

Radiation Safety Training Module: Diagnostic Radiology

Quality Assurance in Diagnostic Radiology



Radiological Safety Division
Atomic Energy Regulatory Board

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- Aim of QA
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- Expected Questions
- References and sources for additional information

Expected questions to know after studying this lecture

- What do you mean by QA in Diagnostic Radiology?
- Why QA tests are required?
- Understanding the concepts of various QA tests.
- Understanding the importance of various QA tests

Introduction

Definition:

Quality Assurance (QA) of medical diagnostic x-ray equipment means systematic actions necessary to provide adequate confidence to the end-user(s) that a medical diagnostic x-ray equipment will perform satisfactory in compliance with safety standards specified by the Competent Authority.

QA Programme

- The goal of QA Program is to ensure the accuracy of the diagnosis.
- The minimum radiation dose should be delivered to the patient to achieve the objective of the diagnostic or interventional procedures.
- QA programme begins with the performance evaluation of diagnostic x-ray equipment at the manufacturing stage and then acceptance testing after the installation of X-ray equipment at user's institution(s) to ensure its conformity with the specifications.
- The QA tests should be carried out thereafter at regular intervals (**periodicity-once in two years**) and also after repairs of the equipment or when equipment malfunction is suspected.

Objective / Aim of Quality Assurance (QA)

Optimum image quality of radiological procedures with minimum possible dose to the patient(s)

TYPE APPROVAL TEST

- **Type approval tests of an equipment are carried out to verify the performance of equipment as per safety requirements of AERB Safety Code and the Safety Standards are in force.**
- Result of type approval tests should meet the tolerances values as specified in Type Approval QA Protocol(s).
- Type approval tests are performed on prototype model of X-ray equipment.
- Type Approval becomes invalid if any change is made in the design specifications of the type approved model.
- **It is the responsibility of the manufacturer/supplier to ensure that type approved x-ray equipment shall be marketed in the country.**

Why QA in Diagnostic Radiology?

To get calibrate all the exposure parameters, to check functional performance of X-ray equipment and radiation safety around the X-ray installation, QA checks are necessary for every diagnostic X-ray equipment.

In other words, to obtain the optimum quality diagnostic information at the lowest radiation risk to the patient, QA of diagnostic X-ray equipment is necessary.

Quality Assurance Test

- The routine QA tests are necessary to ensure that the functional performance of the equipment is similar to its baseline values and within the tolerance values as specified by regulatory body.
- These tests should be performed by qualified service engineer(s) at user institution(s).
- These tests should be performed at regular intervals (once in two years) and at major repairs of X-ray equipment.

DIAGNOSTIC RADIOLOGY



MAMMOGRAPHY



**RADIOGRAPHY &
FLUOROSCOPY**



**COMPUTED
TOMOGRAPHY**



OPG

**INTERVENTIONAL
RADIOLOGY**



QA Tests Equipment



Multimeter



Survey meter



Tissue Equivalent Phantom

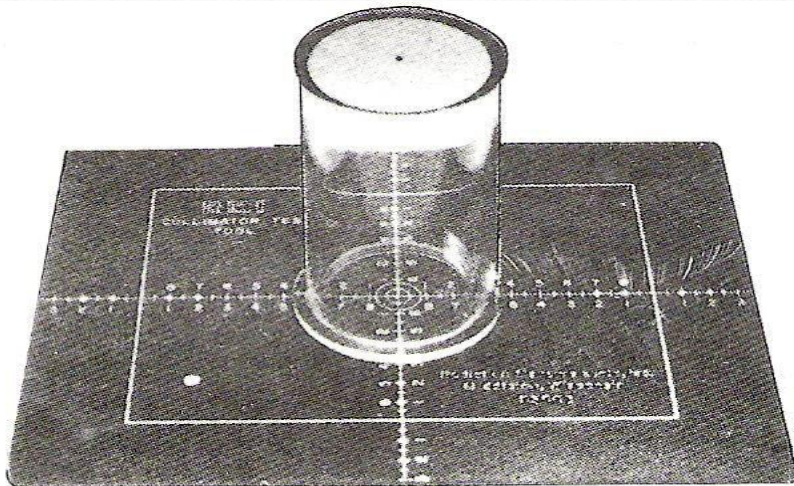


Fig. 4.9: The beam alignment test tool



CATPHAN



Al filter

Parameters affecting image quality

- Operating Potential
- Operating Current
- Exposure Time
- Effective Focal Spot Size
- Total Filtration
- Leakage from tube housing
- Detector Characteristics

Quality Assurance Tests for Diagnostic X-ray Equipment

- Congruence of radiation and optical fields
- Central beam alignment
- Effective Focal spot size measurement
- Timer Accuracy
- Accuracy of Accelerating Tube Potential
- Linearity of radiation output
- Reproducibility of radiation output
- Total filtration
- Radiation leakage through tube housing
- Exposure rate at tabletop
- Fluoroscopic image quality parameters

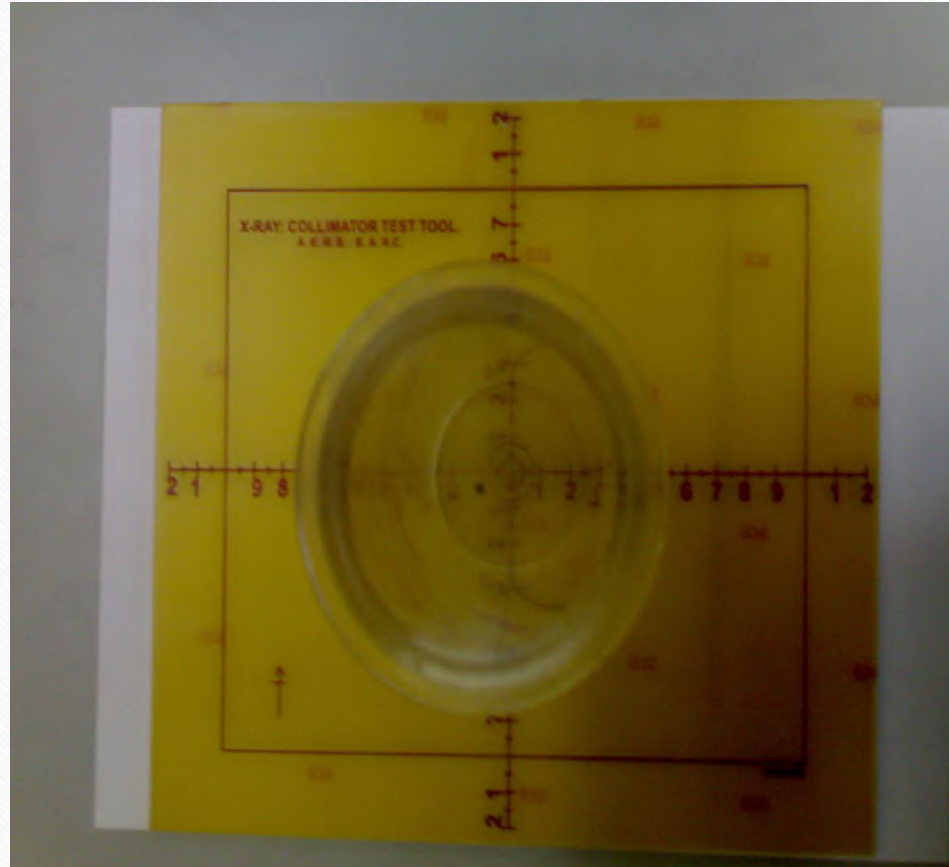
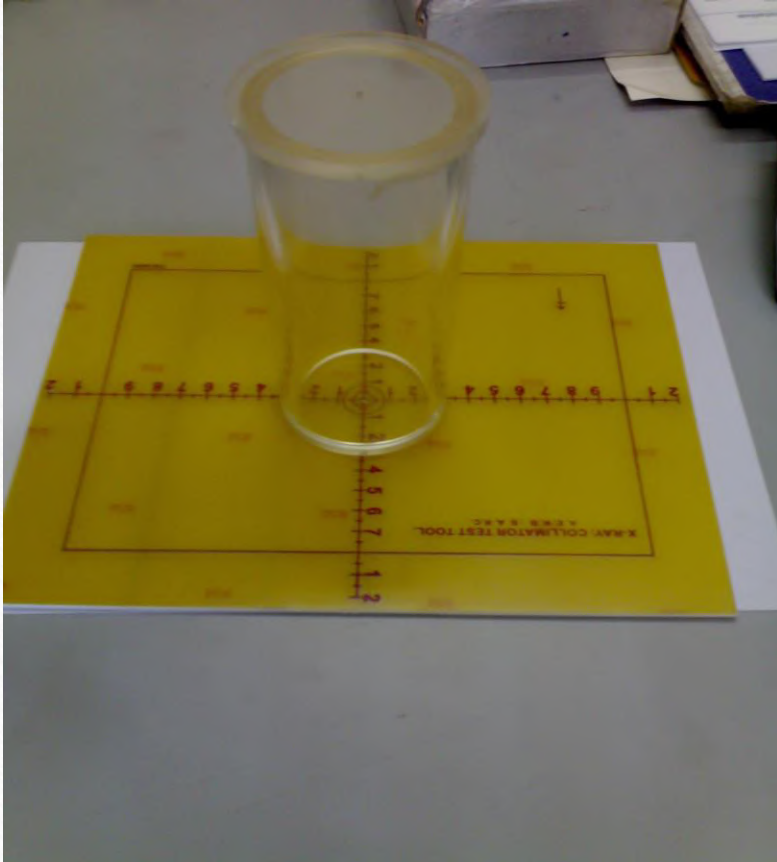
Congruence of Radiation and Optical Fields

- The X-ray field must be aligned with the light field so that the operator can accurately position the body part to be imaged.
- **If the optical field and radiation field are not congruent, the area of clinical interest may be missed in the radiograph leading to retakes and unnecessary radiation exposure to patients.**

$$\text{Tolerance: } |a_1| + |a_2| \leq 0.02 \text{ of } S$$

Here S represents the focal spot to image receptor distance and a_1 and a_2 are the discrepancies in one dimension of imaging field.

Congruence of Radiation and Optical Fields and Beam Alignment



Beam alignment test tool

Central Beam Alignment

- If the x-ray beam is not perpendicular to the image receptor, the image may be distorted. If grid is used, the distortion will be magnified resulting in complete loss of minute details.
- Beam alignment test can be done simultaneously with the test for congruence of optical and radiation field
- Tolerance Central beam alignment $< 1.5^\circ$

Quality Assurance Tests for Diagnostic X-ray (R/R&F) Equipment....

Effective Focal Spot Size measurements:

- Focal Spot size is defined in two ways:

The actual focal spot size is the area on the anode that is struck by electrons and it is primarily determined by the length of cathode filament and the width of the focusing cup slot.

The effective focal spot size is the length and width of the focal spot as projected down the central ray in the x-ray field.

The effective focal width is equal to the actual focal width and therefore is not affected by the anode angle. However, the anode angle causes the effective focal spot length to be smaller than the actual focal spot length.

$$\text{Effective focal length} = \text{Actual focal length} \times \sin \theta$$

Here, θ is the anode angle

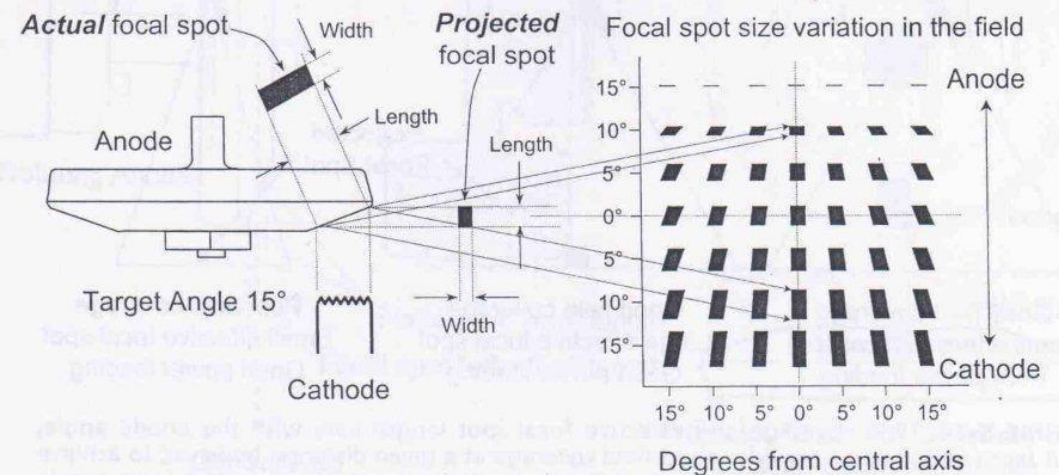


FIGURE 5-15. Variation of the effective focal spot size in the image field occurs along the anode-cathode direction. Focal spot distributions are plotted as a function of projection angle in degrees from the central axis, the parallel (vertical axis), and the perpendicular (horizontal axis).

Quality Assurance Tests for Diagnostic X-ray (R/R&F) Equipment....

Effective Focal Spot Size Measurements:

Tools used for effective focal spot size measurements:

- Pinhole camera
- Slit camera
- Star pattern
- Resolution bar pattern

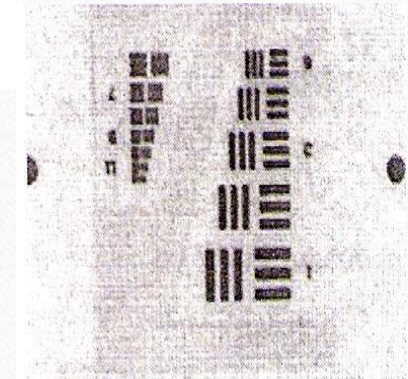
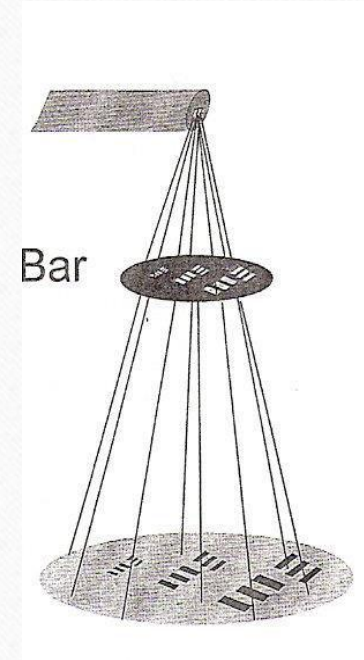
Tolerance:

for $f < 0.8$ mm $+0.5 f$

for $0.8 \leq f \leq 1.5$ mm $+0.4 f$

for $f > 1.5$ mm $+0.3f$

Bar pattern images demonstrate the effective resolution parallel and perpendicular to the A-C axis for a given magnification geometry.



Accelerating Potential (kVp)

- The peak potential of the x-ray generator affects quality of the x-ray beam and exposure to the patient.
- Presently solid – state detectors, which employ non-invasive method for peak tube potential measurement are quite handy for this test.
- **Assessment of the tube potential ensures that the delivered kVp is close to that set on the equipment by the operator.**

Accelerating Potential (kVp)



Tolerance : ± 5 kV

Accuracy of Exposure Timer

- If the exposure time of the x-ray unit is not in order, the radiograph can be under exposed or overexposed.
- For this, absolute timer method is adopted by measuring set and measured time with digital timers.

Tolerance:

Accuracy of exposure timer % Error ± 10 %

Linearity of mA loading stations

- The tube current (mA) is equal to the number of electrons flowing from the cathode to the anode per unit time.
- The exposure of the beam for a given kVp and filtration is proportional to the tube current.
- **This test is carried out to check the linearity of radiation output with respect to change in tube current (mA) stations by keeping timer station constant at a particular kV station.**

Linearity of mA loading stations (contd..)

FFD=100 cm

Radiation field size = 20 cm x 20 cm

- Keeping exposure time and kVp constant, radiation output is measured at different mA stations.
- Measurement for mA loading station is to be repeated for a number of times each to eliminate statistical errors.
- Radiation output readings of each mA loading station readings are averaged and the coefficient of linearity (CoL) is evaluated from average mR/mAs or mGy/mAs as follows:



Dose measuring instrument



Coefficient of linearity = $(X_{\max} - X_{\min}) \div (X_{\max} + X_{\min})$

Tolerance: Coefficient of Linearity < 0.1

Linearity of timer loading stations

- The exposure time is the duration of X-ray production.
- Keeping the kVp and mA constant, radiation output is measured at different timer stations and Coefficient of Linearity is evaluated.

This test is carried out to check the linearity of radiation output with respect to change in timer stations by keeping mA station constant at a particular kV station.

- Tolerance: Coefficient of timer linearity < 0.1

Output Consistency

- To check the constancy of radiation output
- Keeping fixed mA and time, radiation output is measured at various available kV stations. Average(\bar{X}) of (mR/mAs) or (mGy/mAs) is calculated.
- Consistency at each kV station is checked by evaluating the coefficient of variation.

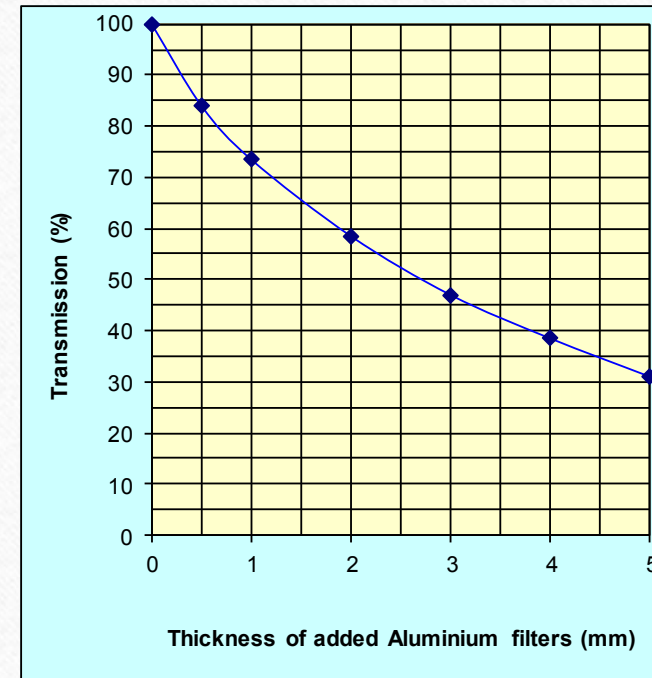
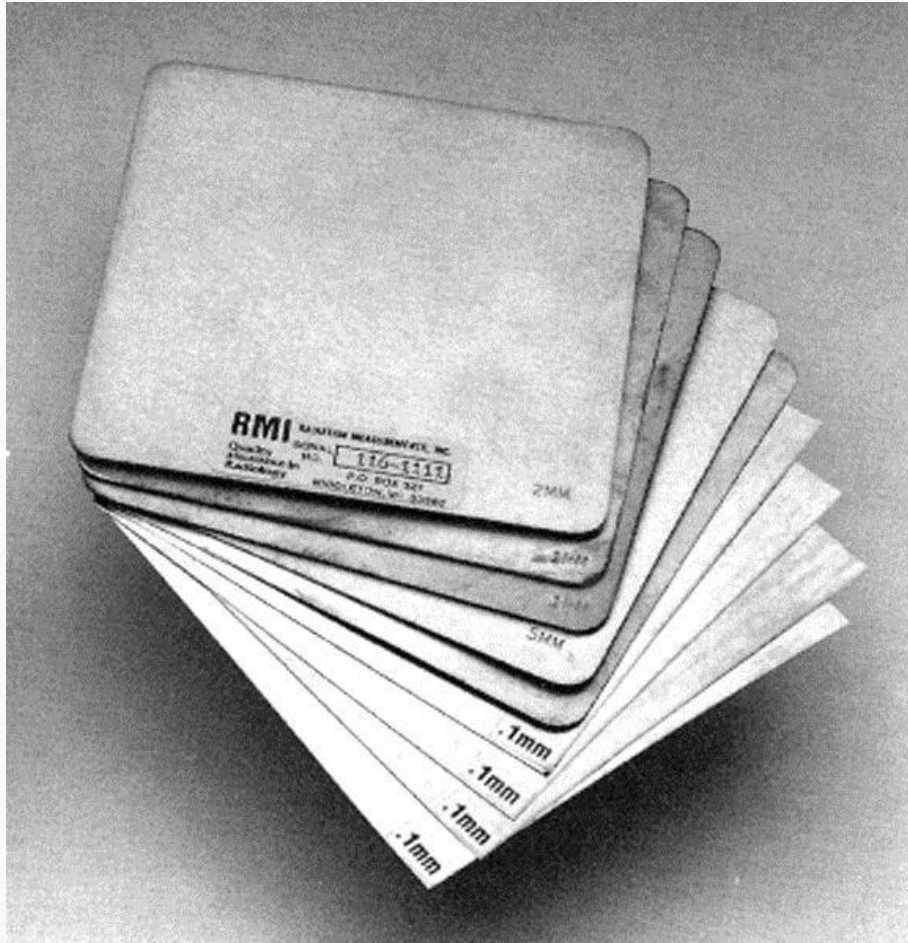
Coefficient of variation

- $COV = 1/\bar{X} \times [(\sum (X_i - \bar{X})^2) / (n-1)]^{1/2}$
- Tolerance : Coefficient of Variation < 0.05

Total Filtration of X-ray tube

- **To cutoff low energy components from X-ray beam, which do not contribute to diagnostic image formation but result in unnecessary patient exposure.**
- If the filtration is too high, image contrast will be poor and unit will be overloaded. Therefore it is necessary that the total filtration (inherent + added) provided for the X-ray tube be as per the recommended value.
- The determination of half value thickness (HVT) of the X-ray beam is the method of evaluation of total aluminum equivalent filtration of the X-ray tube.

Evaluation of HVL and Total Filtration



- Total aluminum equivalent filtration of the x-ray tube is evaluated by determining the half value thickness of the beam.
- Transmission curve of the x-ray beam can be prepared by plotting a graph between the absorber thickness and corresponding percentage transmission.
- **The absorber thickness for 50 % transmission will be the half value thickness of the x-ray beam.**
- Total aluminum filtration could be determined from HVT using calibration tables.
- **Presently, new solid state detectors directly gives the values of HVT and total filtration used in diagnostic X-ray equipment.**

Minimum Filtration for X-ray tubes

For ensuring radiation quality of the x-ray beam, the total filtration in the x-ray source assembly shall comply with the Half- Value Layer requirements.

Material Used : Aluminum filters of purity 99.99% or higher and density 2.70 g cm^{-3}

Tolerance : 1.5 mm Al for $kV \leq 70$
2.0 mm Al for $70 \leq kV \leq 100$
2.5 mm Al for $kV > 100$

Aluminum Equivalence of table top (Couch) $\leq 1.2 \text{ mm Al}$

Radiation Leakage Levels from Tube housing



Radiation leakage through tube housing

- The radiation leakage measurement is carried with an ionization chamber/semiconductor based radiation survey meter. For checking the leakage radiation, the collimator of the tube housing should be fully closed and the tube should be energized at maximum rated tube potential and tube current at that kVp.
- The exposure rate at one meter from the focal spot is measured at different locations (anode side, cathode side, front back and top) from the tube housing and collimator.
- From the maximum leakage rate (mR/h) from both tube housing and collimator, **leakage radiation in one hour** is computed on the basis of the workload of the unit.
- Work load = 180 mA-min in one hour

(for Radiography/Radiography & Fluoroscopy/C-Arm/Interventional Radiology/ dental OPG and dental CBCT equipment)

- Work load = 20 mA-min in one hour for dental (Intra- oral) equipment
- Work load = 40 mA-min in one hr for mammography unit

Radiation leakage from tube housing

Max leakage from tube housing

$$= \frac{\text{mA-min in one hour} \times \text{Max. leakage radiation level (mR/hr)}}{60 \text{ min} \times \text{mA used for measurement}}$$

Tolerance limit:

1. Radiation Leakage at 1 m distance from the focus < 1 mGy in one hour

(for Radiography/Radiography & Fluoroscopy/C-Arm/Interventional Radiology/ dental OPG and dental CBCT equipment)

2. Radiation Leakage limit at 5cm from the external surface of mammography unit < 0.02 mGy in one hour

3. Radiation Leakage limit at 1m distance from the focus of dental (intra-oral) unit < 0.25 mGy in one hour

Table Top Dose Rate (Fluoroscopy)

The air kerma rate, measured in air at the position where the central of the useful beam enters the patient, shall be less than **5cGy/min** for units without automatic brightness control (ABC) and less than **10 cGy/min** for units with ABC.

The focus-to-table top distance shall be not less than 30 cm for fluoroscopy equipment.



Quality Assurance Tests for Diagnostic X-ray (R/R&F) Equipment....

Fluoroscopic Image Quality Parameters

High Contrast Resolution or Spatial Resolution

High Contrast or Spatial resolution refers to the ability of imaging system to visualize small detail, and an imaging system has higher spatial resolution if it can demonstrate the presence of smaller objects in the image.

Tolerance: Mesh pattern of 30 lines/inch or bar pattern of 1.5 lp/mm must be resolved.

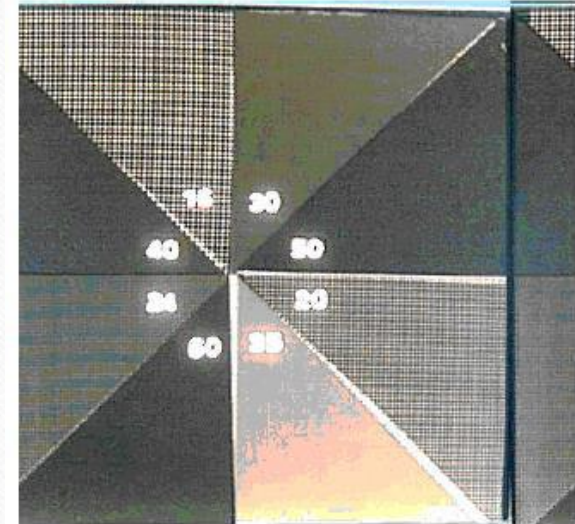


Figure 1. Resolution test tool.

Quality Assurance Tests for Diagnostic X-ray (R/R&F) Equipment....

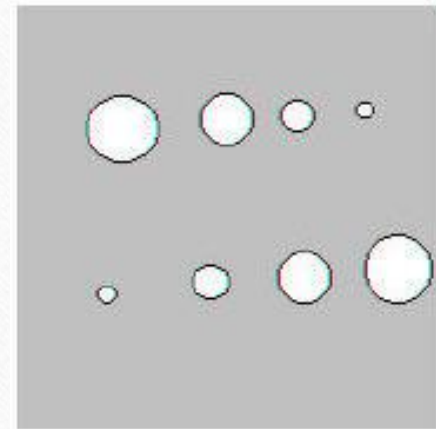
Fluoroscopic Image Quality Parameters

Low Contrast Resolution

Contrast in a radiographic image is the difference in the gray scale of the image.

Low contrast sensitivity refers to the ability of a imaging system to visualize low-contrast objects or structures that differ slightly in radio opacity from the surrounding area.

Tolerance: Minimum diameter of 3 mm hole size of test pattern must be resolved.



Summary of QA Tests

Sr No	Name of QA Test	Tolerance
1	Congruence of radiation and optical field	$ a_1 + a_2 \leq 0.02 \text{ of } S$
2	Central Beam Alignment	Central Beam Alignment $< 1.5^\circ$
3	Effective Focal Size Measurement	$f < 0.8 \text{ mm}$ $+0.5 f$ $0.8 \leq f \leq 1.5 \text{ mm}$ $+0.4 f$ $f > 1.5 \text{ mm}$ $+0.3f$
4	Accuracy of potential (kVp)	$\pm 5 \text{ kV}$
5	Accuracy of exposure time	% Error $\pm 10\%$
6	Linearity of radiation output	CoL < 0.1
7	Output consistency	CoV < 0.05

Summary of QA Tests....

Sr No	Name of QA Test	Tolerance
8	Exposure rate at table top	Exposure Rate without AEC mode ≤ 5 cGy/Min Exposure Rate with AEC mode ≤ 10 cGy/Min
9	Minimum Total Filtration	1.5 mm Al for $kV \leq 70$ 2.0 mm Al for $70 \leq kV \leq 100$ 2.5 mm Al for $kV > 100$
10	Leakage from X-ray tube Housing	1 mGy in 1 hour for R&F equipment 0.02 mGy in one hr for mammography 0.25 mGy in one hour for dental (intra-oral) unit
11	Performance of Imaging System	High contrast resolution : Mesh pattern of 30 lines/inch or bar pattern of 1.5 lp/mm must be resolved Low contrast resolution : 3.0 mm hole pattern must be resolved

Summary/learning Outcomes

- In order to achieve effective diagnostic information, it is essential that diagnostic x-ray equipment meet quality assurance requirements.
- A good diagnostic x-ray procedure is one that provides the highest quality diagnostic information at the lowest radiation risk to the patient, but quality must always take precedence over radiation dose.
- Increased awareness among health professionals will enhance implementation of safety standards in healthcare.

Steps for population dose reduction from diagnostic uses of radiation

- Supply of type approved X-ray units in the country.
- Conducting QA of X-ray equipment at regular intervals.
- Proper training of personnel involved in quality assurance testing of diagnostic X-ray units
- Optimization of X-ray examinations particularly in pediatric studies.

Expected Questions

Q1 - What are the exposure parameters of x-ray unit on which output of x-ray unit depends?

Ans- kVp, mA and time

Q2 -What is the tolerance of operating potential (kV)?

Ans - ± 5 kV

Q3 - What is the tolerance for leakage radiation from tube housing for radiography unit?

Ans – 1 mGy in one hour at 1 m from the focus of tube housing.

Q4 - What is the tolerance for leakage radiation from tube housing for dental (intra-oral) unit?

Ans – 0.25 mGy in one hour at 1 m from the focus of tube housing.

Expected Questions

Q5 - What is the role of filtration in x-ray unit

Ans - To cut-off the low energy components from X-ray beam, which do not contribute to diagnostic image formation but result in unnecessary patient exposure.

Q6 - What is the role of focal spot in image quality

Ans- The ability for resolving the smallest size of the image (i.e detail) in a radiograph depends on the focal spot size. The effective focal spot size is the length and width of the focal spot as projected down the central ray in the X-ray field.

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**

- For AERB QA Formats, visit AERB website: www.aerb.gov.in

<http://www.aerb.gov.in/AERBPortal/pages/English/t/XRay/forms/QAIRCArm.doc>

<http://www.aerb.gov.in/AERBPortal/pages/English/t/XRay/forms/QADental.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