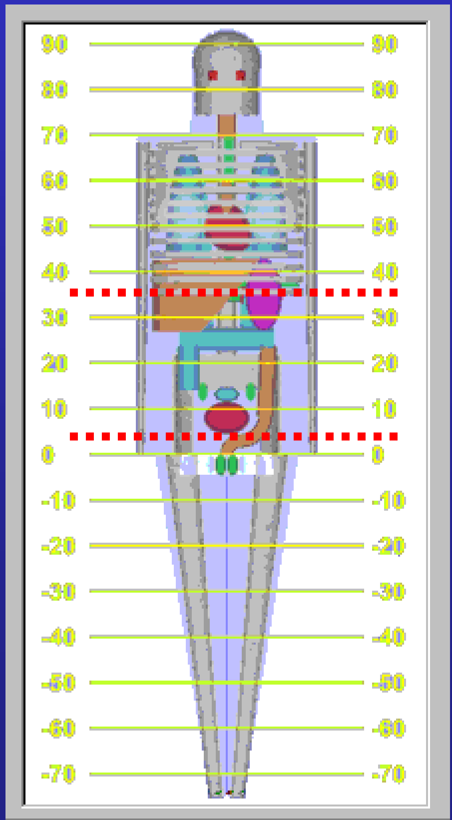
• Scanner model (*database*)

• Acquisition parameters

(*Kv, mA, sec, pitch*, ….)

• Scan range (*interactive*)

• CTDI in air



From: National Institute of Radiation Hygiene - Denmark

Examination Coliche **Mode:** Slice scanning

using scanner: Philips **Model:** Tomoscan 1998

Monte Carlo Dose Data derived from: Philips Tomoscan AV

Scan plans:

Comment: COLICHE 3 IN 5

kV:120 **mAs:**250,00 **Slices:**60 **CTDI (mGy/mAs):** 0,1678

Slice Width (mm):3,0 **Table feed per slice(mm):** 5,0 **nCTDIw (Head) (µGy/mAs):** 127,7 +/- 1,9 %

Scan Start (cm): 35,0 **Scan End (cm):** 5,2 **nCTDIw (Body) (µGy/mAs):** 67,1 +/- 1,9 %

Prime Organs	Equivalent Dose	Error
Lungs	0,28 mGy	3%
Stomach Wall	6,8 mGy	2%
Urinary Bladder Wall	11 mGy	2%
Breasts	0,10 mGy	6%
Liver	4,8 mGy	2%
Esophagus	0,14 mGy	10%
Thyroid	2,6 µGy	10%
Skin	2,7 mGy	1%
Bone Surface	4,5 mGy	2%
Red bone marrow	4,0 mGy	2%
Testes (Gonads)	0,95 mGy	4%
Ovaries (Gonads)	11 mGy	2%
LLI Wall (Colon)	8,9 mGy	2%

Other Organs	Equivalent Dose	Error
Pelvis	26 mGy	2%
Spine	6,2 mGy	2%
Skull Cranium	0 mGy	0%
Skull Facial	1,9 µGy	50%
Rib Cage	1,5 mGy	2%
Clavicles	23 µGy	40%
Eye Lenses	0 mGy	0%
Gall Bladder Wall	10 mGy	2%
Heart	0,30 mGy	5%

Remainder Organs	Equivalent Dose	Error
Muscle	3,7 mGy	1%
Adrenals	1,5 mGy	7%
Brain	0 mGy	0%
Small Intestine	12 mGy	2%
ULI Wall	12 mGy	2%
Kidneys	11 mGy	2%
Pancreas	3,4 mGy	3%
Spleen	4,6 mGy	2%
Thymus	92 µGy	30%
Uterus	11 mGy	2%

Marrow Doses	Equivalent Dose	Error
Pelvis	9,6 mGy	2%
Spine	2,3 mGy	2%
Skull Cranium+Facial	0,17 µGy	50%
Rib cage	0,48 mGy	2%
Clavicles	6,5 µGy	40%
Scapulae	33 µGy	10%
Upper Part of Legs	0,36 mGy	2%
Upper Part of Arms	21 µGy	10%

DLP (head phantom) 0,57 Gy cm +/- 2%

Effective Dose (ICRP 60) 4,9 mSv +/- 2%

DLP (body phantom) 0,30 Gy cm +/- 2%

Thank you for your attention.