Radiation Safety Training Module: Diagnostic Radiology

Quality Assurance Tests for Computed Tomography Equipment

Radiological Safety Division
Atomic Energy Regulatory Board

Content

Expected questions to know after studying this lecture

- What are the parameters to be checked in the QA of CT scan equipment?
- How to calculate workload of CT equipment and what is the typical value of workload to be used for RPS measurements?
- What is the allowed leakage from the x-ray tube of CT equipment?
- Which QA test is carried out for comparing the doses received from different CT (Type/Model/Make) equipment

Computed Tomography

- Shared nobel prize in medicine in 1979

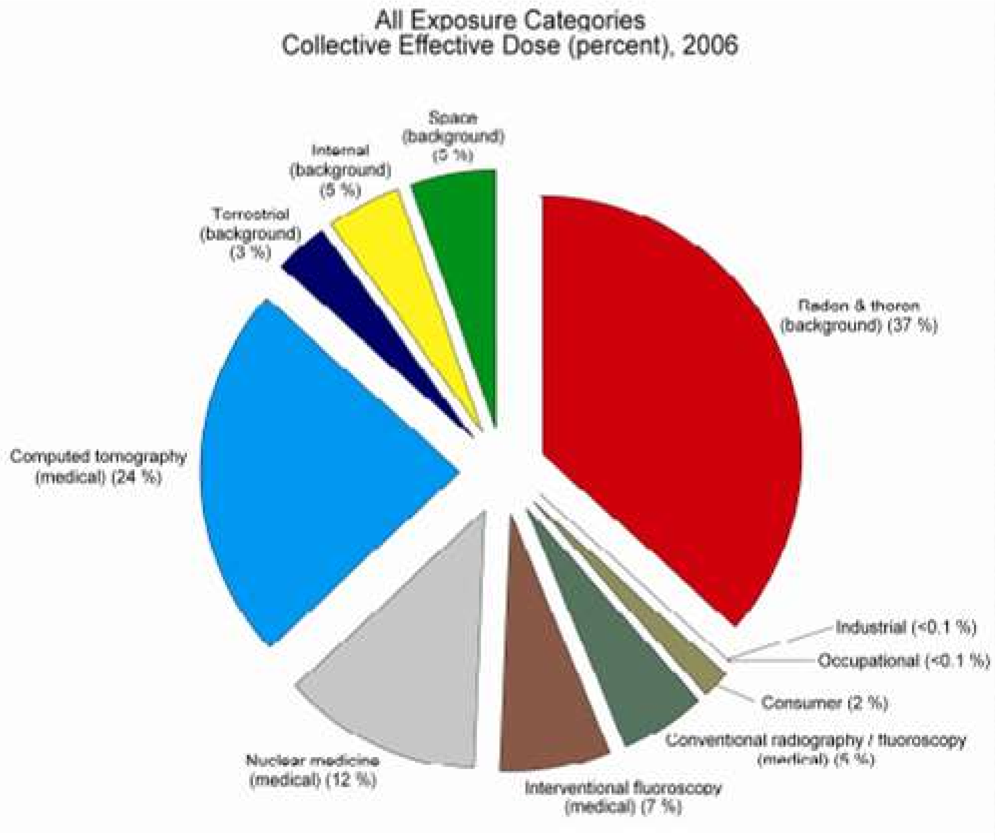
G.N. Hounsfield

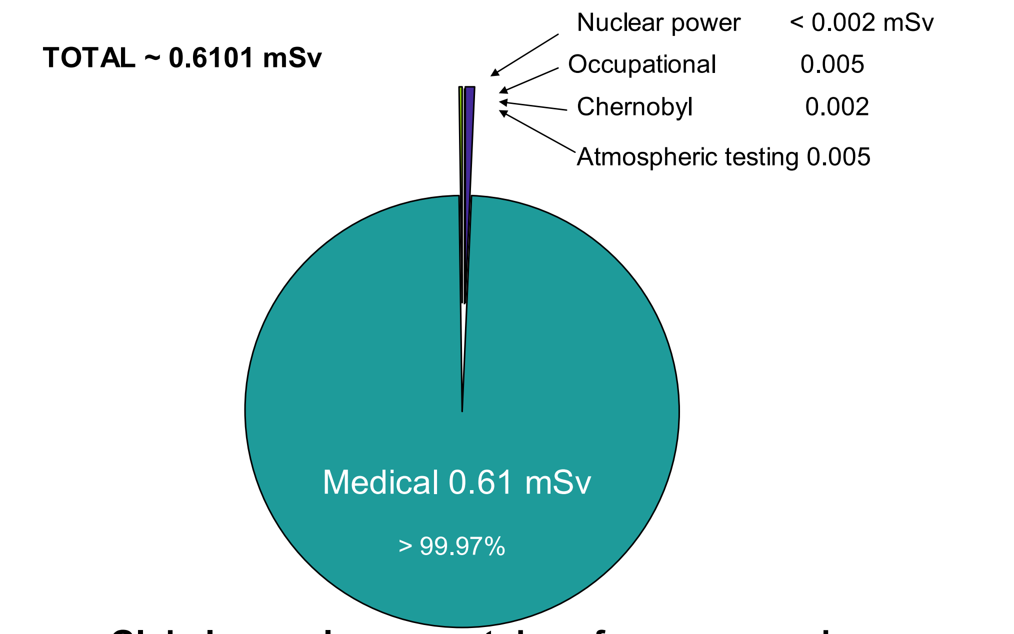
A.M. Cormack

Advantages

- Excellent soft tissue contrast
- Accurate anatomical information
- Better differential diagnosis
- Early diagnosis
- CT in OT, post operative, pre-operative, before therapy, after therapy, first level of investigation

In many developed countries CT contributes ≈ 70% of dose and it is 10-15% of all radiological examinations





Global annual per caput dose from man-made sources (1997-2007) UNSCEAR 2008

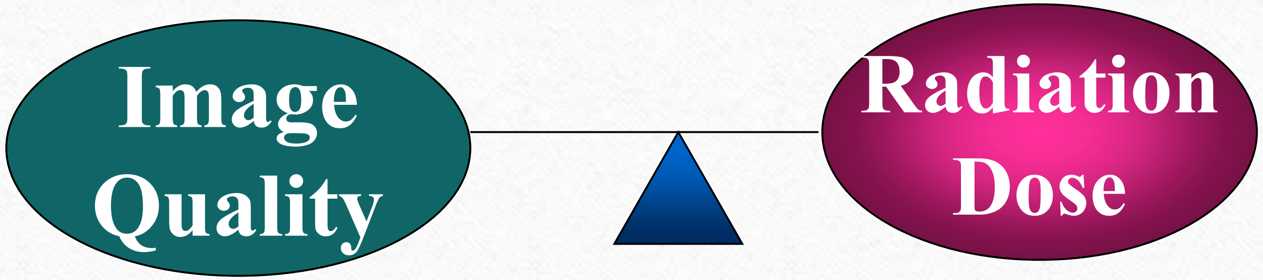
Objective

- To know the parameters to be checked in the quality assurance of Computed Tomography equipment for ensuring compliance with respective standards and specifications.

- To know the test procedures and significance of such tests

Quality Assurance

Optimization of Image Quality and Dose to the patient



With Built- in Safety of the equipment

QA Kit

Test tool/meter	Model/Make	Calibration date
kVp meter		
Dose meter/ Timer		
mA/mAs meter		
Al filters		
Imaging phantom		
Survey meter		

Multiometer

Survey meter

CATPHAN

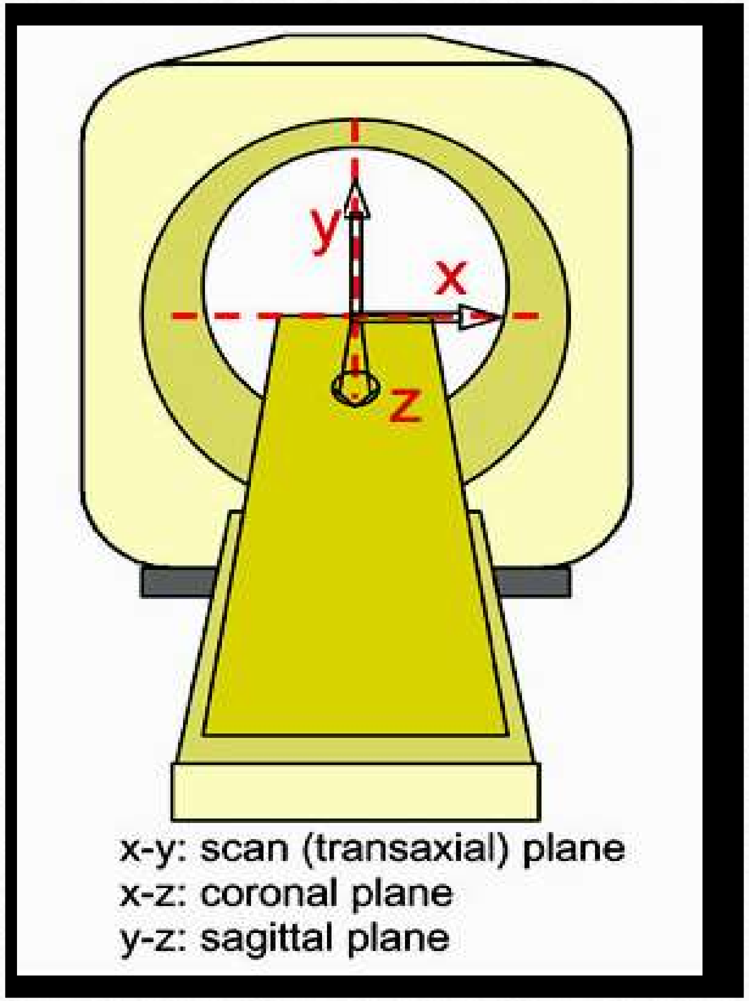
Quality Assurance Tests

(I) Mechanical tests:

- Alignment of table to gantry
- Gantry tilt
- Positioning of the patient support (longitudinal)
- Axial patient positioning accuracy
- Collimation test (slice width)

Alignment of Table to Gantry

- Result: ----------
- Tolerance: ± 5 mm



Gantry Tilt

- The accuracy of displayed gantry tilt can be assessed by supporting envelope-wrapped x-ray film at the gantry end of the patient table

- The film must be held vertically (e.g. by taping to a Perspex block), so that it is parallel to the sagital plane and intersects scan and coronal planes at right angles

Ref: IEC 61223-3-5 Annex D

Gantry Tilt

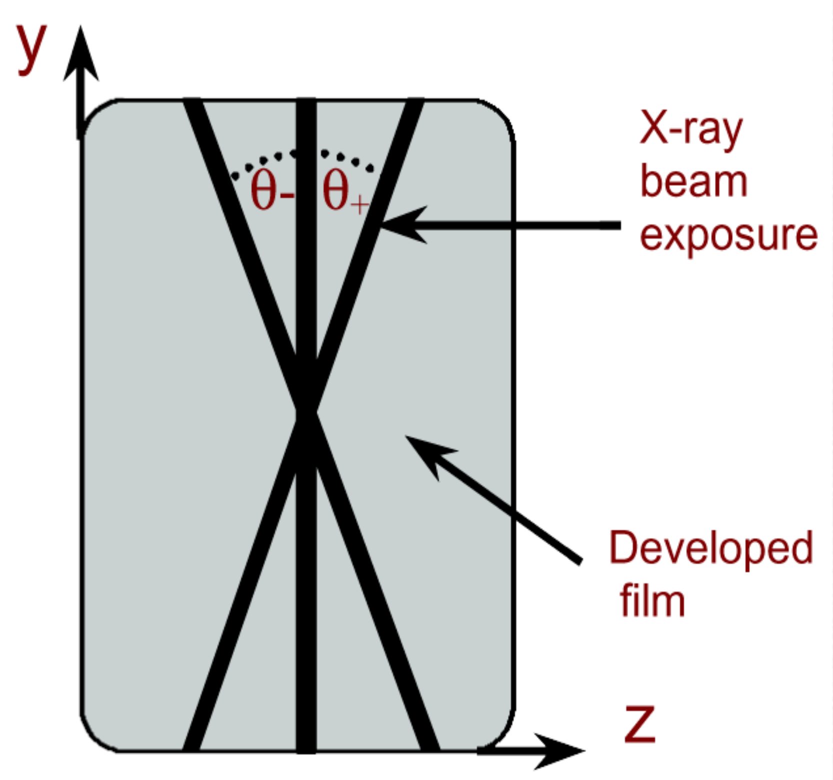
- Three axial exposures are made using the same film:
  - one for the maximum superior gantry tilt,
  - one for the maximum inferior gantry tilt
  - one at 0º gantry tilt
- The three scan planes should then be visible on the developed film
- The angles θ+ and θ- between scan planes at maximum tilt relative to that at 0º tilt should equal tilt angles displayed on the gantry.

Assessment of accuracy of gantry tilt

- Result: ----------

Set gantry tilt	Measured gantry tilt

- Tolerance: $\pm 2^0$



Ref: IEC 61223-3-5 Annex D

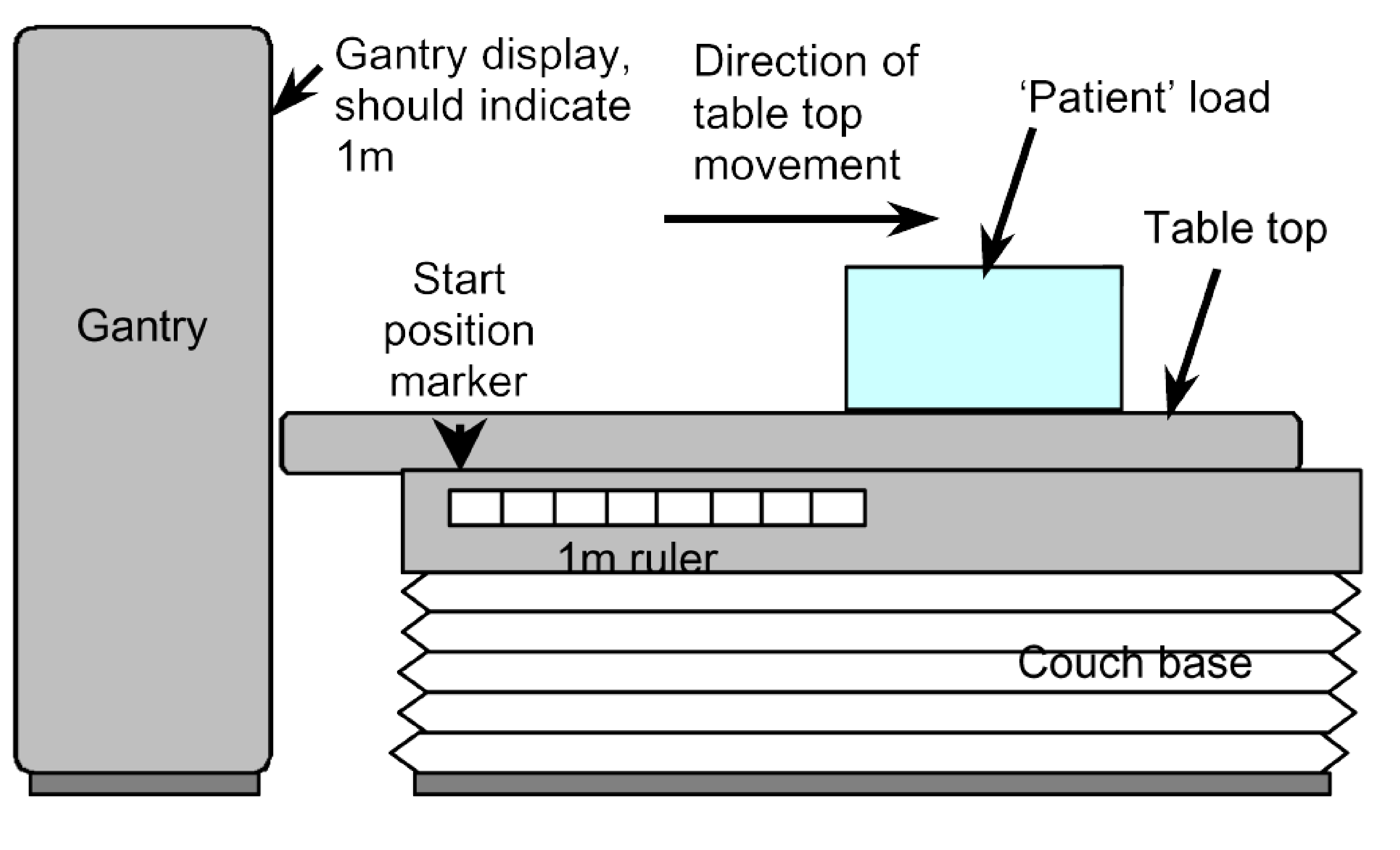
Positioning of the Patient Support

- A ruler or tape measure placed alongside the table, can be used to check that the degree of couch movement indicated on the gantry agrees with the actual distance moved.

- A load of approximately 70- 80 kg should be placed on the table in order to simulate the weight of a patient.

- The test should be performed twice: by driving the table top both away (forward) from and towards (backlash)the gantry.

Positioning of patient support



Assessment of distance indicator accuracy

Positioning of patient support

- Initial table position: ------
- Applied table increment:

Table position from reference position	1 cm	2 cm	3 cm	4 cm	5 cm
Forward					
Backlash					

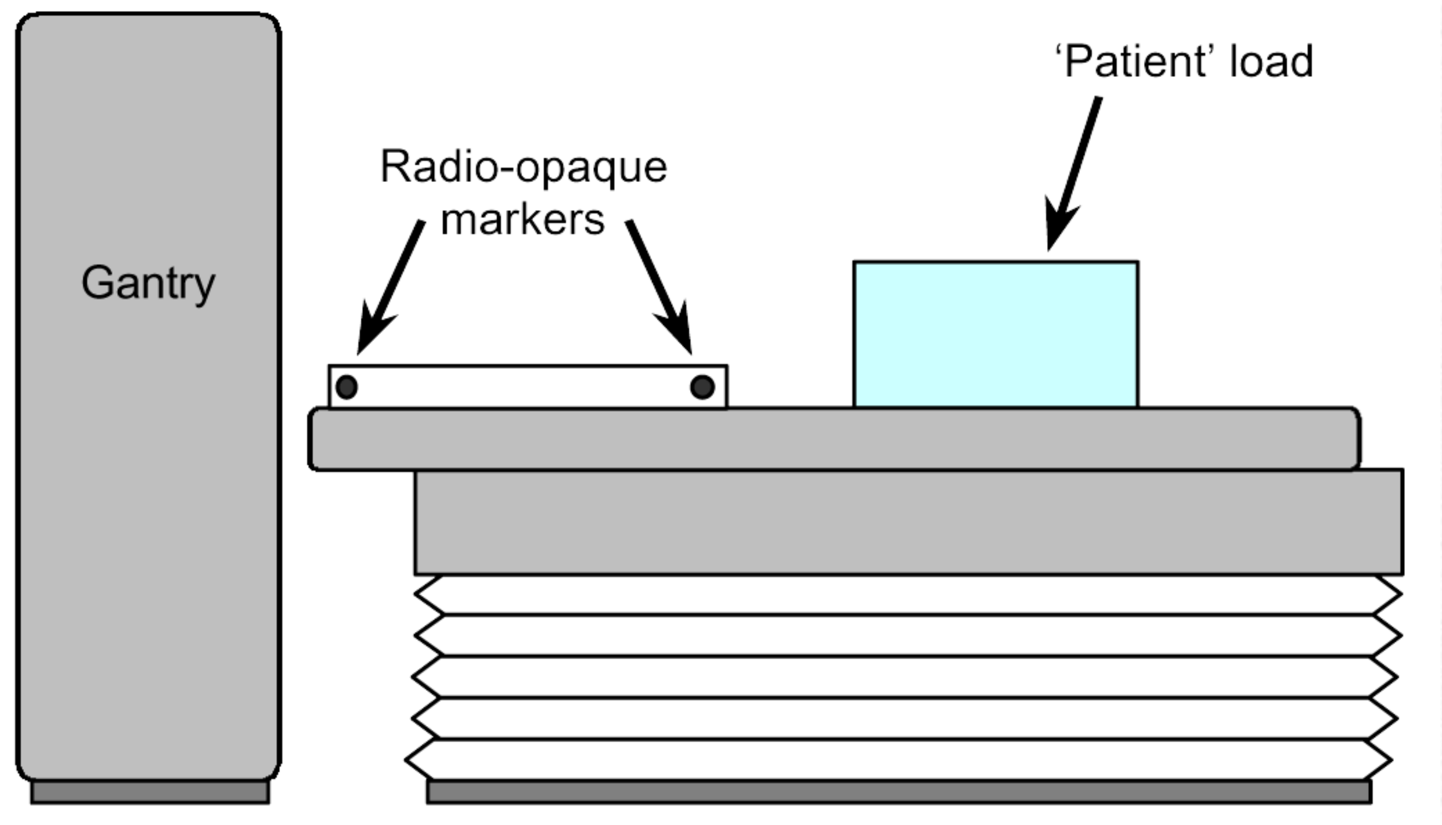
- Result:
- Tolerance: ± 1.0 mm

Ref: IEC 61223-3-5 clause 5.1

Couch travel accuracy for helical scans

- In helical scanning, it is not sufficient to use a simple mechanical test because the distance imaged depends on couch speed and scanner software
- One method of assessing imaged distance accuracy is to use a Perspex test object containing two small radio-opaque markers, separated by a fixed distance (ex:20 cm)
- The test object is scanned in Scan Projection Radiography (SPR) mode and a helical run is planned to start at the first marker and to end at a distance of 20 cm from the first marker
- If couch travel is accurate during the helical scan, the markers should be clearly seen on the first and final images of the series.

Couch travel accuracy for helical scans



Axial patient positioning accuracy/Agreement between internal and external scan plane lights

- Use the envelope-wrapped film recommended for that measurement, however, a piece of paper or card can also be used
- The wrapped film is placed flat on the table and illuminated by the external scan plane light
- The position of the light is marked on the film envelope and the table is moved automatically to the scan plane
- If the distance between the internal and external lights is correct, the internal light should now coincide with the mark on the film envelope.

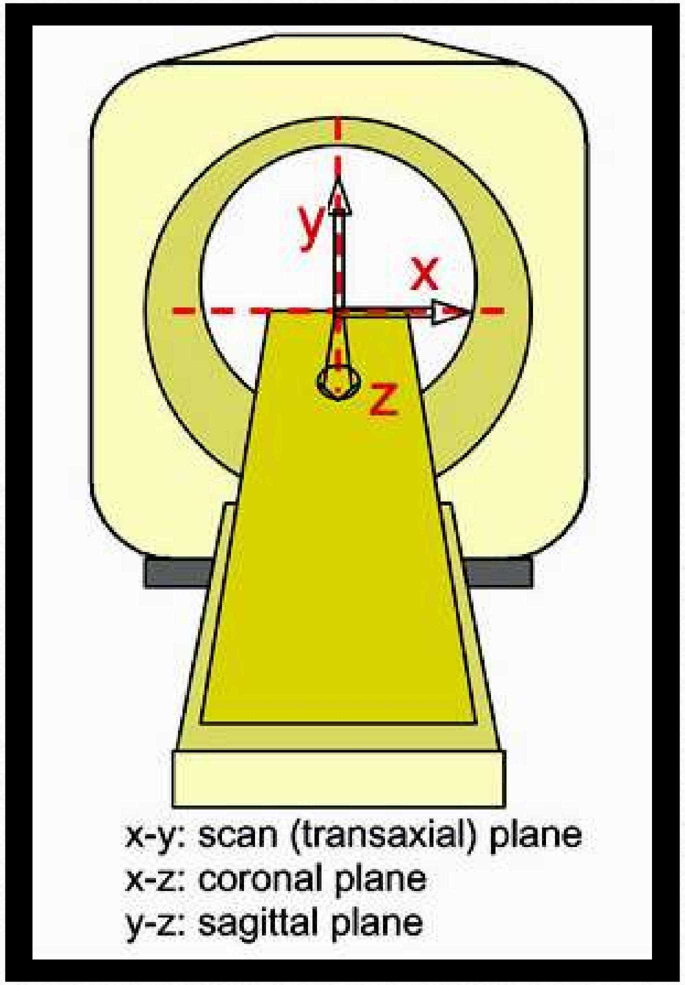
IEC 61223-3-5 Clause 5.2

Axial Patient Positioning Accuracy

Result:

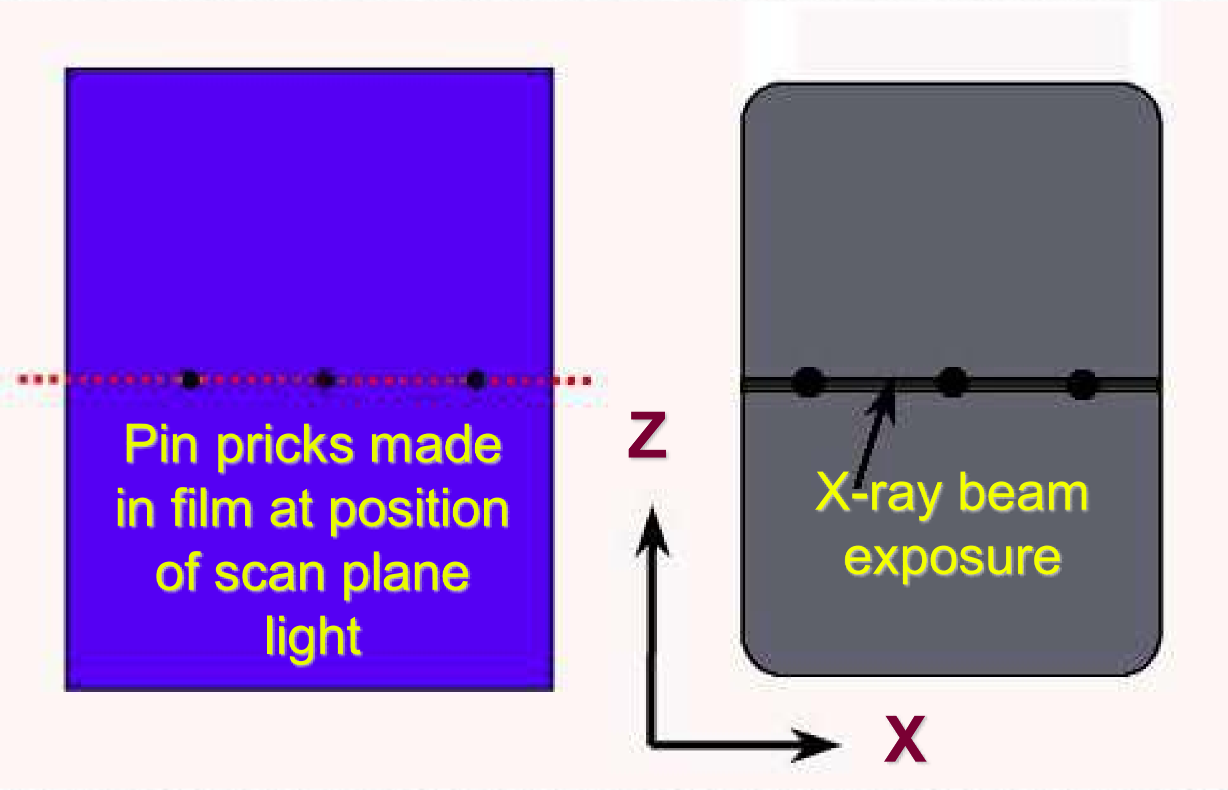
- Alignment error:
  - Internal laser light :-----mm
  - External laser light:-----mm

- Tolerance: ± 2.0 mm



Ref: IEC 61223-3-5 clause 5.2

Co-incidence of internal scan plane lights and scan plane



Coronal and Sagital plane lights

- A long, thin object, with a high CT number relative to air, such as the ‘lead’ in a pencil or a straightened paper clip, can be used as a marker to perform this test
- The marker is supported above the patient table and aligned, using the indicating lights, so that it is positioned at the isocentre, parallel to the z-axis and perpendicular to the scan plane
- If indicating lights are accurately aligned to the coronal and sagital planes, the **marker should appear as a dot at exactly x = 0, y = 0** on the axial image.

Slice width (tomographic section thickness)

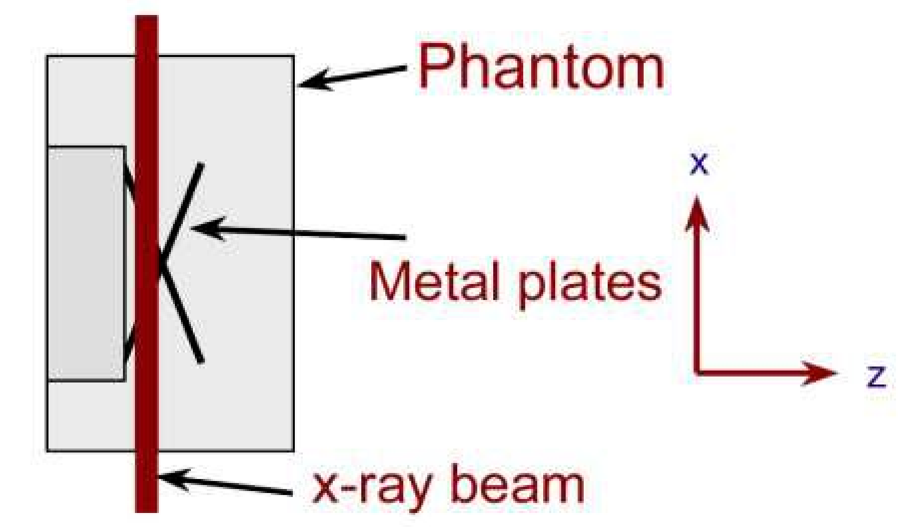
- Axial mode measurements
- Phantoms used for axial measurements may contain thin metal plates or wires inclined at an angle to the image plane

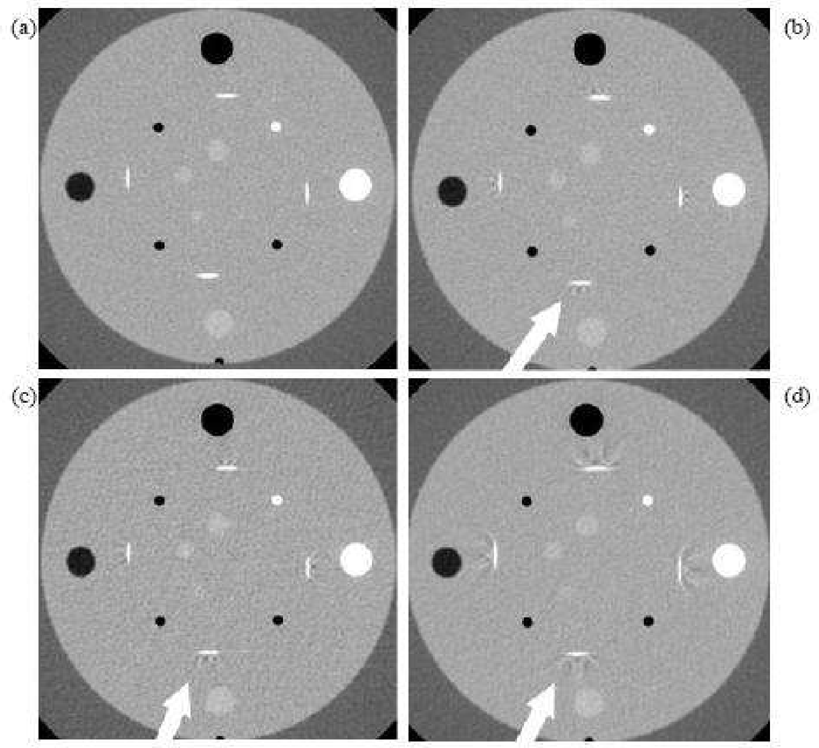
- Manufacturers should be able to supply an appropriate phantom or, alternatively, the ***Catphan*** contains an insert suitable for this test

- **Note**: to obtain meaningful measurements, the thickness of the plates, wires or holes cannot be greater than the nominal slice width concerned. There may be problems for the sub-millimetre slice widths offered on multi-slice scanners.

Ref: IEC 61223-3-5 Clause 5.3

Slice width (tomographic section thickness)





- Plan view of a test object used to measure imaged slice widths for axial scans

Ref: IEC 61223-3-5 Clause 5.3

Slice width (tomographic section thickness)

Axial mode measurements

- Phantoms Manufacturers may quote the tolerance for each nominal slice width setting in their specification documentation

- Tolerance:

  For Slice thickness

- above 2 mm: ± 1mm
- 1mm to 2mm: ± 50%
- less than 1mm: 0.5 mm

Applied Slice thickness	Measured Slice thickness

Ref: IEC 61223-3-5 Clause 5.3

Dose Profiles (Irradiated slice width)

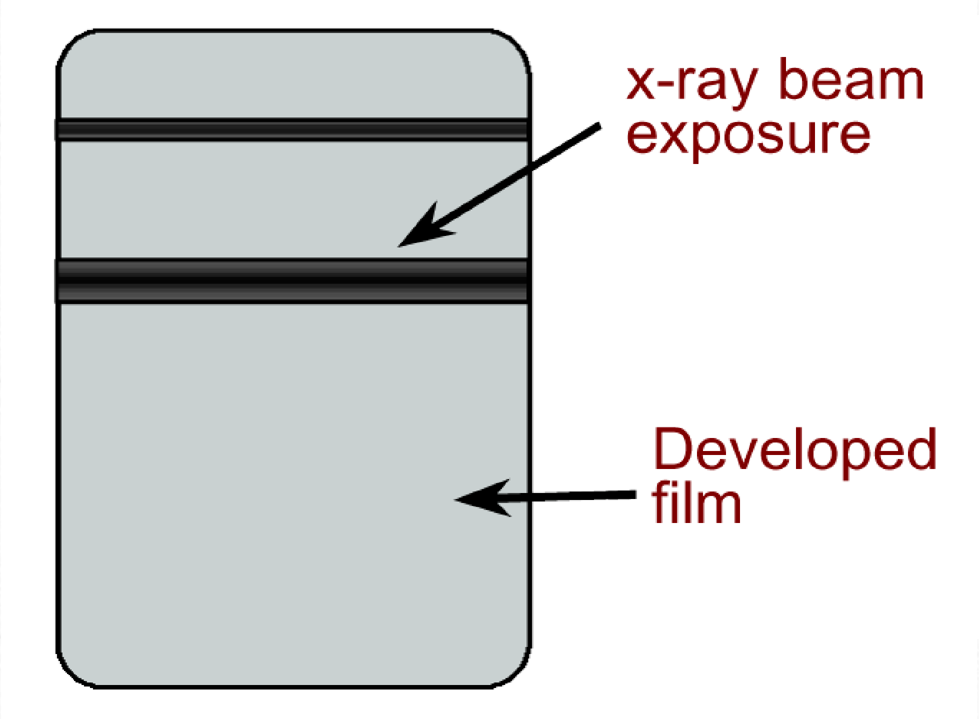
-pre patient collimator

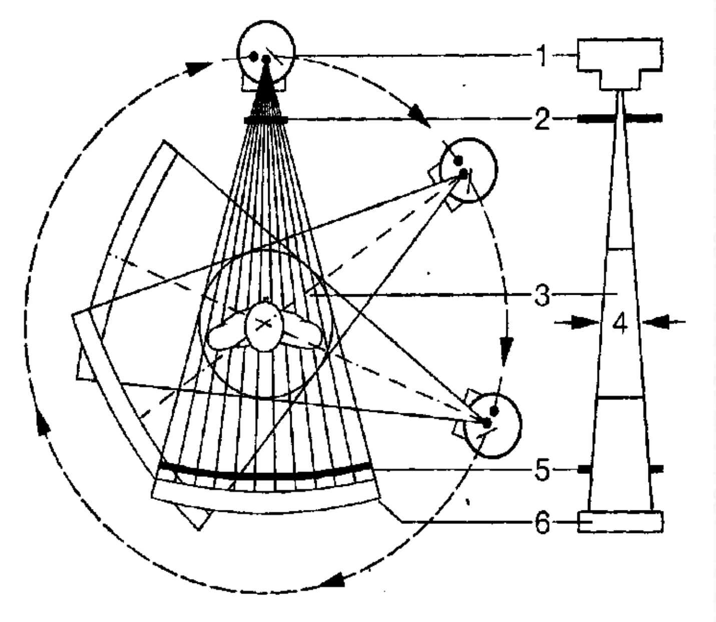
- Expose envelope-wrapped x-ray film, supported in air at the isocentre, at each of the slice width settings

- Once developed, optical density profiles may be plotted using a scanning microdensitometer or the width measured using a ruler

- To provide an accurate dose profile, a calibration curve can be applied to convert optical density profiles into dose profiles, from which irradiated slice widths (FWHM of dose profiles) may be derived

Dose Profiles (Irradiated slice width)





Measurement of irradiated slice widths
for a range of nominal slice width settings

(II) Tests for High Frequency generators:

- Accuracy of X-Ray Tube Voltage (kV)
- Linearity of X-Ray Tube Current (mA)
- Accuracy of Irradiation Time (t)
- Consistency of Radiation Output
- Radiation Quality (Total filtration – HVL)

Tests for High Frequency generators

Parameters to be tested	Tolerance
Accuracy of X-Ray Tube Voltage (kV)	± 5 kV
Linearity of X-Ray Tube Current (mA)	CoL < 0.1
Accuracy of Irradiation Time (t)	% Error ± 10%
Consistency of radiation output (CoV)	CoV < 0.05
Total Filtration	2.5 mm Al for kV > 100

(III) Radiation Dose Test

Measurement of Computed Tomography Dose Index (CTDI):

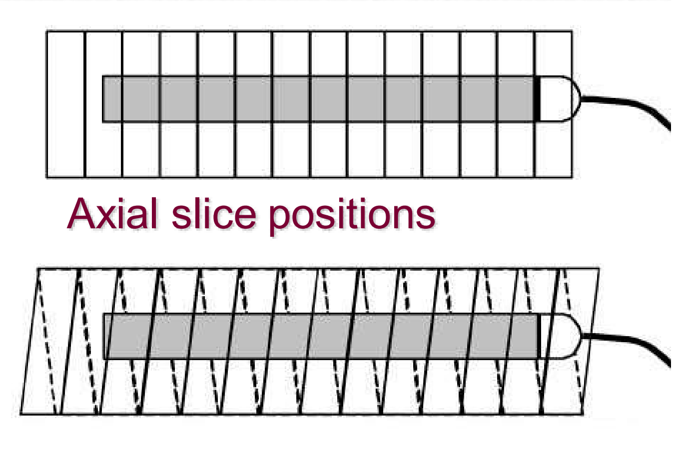
- When more than 3 selections of a CT condition of operation are available then measurement should be carried out at least for minimum, maximum and one mid range value of the CT condition of operation.

CTDI in Perspex Phantoms

- The body phantom placed on the patient table and the head phantom is supported in the head rest
- Phantoms are aligned centred at the scan isocentre
- The ion chamber is inserted into either the central or one of the peripheral cavities of the phantom (all other cavities being filled with Perspex rods)
- Dose measurements at the center are used to calculate the central CTDI
- Peripheral CTDI is measured in at least four positions around the phantom, so as to achieve a true average

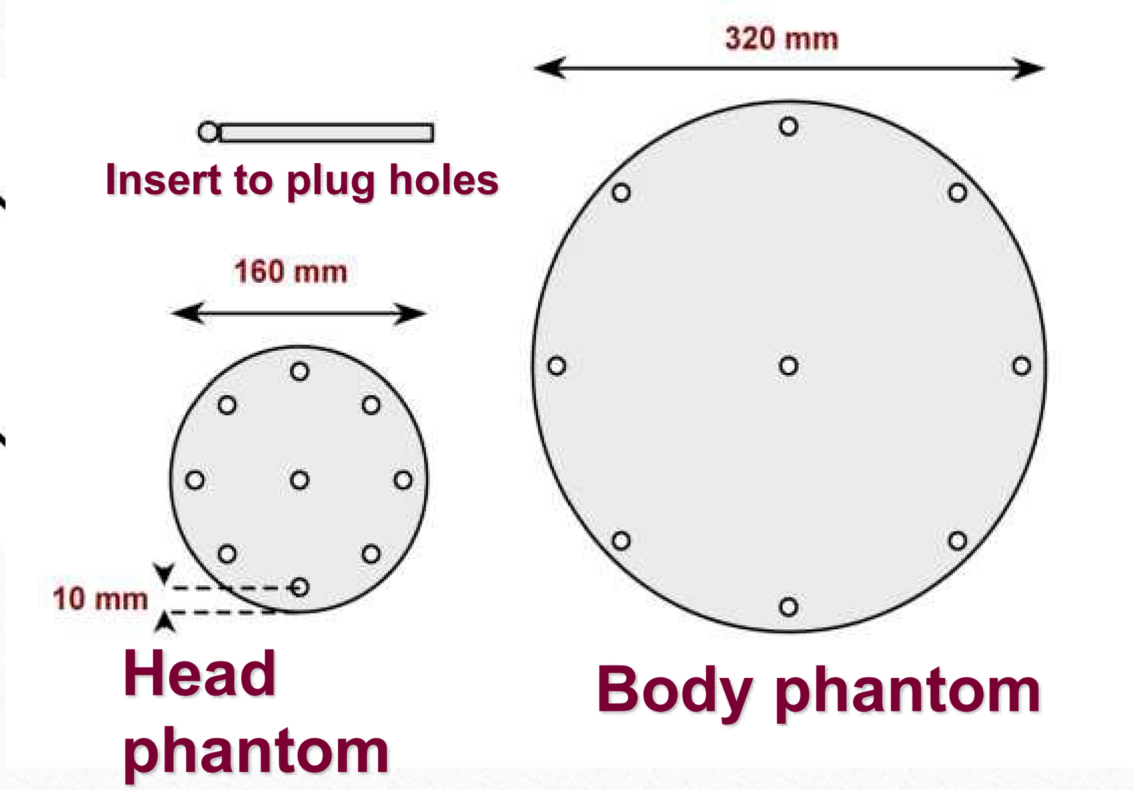
IS 13450 (Part 2/Section 44) and IEC 61223-3-5 Clause 5.4

Dosimetry - CTDI in Perspex Phantoms

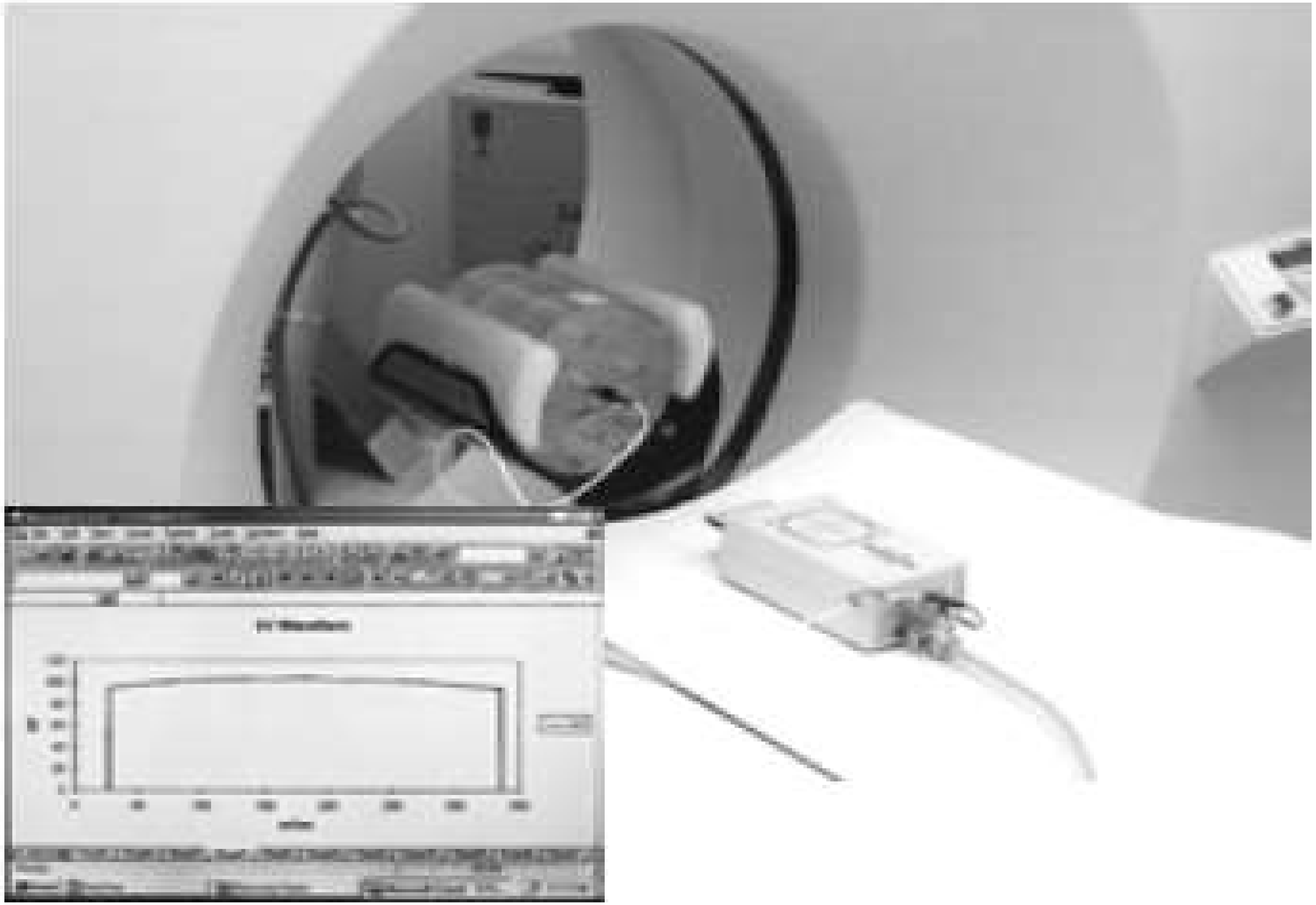


Axial slice positions

Helical scan (pitch 1)



Real-time CT



Dosimetry - CTDI in Perspex Phantoms

- Central and peripheral CTDI's are used to calculate weighted CTDI, CTDIw:

$$CTDI_w = \left(\frac{1}{3}CTDI_{100,c} + \frac{2}{3}CTDI_{100,p}\right)$$

- CTDIw can be compared against diagnostic reference levels for standard scan examinations

- Tolerance: ± 20 % of the quoted value

IS 13450 (Part 2/Section 44) and IEC 61223-3-5 Clause 5.4

(IV) Image Quality Parameters

- CT number Uniformity
- CT number Linearity
- Noise
- Low contrast resolution
- Spatial resolution

Physical parameters of CT image

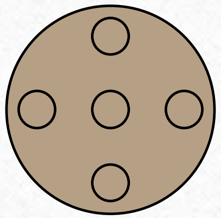
Image quality

- May be expressed in terms of physical parameters such as *uniformity, linearity, noise, spatial resolution, low contrast resolution*
- It depends on the technological characteristics of the CT scanner, the exposure factors used and image viewing conditions.
- Quality may be assessed by quantitative measurement using test phantoms.

Test Phantoms:

- Test phantoms of a standardized human shape or test objects of a particular shape, size and structure, are used for the purposes of calibration and evaluation of the performances of CT scanners (supplied by manufacturer)
- They should allow for the parameters to be checked: *CT number; uniformity; linearity; noise; spatial resolution; low contrast resolution; slice thickness; positioning of couch etc*.

Image Quality parameters



CT Number Accuracy

- CT number depends on tube voltage, filtration, object thickness/attenuation
- CT number of water is by definition equal to 0
- Measured CT number should be < ± 4 HU in the central *ROI*

CT Number Uniformity

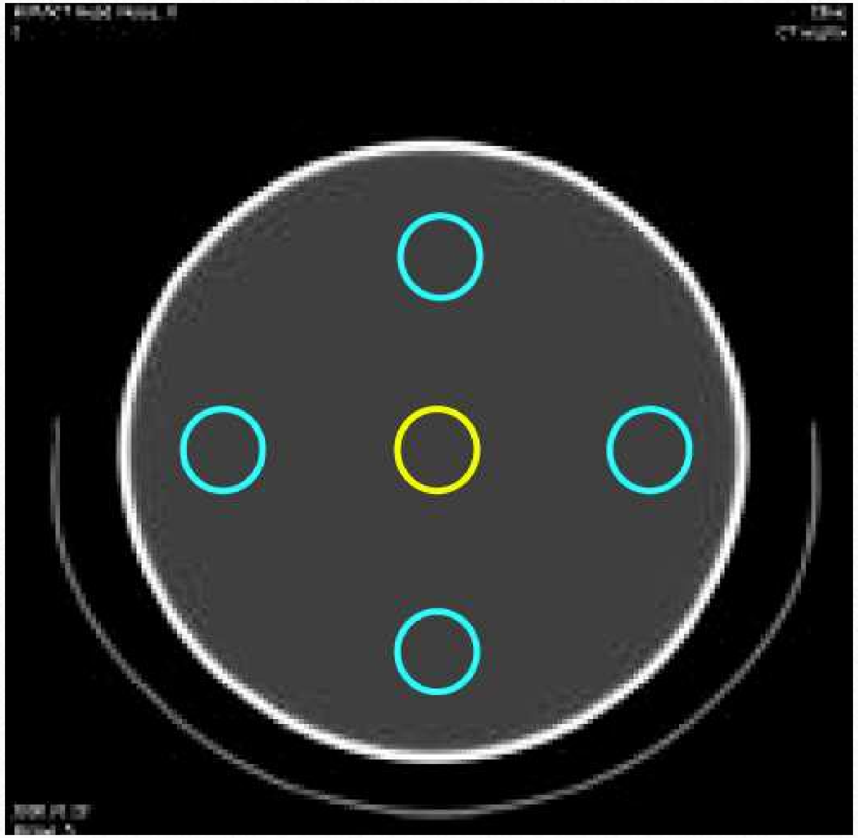
- It relates to the fact that a CT number of each pixel in the image of an homogeneous object should be the same over various regions
- The difference in the CT number between a peripheral and a central region of an homogeneous test object should be < ± 4 HU

CT number uniformity

- CT number uniformity can be assessed at the same time as measuring noise, by placing four additional ROI (N, E, S and W) at positions near the edge of the image of a uniform phantom
- Mean CT number is then noted for these four regions, as well as the central one
- The deviation from the central value should be calculated
- It can be valuable to check CT number uniformity for large fields of view

Ref: IEC 61223-3-5, Clause 5.5

CT number accuracy and uniformity



	Measured value (HU)	Difference
Central		
Peripheral-1		
Peripheral-2		
Peripheral-3		
Peripheral-4		

Tolerance: < ± 4 HU

Axial image of an homogenous phantom

Ref: IEC 61223-3-5, Clause 5.5

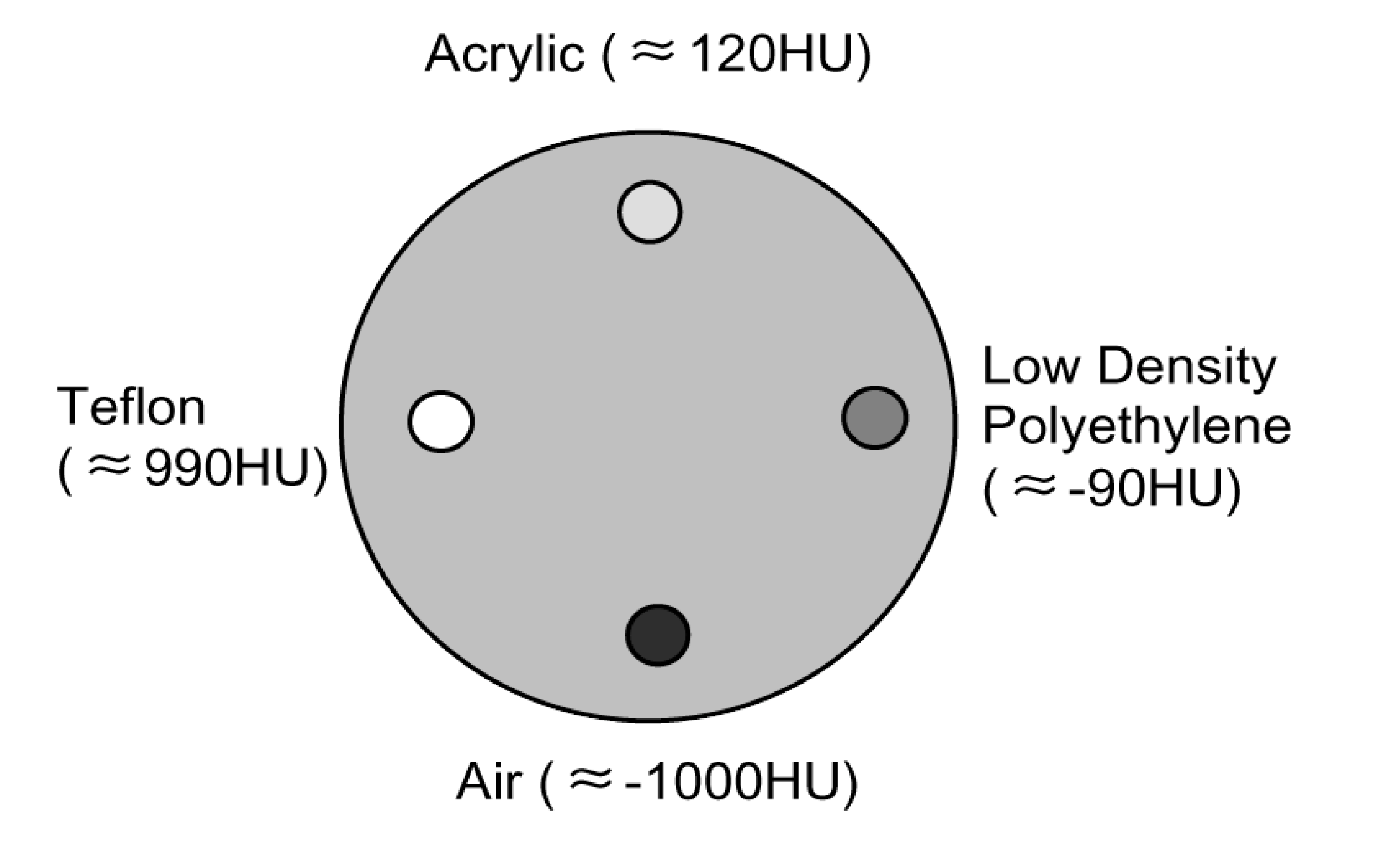
Image Quality parameters

CT Number Linearity

- It concerns the linear relationship between the calculated CT number and the *linear attenuation coefficient* of each element of the object
- Deviations from linearity should be < ± 4 HU
- CT number linearity is assessed using a phantom containing inserts of a number of different materials (materials should cover a wide range of CT numbers

Ref: IEC 61223-3-5, Clause 5.5

CT number linearity



Ref: IEC 61223-3-5, Clause 5.5

CT number linearity

Material	Specified Value	Measured Value	Difference
Water	0		
Acrylic	~ (120 HU)		
Teflon	~ (990 HU)		
Low Density Polyethylene	~ (- 90 HU)		
Air	~ (- 1000 HU)		

Tolerance: < ± 4 HU

Ref: IEC 61223-3-5, Clause 5.5

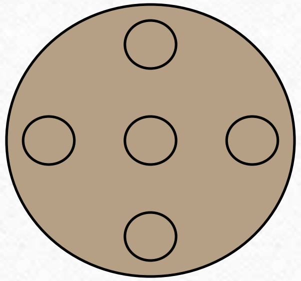
Noise

- Is the local statistical fluctuation (standard deviation) of CT numbers of an homogeneous ***Region Of Interest*** (ROI)

- It strongly affects the low contrast resolution

- Noise is dependent on the radiation dose

$$\textit{Noise} = \frac{1}{\sqrt{dose}}$$



- Image noise should be measured over an area of about 10% of the cross-sectional area of the test object.

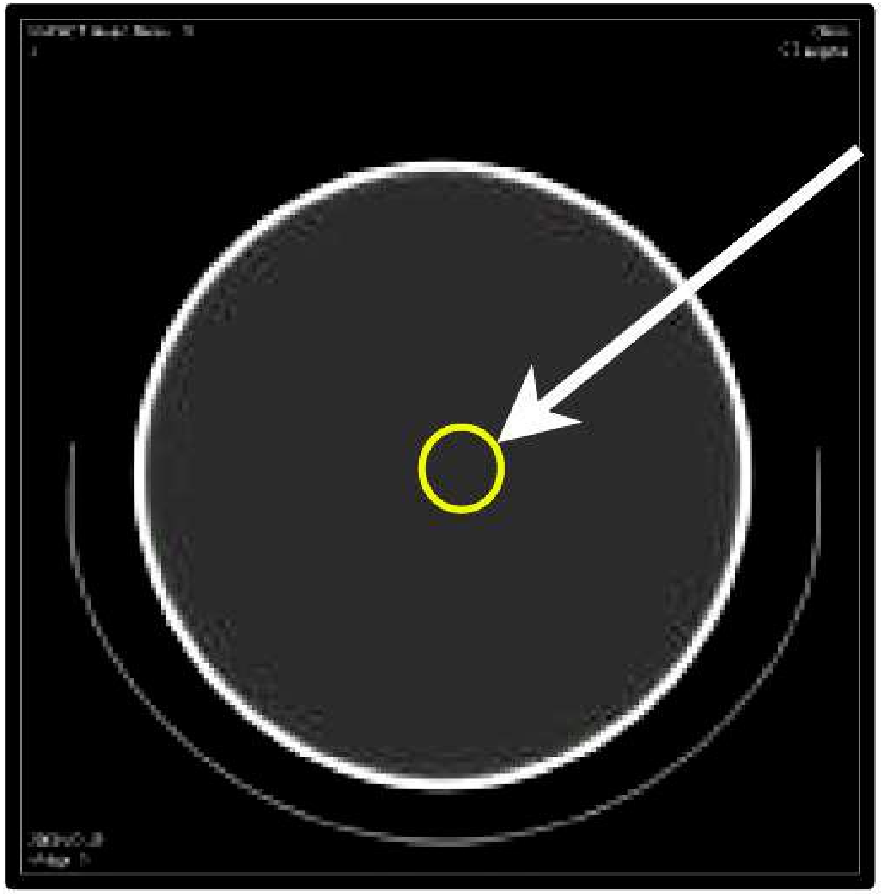
Noise

- Noise is generally 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, noise is obtained from the standard deviation in CT number in a region of interest (ROI) placed centrally within the image

Noise

- Noise figures given in manufacturers' specifications are quoted for a specific phantom (e.g. manufacturer's QA phantom) and for specified scan parameters
- These conditions must be matched exactly for the purposes of the measurements/acceptance test
- Manufacturers often quote noise at a particular surface dose
- If this is the case, dose for axial scans can be measured by taping an ion chamber to the surface of the phantom

Noise



Region of interest (ROI)

Specified Value	Measured Value

Tolerance: ± 15%

Low contrast resolution

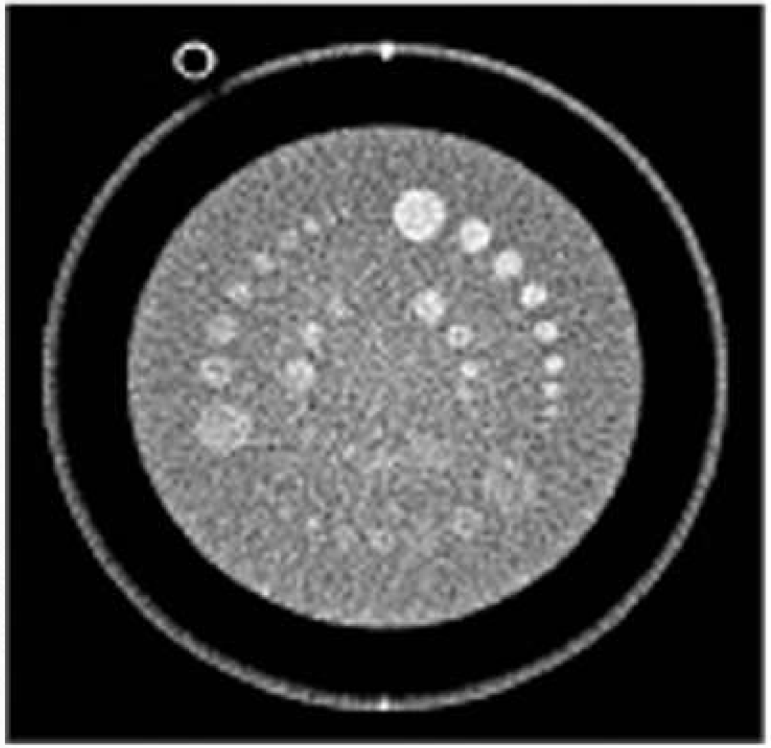
- Low contrast resolution (or low contrast detectability) is quoted in specification documentation, as the smallest visible object at a given contrast for a given dose.

- The *low contrast resolution* determines the size of detail that can be visibly reproduced when there is only a small difference in density relative to the surrounding area.

    - Low contrast resolution is considerably limited by noise.

    - The perception threshold in relation to contrast and detail size can be determined, for example, by means of a contrast-detail curve.

Low contrast resolution



Typical image of the Catphan LCR insert

Result:

LCR is -----mm at -----------% contrast difference

Tolerance: As per the manufacturers specification in the accompanying document

OR

5.0 mm at 1% contrast difference

Spatial resolution (high contrast)

Spatial Resolution

The *high contrast resolution* determines the minimum size of detail visualized in the plane of the slice with a contrast >10%.

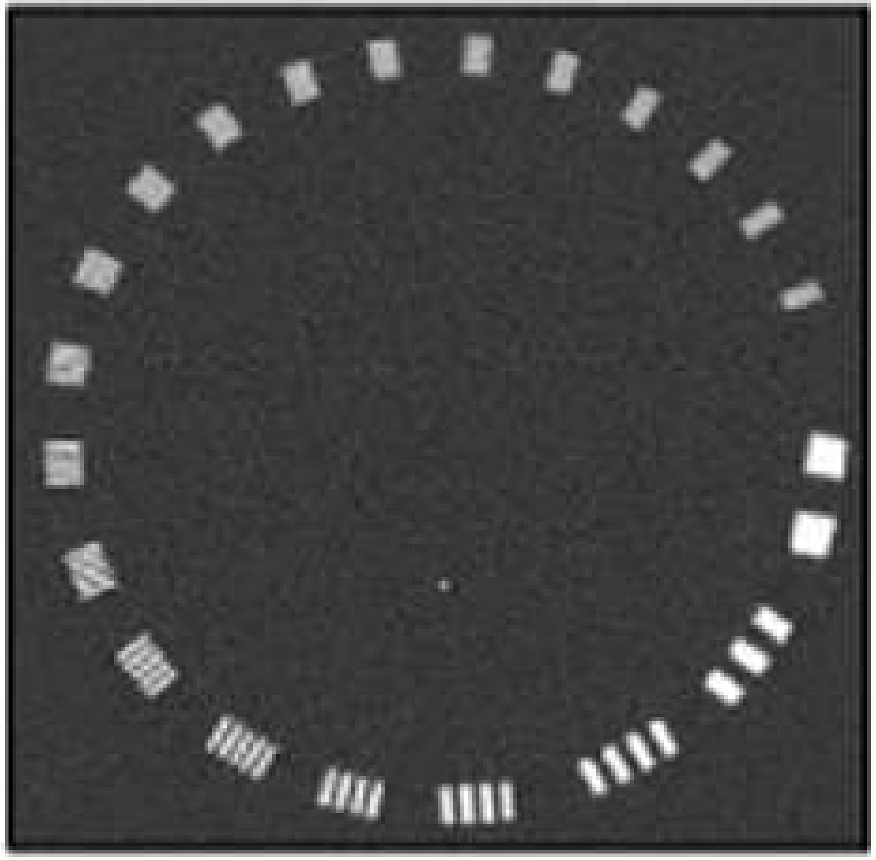
It is affected by:

- the reconstruction algorithm
- the *detector width*
- the effective slice thickness
- the object to detector distance
- the X-ray tube *focal spot* size
- the matrix size.

Spatial resolution (high contrast)

- There exist two broad categories of measuring techniques :
  - those involving analysis of the point spread function, usually by calculation of the modulation transfer function (MTF)
  - those involving either objective analysis or visual assessment of images of a resolution bar phantom.
- The resolution is quoted as the spatial frequency (in line pairs / cm) at which the modulation falls to 50%, 10% or 2% MTF.
- These figures are often given for more than one reconstruction algorithm, e.g. for standard and high-resolution scans.

Spatial resolution (high contrast)



- The number of line pairs per cm just visible in the image is approximately equivalent to the 2% value of the MTF
- This result can then be compared with the 2% MTF, if this is quoted in the manufacturer's specification

Spatial resolution (high contrast)

Result:

Size of the smallest resolvable bar/hole pattern is ------mm (----lp/cm)

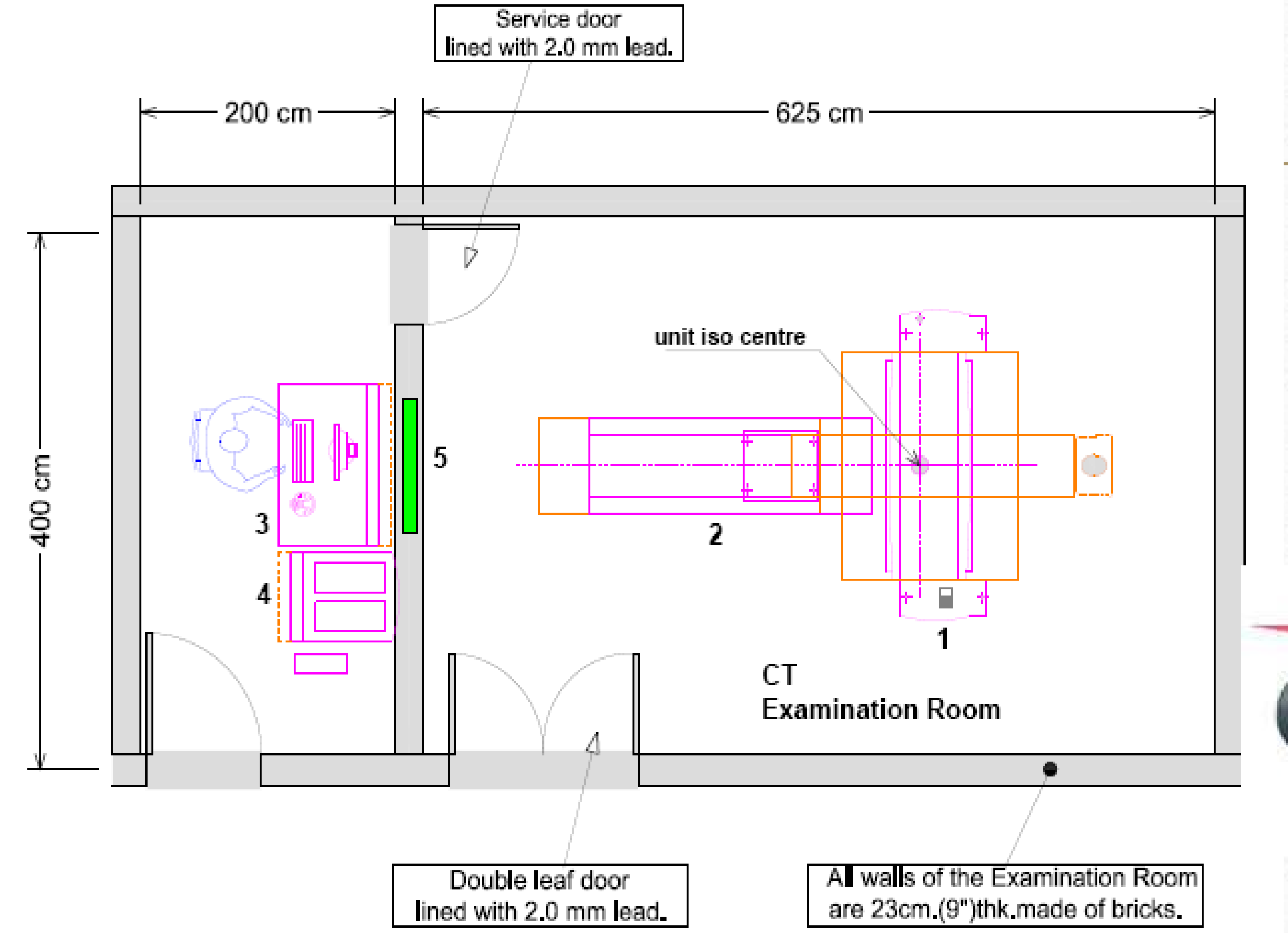
Tolerance:

At 10% contrast difference the size of the bar/hole patteren that should be resolvable is 0.5 lp/cm

OR

± 10 % of the specified nominal value

(V) Radiation leakage levels and Radiological Protection Survey:



The aim of conducting radiological protection survey of a diagnostic X-ray installation is to ensure that radiation doses received by the radiation workers such as radiologists, X-ray technologists, and public are as low as reasonably achievable and are unlikely to receive doses in excess of limits prescribed for them by the competent authority.

Instruments and Accessories required:

- Ionisation chamber/Semiconductor based type survey meter
- Water Phantom

Area Monitoring at various locations(s)

- Keep the water phantom on the couch. The water phantom is used instead of patient. The primary beam has to be directed to the water phantom and scatter dose measurement has to be made at different locations of interest such as control panel, at entrance door patient waiting area, dark room, corridor, near the patient table where radiologist, operator or attendants stand during fluoroscopy etc.

- Normally the unit is operated for highest kV used and minimum mA available in the control panel.

- The Ionisation Chamber/Semiconductor based survey meter is used to measure the radiation levels.

The exposure parameters to be selected for while carrying out survey are given in the table:

Type of Equipment	Applied Voltage # (kV)	Applied Current (mA)	*Exposure time (Sec)
Interventional Radiology Radiography & Fluoroscopy Radiography(fixed)	80-100	50 – 100	1.0 -2.0
Dental (OPG) CBCT	60-100	8-20	1.0 -2.0
Computed Tomography	110-140	50 - 100	1.0 – 2.0
Mammography	30-35	100-200	1.0 – 2.0

Exposure time should not be less than 1 Sec

Workload to be used for radiation protection survey for various diagnostic radiology modalities are given in the table:

Type of Equipment	Workload (mA-min/week)
Radiography & Fluoroscopy	400
Interventional Radiology	4800
Dental (OPG)/ CBCT	150
Computed Tomography	20,000
Mammography	650

Exposure time should not be less than 1 Sec

Provide the values of maximum radiation level (mR/hr) at following places:

- Near control console (operators position)
- Outside patient entrance door
- Behind chest stand wall
- Behind window (if any)
- Patient waiting area

Area Monitoring at various locations(s)…

If the dose rate at operators position =
4 mR/hr for 20 mA

Dose received by the operator is =

$$\frac{400\ \text{mAmin/wk} \times 4\ \text{mR/hr}}{60\text{min/hr} \times 20\ \text{mA}}$$

=1.33 mR/week

The allowable weekly dose for radiation worker is 40 mR/week.

AN APPROPRIATE WARNING PLACARD AS INDICATED BELOW SHALL BE POSTED OUTSIDE THE X-RAY ROOM

Type of equipment:
Model Name:
Licence No.

X-RAY EXAMINATION IS GOING ON INSIDE, DO NOT ENTER

PLEASE WAIT FOR YOUR TURN

DO NOT STAY INSIDE X-RAY ROOM, IF REQUIRED TO ASSIST THE PATIENT, INSIST FOR PROTECTIVE APRON!

Similar display shall be prepared in local/regional language

Format of warning sign to be pasted outside medical diagnostic x-ray installation

PASTE COPY OF AERB LICENCE HERE

To be printed in appropriate size

Summary of QA Tests

Sr. No.	Parameters tested	Set values	Measured values	Tolerance	Remarks
1	Alignment of Table to gantry			± 5 mm	
2	Gantry tilt			$\pm 2^0$	
3	Table indexing accuracy			± 1 mm	
4	Slice thickness			± 1 mm	
5	Accuracy of kV			± 5 kV	
6	Linearity of mA				
7	Accuracy of irradiation time			Error ≤ ± (10 % + 1 ms)	

Sr. No.	Parameters tested	Set values	Measured values	Tolerance	Remarks
9	Total filtration (100 kVp)			HVL> 2.7 mm Al	
10	Output consistency			COV ≤ 0.05	
11	Radiation dose test			± 20 %	
12	Noise			± 15 %	
13	CT number uniformity			± 4 HU	
14	CT number linearity			± 4 HU	
15	Low contrast resolution			5.0 mm at 1% contrast	
16	Spatial resolution			0.5 lp/cm at 10% contrast	
17	Radiation leakage			< 1 mGy in one hr	

Summary

- CT produces high quality diagnostic images at the expense of increased radiation dose compared to routine radiographic examinations.
- QA is the components that measures CT scanner performance to assure operation is at an acceptable level.
- QA takes action to correct inadequacies before they are problematic. These measures assure high imaging performance standards, and reduce the risk of patient harm due to change in equipment performance characteristics.
- The doses from CT examinations can be reduced by controlling certain scanning parameters by performing periodic QA tests.

Expected Questions

References and sources for additional information:

- AERB SAFETY CODE NO.AERB/RF-MED/SC-3 (Rev. 2), RADIATION SAFETY IN MANUFACTURE, SUPPLY AND USE OF MEDICAL DIAGNOSTIC X-RAY EQUIPMENT
- IS 13450 (Part 2/Sec 44) : 2007 / IEC 60601-2-44: 2001 Part 2: Particular requirements for the safety , Sec 44: X-ray equipment for Computed Tomography
- IEC 61223-2-6: Evaluation and routine testing in medical imaging departments; Constancy tests – Imaging performance of CT
- IEC 61223-3-5: Evaluation and routine testing in medical imaging departments; Acceptance tests – Imaging performance of CT
- IEC 60601-1-3: General requirements for safety-3. Collateral standard: General requirements for radiation protection in diagnostic X-ray equipment
- For AERB QA Formats, visit AERB website: www.aerb.gov.in

  http://www.aerb.gov.in/AERBPortal/pages/English/t/XRay/forms/QACT.doc

List of presentations in the training Module

Basics of Diagnostic X-ray Equipment
Biological effects of Radiations
Medical X-ray imaging techniques
Planning of Diagnostic X-ray facilities
Quality Assurance of X-ray equipment
Quality Assurance of Computed Tomography equipment
Radiation Protection in Diagnostic Radiology Practice
Causes, prevention and investigation of excessive exposures in diagnostic radiology
Regulatory Requirements for Diagnostic Radiology Practice

THANK YOU