Quality Assurance of a Diagnostic X-ray Machine

Aim:

To perform the quality assurance tests of a Diagnostic X-Ray Machine.

Equipment Required:

1. Diagnostic X-Ray Machine
2. X-Ray QA Kit. (Equipment Details given below)
3. Water/ Slab Phantoms

Theory:

A QA program in diagnostic radiology ensures that the diagnostic images produced are sufficiently high quality. They reliably provide adequate diagnostic information with the lowest possible cost and the least possible exposure of the patient to radiation. A QA program of imaging equipment used in Diagnostic radiology should address the image quality and geometry, including laser/couch and other geometric alignments.

If the image is of poor quality, radiologists may not be able to extract diagnostic information from the radiograph, which may necessitate the repetition of patient examination (retake). Retakes result in unnecessary radiation doses to patients, radiological personnel, and the public. Retakes also result in machine overloading, reducing the tube life. The quality assurance (QA) program in diagnostic x-ray departments aims to obtain good quality images with optimal doses, considerably reducing the chances of retakes and, thereby, patient dose.

The quality assurance (QA) program begins with the performance evaluation tests of the x-ray diagnostic equipment at the manufacturing stage and then the acceptance tests after the installation of the units for users to ensure conformity with the specifications. The QA tests are carried out at regular intervals and after repairs that might affect equipment performance or when equipment malfunctions are suspected.

The responsibility of quality control rests upon the Medical Physicist and the Technical staff of the diagnostic department. The test procedure involves the following steps:

- Carry out the QA tests as per the prescribed procedures
- Record the results
- Analyze the results
- Seek corrective and preventive measures if the results are not satisfactory
- Repeat the tests until satisfactory results are obtained

In QA tests, the accuracy and consistency of various parameters, which influence the quality of diagnostic images and patient dose, are checked. The procedure for each experiment is given below.

- Congruence of optical and radiation fields
- Central beam alignment
- Focal spot size
- Exposure time
- Applied tube potential (kVp)
- Total filtration
- Linearity of mA loading stations
- Consistency of radiation output
- Radiation leakage through tube housing
- Measurement of Low & High Contrast sensitivity
- Radiation protection survey

Details of the QA tools

Pro-RF Basic tool: The Pro-RF BacisTool phantom is a compact general radiography image quality testing phantom. The technical data of the device are given below.

- Outside dimensions: 335x280mm
- High contrast array of 5 and 10mm uniformly pitched mesh
- Highlight and Lowlight details
- 0.6 to 5.0 LP/mm resolution pattern
- 7x 11.0mm diameter low contrast details
- 11x 0.5mm diameter high contrast details
- Extra stand for the spatial resolution pattern for focal spot size evaluation
- cone for the perpendicular X-Ray beam control in the range of 0° - 1.5°
- 1mm Cu filter
- An area of uniform attenuation suitable for noise measurements

All test structures are marked on the surface of the phantom, making it easy to identify them on the X-ray image.

Cobia Smart R/F consists of solid-state detectors that measure kVp, time, dose, dose rate, total filtration, and HVL.

RTI Scatter Probe consists of Flat solid-state detectors used to measure the leakage radiation from X-ray tube housing in terms of Air Kerma rate.

Ocean Next Software is associated with the above QA tools for evaluation and analysis of the test results.

Procedure:

Congruence of Optical and Radiation Fields

The optical field in the X-ray equipment is used for defining the radiation field. This optical field is limited to the area of clinical interest in the patient. This shift may be caused due to the shift in the mirror position or the collimator position. If the optical and radiation field is not congruent, the area of clinical interest may be missed in the radiograph leading to retake and unnecessary radiation dose to patients.

Place the phantom on the table, between the image detector and the X-ray tube in such a way that the phantom so its center and main axis align with the markers of the apparatus. Limit the light field to the chosen rectangular marking on the phantom surface. Make the exposure. Measure the distance between the light field borders and actual X-ray beam borders (Shown on the X-ray picture) in perpendicular and parallel directions. Use a clearly marked scale on the phantom. The sum of differences between the light and the X-ray field in perpendicular and parallel directions should not be greater than 2% of the FFD (Focal spot to Film distance).

Central beam alignment:

The image may be distorted if the X-ray beam is not perpendicular to the image receptor (Detector). For this test, screw the optional cone on the phantom. The optional cone has a stainless-steel ball on the top and a circular steel patch at the bottom. Make the exposure. If the image of the ball lies entirely within the image of the circular patch, then the deviation of the beam from the tube axis is not more significant than 1.5°.

Focal spot size:

The ability to resolve the smallest image size (i.e., Spatial Resolution) in a radiograph depends on the focal spot size. Since the focal spot size may be altered due to the bombardment of electrons with the target, it must be checked periodically to ensure that it is within acceptable limits.

Focal spot size is evaluated on the principle of minimum resolution and a Bar/hole test pattern is employed for evaluating focal spot size. At minimum resolution, the edge gradient (penumbra) of one pattern of the pair merges with the image of the other, and the images of both patterns of the pair cannot be resolved separately. When this happens, focal spot size (f), line width, and Magnification (M) are related as follows:

$$f = \frac{M}{(M-1)} \; X \; Line \; Width$$

To perform this test, a resolution bar pattern is mounted on the phantom such that the source-to-pattern distance is three times the pattern-to-film/detector distance. The resolution bar pattern consists of several groups of lines (slits) of sizes gradually decreasing in dimension. Expose the bar pattern. Perform two measurements in two bar pattern positions: parallel and perpendicular to the bottom edge of the phantom. A given pattern must be resolved in both directions to count. From the resolved Line Width, the focal spot size can be calculated using the above formula.

Exposure time/ Timer:

If the exposure time of the X-ray diagnostic unit is not in order, the radiograph can be underexposed or overexposed. There may be a change in the adequate tissue contrast resolution in the image. The Cobia Smart R/F detector can measure the exposure time.

Measurement of Peak Kilovoltage (kVp)

The applied kilovoltage affects the quality and quantity of X-rays reaching the image receptor (Detector) and hence the contrast and density of the radiograph. Since any variation from the set kVp can affect the quality of the radiograph, the kVp settings must be checked periodically. kVp can be measured by the Cobia Smart R/F.

Evaluation of Total Filtration of the X-ray Tube

A specific minimum filtration must be present in the X-ray tube to cut off low-energy components from the X-ray beam. These low-energy components do not contribute to image formation but result in unnecessary patient exposure. If the filtration is too high, the attenuation will be more and image contrast will be reduced. Therefore, the total filtration for the X-ray tube should be optimum for patient safety and image quality. For this purpose, regulatory bodies (AERB) recommend total filtration for X-Ray machines for different maximum-rated tube potentials. Total filtration includes inherent filtration and added filtration. Hence total filtration evaluation is necessary to verify whether the added filtration is adequate. If not adequate, additional filtration must be provided for the x-ray tube. The Cobia Smart R/F detector can measure the total filtration.

Linearity of the mA loading station

Keeping the kVp and time constant, the radiation output is measured at different mA stations. Measurement for each mA station is to be repeated for several times to eliminate statistical errors. Each mA station reading is averaged, and the coefficient of linearity (COL) is evaluated from average mR/ mAs or mGy/ mAs (X) as follows. The tolerance is 0.1.

$$Coefficient \; of \; Linearity = \frac{x_{max} - x_{min}}{x_{max} + x_{min}}$$

Consistency (reproducibility) of radiation output

Keeping fixed mA and time, radiation output is measured at various available kVp stations. The average of mR/mAs (mGy/mAs) is calculated (X). Consistency at each kVp station is checked by evaluating the Coefficient of Variation (COV). The COV should not exceed 0.05.

$$\boldsymbol{COV = \frac{1}{X}\sqrt{\frac{(X_i - X)^2}{(n-1)}}}$$

Radiation leakage through Tube Housing

As per AERB Safety Code on Diagnostic X-ray Equipment and installations, every housing for medical diagnostic X-ray equipment shall be so constructed that the leakage radiation through the protective tube housing in any direction shall not exceed an air kerma of 1.0mGy (about 114mR) in one hour at 1.0m from the x-ray target. The measurement conditions are given below.

- Averaged over an area not larger than 100 cm^2
- No linear dimension greater than 20cm
- Operating at maximum rated kVp and for the maximum rated current at that kVp.

The radiation leakage measurement is carried out with an ionization radiation survey meter. For checking the leakage radiation, the collimator of the tube housing is fully closed. The operating time should be greater than the time constant of the survey meter. The exposure rate at one meter from the target is measured at different locations (anode side, cathode side, front back, and top) from the tube housing and collimator. For the maximum leakage rate (mR/h) for both tube housing and collimator, leakage in one hour is computed based on the workload of the machine. 180mA-min in one hour is taken as the maximum workload of a diagnostic machine.

Hence leakage in one hour will be:

$$Leakage\ in\ 1\ hr = \frac{Maximum\ Leakage\ (mR/min)\ X\ \ 180mA - min}{Applied\ mA}$$

Measurement of Low Contrast Sensitivity

Low contrast sensitivity refers to the ability of a system to visualize low-contrast objects or structures. In clinical practice, patient diagnoses are frequently made on the perception of the fluoroscopic image of small low-contrast anatomic structures. The number of visible low-contrast objects should not change over time.

High Contrast Sensitivity / Spatial Resolution

This test allows for a simple evaluation of system resolution to ensure that optimal anatomic detail is visible to the practitioner. High contrast resolution is essential for all fluoroscopic procedures. Using the zoom tool, assess the Line Pairs per millimeter resolution. It is the highest number next to the group of lines where three separate lines can be distinguished.

Radiation Protection Survey

A radiation protection survey is a series of measurements of radiation levels at various locations around the diagnostic X-Ray machine installation. This is done to check whether the radiation levels around the building are within the permissible limits as mandated by the Competent Authority (AERB). A pressurized ion chamber-based survey meter is used to measure the radiation levels.

The filled datasheet of AERB is given below for demonstration purpose. It can be downloaded from:

https://www.aerb.gov.in/images/PDF/DiagnosticRadiology/1-FORMAT-FOR-QUALITY-ASSURANCE-TEST-FOR-DIAGNOSTIC-X-RAY-EQUIPMENT.pdf

FORMAT FOR QUALITY ASSURANCE TEST FOR DIAGNOSTIC X-RAY EQUIPMENT
(*Applicable for Radiography/Radiography & Fluoroscopy/C-Arm/Interventional Radiology Equipment)*

(Periodic Quality Assurance shall be carried out at least once in two years and after any repairs having radiation safety implications)

A. DETAILS OF THE DIAGNOSTIC X-RAY EQUIPMENT

1	Name of the Institution and City	
2	Type of Equipment	
3	Model Name	
4	Name of the Manufacturer	
5	Name(s) of Person(s) testing the equipment and Name of Supplier/Service Agency	
6	Dates and Duration of the Tests	

1. CONGRUENCE OF RADIATION & OPTICAL FIELD

Operating parameters:

FFD (cm)	100	kV	60	mAs	5

Shift in the edges of the radiation field.				
Dimensions (cm)	Observed shift	% of FFD	Tolerance	Remark
I X I +I X' I	0.8	0.8%	2% of FFD	
I Y I +I Y' I	1.2	1.2%	2% of FFD	

2. CENTRAL BEAM ALIGNMENT

Operating parameters:

FFD (cm)	100	kV	60	mAs	5

Observe the images of the two steel balls on the radiograph and evaluate the tilt in the central beam.		
Observed tilt	< 1.5°	Remark
Tolerance: Central Beam Alignment < 1.5°		

3. EFFECTIVE FOCAL SPOT MEASUREMENT

FDD (cm)	60

	The stated value of Focal Spot Size (mm x mm)	The measured value of Focal Spot Size (mm x mm)	Tolerance: 1. + 0.5 f for f < 0.08 mm 2. +0.4 f for 0.8 ≤ f ≤ 1.5 mm 3. + 0.3 f for f . 1.5 mm
Large Focus	2	2.2	
Small Focus	1	1.8	

4. ACCURACY OF OPERATING POTENTIAL

Applied kVp	Set time (s)	Measured values								
		mA stations								
		Minimum mA station		Routinely used mA station		Maximum mA station		Average kVp	Average Time (s)	Remark
		kVp	Time (s)	kVp	Time (s)	kVp	Time (s)			
60	50	60.15	49.95	61.3	50.61	63.65	49.4	61.7	49.98	
80	50	80.9	51.62	80.4	49.66	79.05	49.69	80.1	50.32	
100	50	101.2	51.91	100.7	50.21	102.3	49.55	101.4	50.55	
120	50	122.5	53.48	120.5	49.92	120.3	49.63	121.1	51.01	
Max. kVp	Tolerance for kVp: ± 5 kV Tolerance for Timer: % Error: ± 10% Total Filtration (measurement at maximum kVp): 3.2 mm of AL Tolerance for Total Filtration: 1.5 mm Al for for kV ≤ 70, 2.0mm Al for kV ≤ 100, 2.5 mm Al for kV > 100									

5. LINEARITY OF (mA/mAs) LOADING STATIONS

Operating parameters:

FFD (cm)	100	KV	120	Time (s)	0.05

mA applied	Radion Output (mGy)			Average Output	mGy / mAs (X)	Coefficient of Linearity (CoL)	Remarks
	Reading 1	Reading 2	Reading 3	(mGy)			
250	1.457	1.451	1.469	1.459	0.11672	0.0135	
200	1.176	1.143	1.182	1.167	0.1167		
160	0.848	0.934	0.944	0.9085	0.1136		
Tolerance: COL < 0.1							

6. OUTPUT CONSISTENCY

FFD (cm)	100

Applied kV	mAs	Radiation Output (mGy)					Average (X)	Coefficient of Variation (COV)	Remarks
		1	2	3	4	5			
80	10	0.5757	0.5752	0.5764	0.5749	0.5763	0.5757	0.00114	
120	5	0.6473	0.6336	0.6340	0.6334	0.6327	0.6362	0.00978	
Tolerance: CoV < 0.05									

7. LOW CONTRAST SENSITIVITY

The diameter of the smallest size hole resolved on the monitor	1.0 mm
Recommended performance standard	3.0 mm hole pattern must be resolved

8. HIGH CONTRAST SENSITIVITY

Bar strips resolved on the monitor (lp/mm)	2.2 lp/mm

Recommended performance standard	1.5 lp/mm pattern must be resolved

9. TUBE HOUSING LEAKAGE

Operating parameters:

FDD (cm)	100	kVp (Max) = 120	mA	200	Time(s)	≈ 1 sec

Location (At 1.0m from the focus)	Exposure level (μGy/hr)					Result
	Left	Right	Front	Back	Top	
Tube	7675	11220	3293	2618	6941	
Collimator	2893	7949	3065	5033	12960	
Tolerance: Maximum leakage radiation level at 1 meter from the focus should be ≤ 1 mGy (114mR) in one hour.						

Work load 180 mAmin in one hr

Max leakage = $\frac{\text{180 mAmin in 1hr X----- Max Exposure level (mR/hr)}}{\text{60 X -----mA used for measurement}}$

Maximum radiation leakage from tube housing = 16.83 mR in one hour

Maximum radiation leakage from tube collimator = 19.44 mR in one hour

10. DETAILS OF RADIATION PROTECTION SURVEY OF THE INSTALLATION

Date of radiation protection survey:
Whether the radiation survey meter used for the survey has a valid calibration certificate: Yes

Equipment Setting: -
Applied Voltage (kV): 120
Applied Current (mA): 100
Exposure time(s): 1s
Workload: 500mA-min/wk
Provide the measured maximum radiation levels (mR/hr) at different locations

Location	Max. Radiation level (mR/hr)	Weekly Radiation Level (mR/week)
Control console (Operator Position)	0.95	0.079
Outside the patient entrance door	0.1	0.0083
Behind windows (if applicable)	NA	NA
Patient Waiting Area	0.03	0.0025

Maximum Radiation level /week (mR/wk) = $\frac{\text{---- mAmin/week X ----Max. Radiation level (mR/hr)}}{\text{60 X ----mA used for measurement}}$

Permissible limit

For the location of Radiation Workers: 20 mSv in a year (40 mR/week)
For the location of Member of Public: 1 mSv in a year (2mR/week)