# Quality Assurance of a Diagnostic CT Machine

Lab report

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# 1 Aim of the experiment

To perform the Quality Assurance tests of a Diagnostic CT Machine.

# 2 Apparatus

1. CT simulator machine
2. CT QA Kit: Pro CT mini Phantom
3. Pocket Dosimeter
4. 100mm pencil ionisation chamber

# 3 Theory

The goals of a CT-simulation QA program are to assure safe and accurate operation of the CT-simulation process as a whole. The QA program design should include tests which will assure accurate target and critical structure localization and accurate placement of treatment beams with respect to a volumetric CT-scan of a patient. Another goal of the QA program is optimization of image quality and dose to the patient.

When new equipment is installed, acceptance testing at the customer's end for the first time and periodic QA of this equipment are mandatory requirements per AERB guidelines. The quality assurance tests for CT equipment fall into four categories:

1. Mechanical tests
2. Tests for High-Frequency generators
3. Image Quality Parameters
4. Radiation Safety

## 3.1 Tests for High-Frequency Generators

### 3.1.1 Accuracy of operating potential (kVp)

The applied kilovoltage affects the quality and quan-tity 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.

Tolerance: $\pm 5kV$

### 3.1.2 Accuracy of time

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 and resolution in the image.

Tolerance: $\pm 10\%$

### 3.1.3 Total Filteration

A minimum filtration must be added to the X-ray tube to remove low-energy components from the X-ray beam. These low-energy components do not contribute to image for-mation but result in unnecessary patient exposure. If the filtration is too high, the attenuation will be greater, 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, the regulatory body (AERB) recommends 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.

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

### 3.1.4 Linearity of radiation output (mA/mAs linearity)

Keeping the kVp and time constant, the radiation output is measured at different mA stations. Each mA station reading is averaged, and the coefficient of linearity (COL) is evaluated from average mR/mAs or mGy/ mAs (X) as follows:

$$Coefficient\ of\ linearity\ (COL) = \frac{x_{max} - x_{min}}{x_{max} + x_{min}} \tag{1}$$

Tolerance: COL $< 0.1$

### 3.1.5 Consistency (reproducibility) of radiation output

The radiation output of the diagnostic X-ray machine must be consistent for a particular set of kVp and timer values. 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). Coefficient of Variation,

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

Tolerance: COV $< 0.05$

## 3.2 Image Quality tests

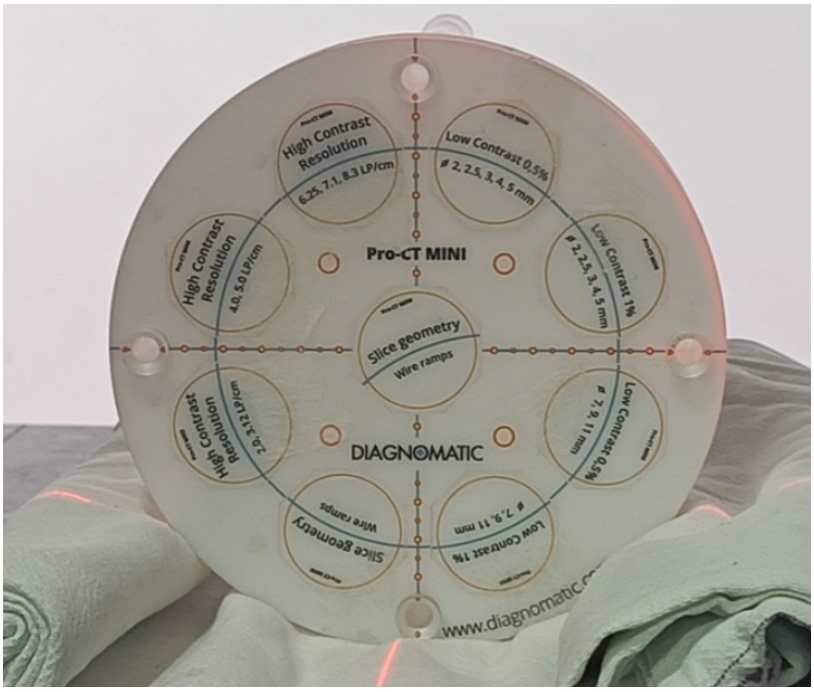


Figure 1: Pro-Ct MINI phantom

### 3.2.1 High Contrast Resolution

High contrast resolution (spatial resolution) is an image quality parameter related to the imaging system's ability to visualize objects with small dimensions and high contrast relative to the background. In medical imaging, including CT, higher spatial resolution is desirable as it allows for the visualization of fine anatomical structures, smaller lesions, and more precise evaluation of subtle abnormalities. It provides greater clarity and detail in the images. The high contrast resolution determines the minimum size of detail visualized in the plane of the slice with a contrast difference $> 10$ % with respect to background. It is affected by:

- The reconstruction algorithm

- Detector width
- Effective slice thickness
- Object to detector distance
- X-ray tube focal spot size

Either qualitative (based on visual assessment) or quantitative methods can be used to assess spatial resolution, depending on local regulations and adopted standards. Spatial frequency, typically expressed in line pairs per centimeter (LP/cm), is a parameter used to describe the level of detail or the number of line pairs within a specific distance in an imaging system. It quantifies the frequency of repetitive patterns or alternating high-contrast lines in an image.

The **Pro-CT Mini phantom** includes 4 high contrast resolution inserts containing 11 aluminium bar patterns in the range of spatial frequencies from 1 to 11 LP/cm. Optional set of 3 inserts contain additional 19 bar patterns covering the extended range from 12 to 30 LP/cm. Each insert can contain 2 to 4 bar patterns. Their spatial frequencies are specified on the label. One should visually inspect the bar patterns in the Pro-CT Mini images in terms of sharpness, clarity, and visibility of the individual lines. The assessment should be performed using reading station. The window width and the window level (contrast and brightness) should be adjusted to obtain optimal visualization of the test objects. Using the zoom tool is recommended as well. Consequently, the highest spatial frequency at which the bar pattern is reliably discernible should be determined. The observer evaluates whether the bars appear distinct and well-defined or if they blend together or become indistinguishable at certain spatial frequencies.

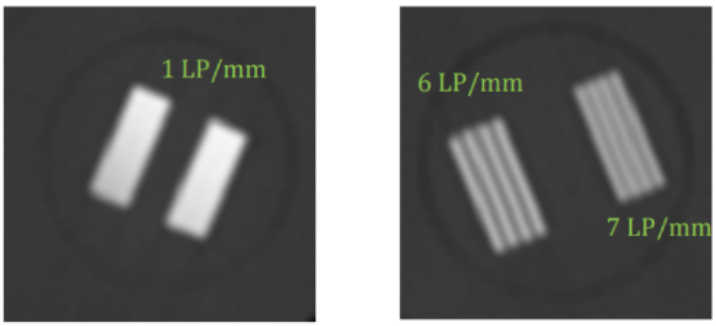


Figure 2: CT images of the high contrast resolution insert

### 3.2.2 Low Contrast Resolution

Low contrast performance refers to the ability of the imaging system to detect small differences in contrast between adjacent structures or tissues in the body. This is particularly important as many diseases and conditions manifest as subtle changes in tissue contrast. The low contrast resolution of a CT system depends on several factors including the X-ray energy spectrum, detector efficiency, noise characteristics and image reconstruction algorithm. Dedicated phantoms allow the evaluation of contrast visibility for standardised objects for quality control or imaging optimisation purposes. The **Pro-CT Mini phantom** contains 3 low contrast inserts differing in nominal contrast value:0.3 %, 0.6 % and 1.0 %. Each of these inserts consists of 2 merged parts (A and B). One contains test rods with diameters of 14 mm, 10 mm, 6 mm and 2 mm, while the other contains 12 mm, 8 mm, 5 mm and 4 mm.

All rods are 9.5 mm in height. The design of the piece is shown in the figure below.

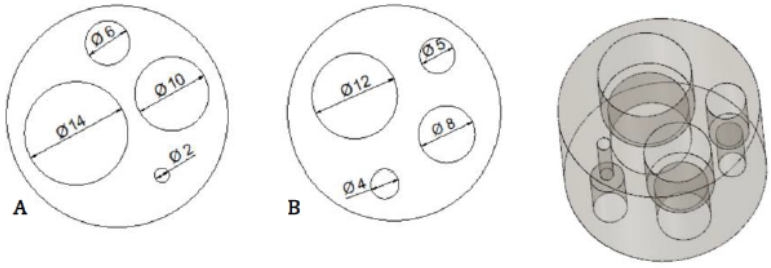


Figure 3: Pro-CT MINI low contrast insert - part A & B and visualisation of the insert structure. Rods diameters are given in mm

Low contrast performance can be qualitatively evaluated by visual evaluation of the low contrast test objects in the in the Pro-CT Mini images. This method is based on the determination of the threshold diameter at which an object of a given nominal contrast becomes indistinguishable from the background. The assessment should be performed using reading station. The window width and the window level (contrast and brightness) should be adjusted by observer to obtain optimal visualization of the test objects. Using the zoom tool is recommended as well.

## 3.3 Radiation Safety

### 3.3.1 Radiation Dose Test (CTDI)

**CTDI** represents the average absorbed dose, along the z-axis, from a series of contiguous irradiations. It is measured from one axial CT scan (one rotation of the x-ray tube), and is calculated by dividing the integrated absorbed dose by the nominal total beam collimation.

$$CTDI = \frac{1}{NT}\int_{-\infty}^{\infty} D(z)dz \tag{3}$$

Where,

$D(z)$ = the radiation dose profile along the z-axis,

$N$ = the number of tomographic sections imaged in a single axial scan. This is equal to the number of data channels used in a particular scan.

$T$ = the width of the tomographic section along the z-axis imaged by one data channel. In single-detector-row (single-slice) CT, the z-axis collimation (T) is the nominal scan width.

$MSAD$ : The MSAD represents the average dose over a small interval (I/2, I/2) about the center of the scan length (z = 0) for a scan interval I, but requires multiple exposures for its direct measurement.

The CTDI offered a more convenient yet nominally equivalent method of estimating this value, and required only a single-scan acquisition, which in the early days of CT, saved a considerable amount of time.

The average dose parallel to the scan axis over an interval I in length is independent of position. The multiple scan average dose (MSAD) is defined as:

$$MSDA = \frac{1}{I}\int_{-I/2}^{+I/2} D_{N,I}(z)dz \tag{4}$$

where $D_{N,I}(z)$ is the dose as a function of position for a multiple scan dose profile consisting of N scans separated by a constant distance between scans equal to I.

$CTDI_{FDA}$ : Theoretically, the equivalence of the MSAD and the CTDI requires that all contributions from the tails of the radiation dose profile be included in the CTDI dose measurement. To standardize CTDI measurements (infinity is not a likely measurement parameter), the FDA introduced the integration limits of ± 7T, where T represented the nominal slice width.

$$CTDI_{FDA} = \frac{1}{NT}\int_{-7T}^{+7T} D(z)dz \tag{5}$$

$CTDI_{100}$ : It represents the accumulated multiple scan dose at the center of a 100-mm scan and underestimates the accumulated dose for longer scan lengths. It is thus smaller than the equilibrium dose or the **MSAD**.

In the case of $CTDI_{100}$, the integration limits are ± 50 mm, which corresponds to the 100-mm length of the commercially available "pencil" ionization chamber.

$$CTDI_{100} = \frac{1}{NT}\int_{-50}^{+50} D(z)dz \tag{6}$$

$CTDI_w$ : The average radiation dose across an axial section of the CTDI phantom is weighted CTDI. The dose distribution imparted by a CT scan is much more homogeneous than that imparted by radiography, but is still somewhat larger near the skin than in the centre of the body. The weighted CTDI was introduced to account for this.

$$CTDI_w = \frac{2}{3}CTDI(Perifery) + \frac{1}{3}CTDI(center) \tag{7}$$

$CTDI_{vol}$ : To represent dose for a specific scan protocol, which almost always involves a series of scans, it is essential to take into account any gaps or overlaps between the x-ray beams from consecutive rotations of the x-ray source. This is accomplished with use of a dose descriptor known as the Volume $CTDI_w$ or $CTDI_{vol}$, where

$$CTDI_{Vol} = \frac{N.T}{I} \times CTDI_w \tag{8}$$

where N is the number of simultaneous axial scans per x-ray source rotation,T is the thickness of one axial scan(mm),and I is the table increment per axial scan(mm).
In spiral CT, the ratio of the table travel per rotation (I)to the total nominal beam width (N.T) is referred to as pitch.Therefore,

$$CTDI_{Vol} = \frac{1}{Pitch} \times CTDI_W \tag{9}$$

The $CTDI_w$ represents the average radiation dose over the x and y directions and the $CTDI_{Vol}$ represents the average radiation dose over the x,y, and z directions. $CTDI_{Vol}$ is useful indicator of the dose for a specific exam protocol, because it takes into account protocol specific information such as pitch.
Dose-Length Product (DLP)is used to define the total energy absorbed by a scanned volume from a given protocol.DLP represents integrated dose along the scan length.

$$DLP(mGycm) = CTDI_{vol}(mGy) \times scanlength(cm). \tag{10}$$

While two scan protocols may have the same $CTDI_{Vol}$, their DLP value may be substantially different due to difference in scanned volume length. Several manufacturers include DLP information on the scanner control console for programmed scan protocols and scan lengths. Now we calculate the Effective Dose from DLP.

$$Effective\ Dose = DLP \times k \tag{11}$$

Unit of k is $(\frac{mSv}{mGy-cm})$

k value is different for different organs,

Table 1: k Values for Different Organs

| **k** | **mSv/ mGy-cm** |
|---|---|
| **Head** | **0.0021** |
| **Neck** | **0.0059** |
| **Chest** | **0.014** |
| **Abdomen** | **0.015** |
| **Pelvis** | **0.015** |

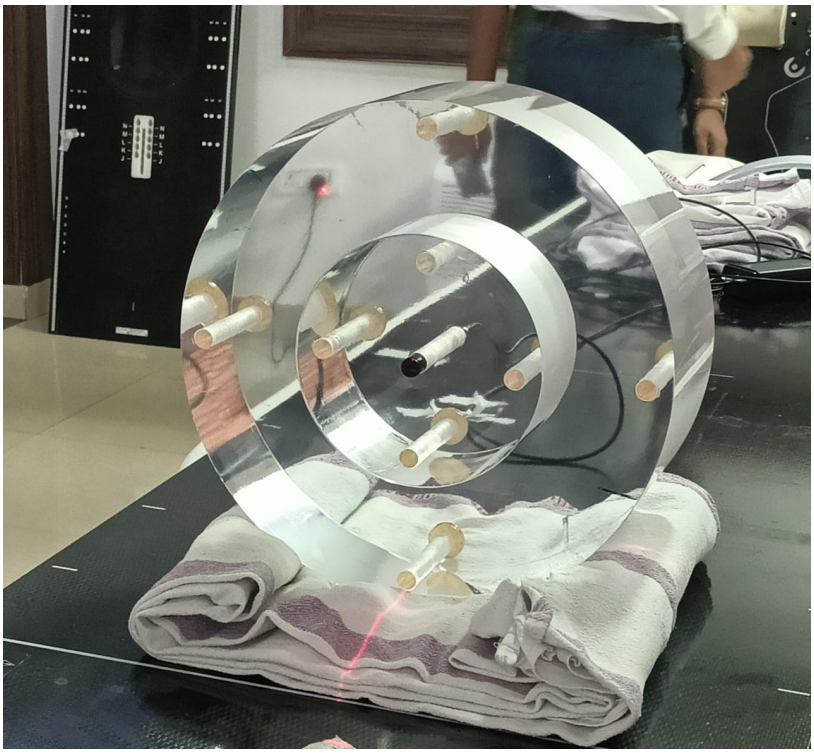

Figure 4: CTDI Head and Body Phantom Setup

**Process**

- Patient dose from a CT scan is assessed by measuring CTDI.
- Pencil ionization chambers of 10cm in length are used for this measurement.
- Two CT dosimetry phantoms are commonly used (a 15cm long, 16cm diameter transparent acrylic cylinder is used for "head" measurements and a 15cm long and 32cm diameter cylinder is used for "body" measurements.
- Five to nine holes are strategically placed in the phantoms to accept the pencil ionization chamber.
- The body phantom is placed on the patient's table, and the head phantom is supported on the headrest.
- Phantoms are aligned and centered at the scan isocenter.
- 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.

### 3.3.2 Measurement of radiation leakage level

As per the 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 a distance of 1.0m from the x-ray target. The measurement conditions are given below:
1. Averaged over an area not larger than 100 cm2
2. No linear dimension greater than 20cm
3. 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. To check 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 on the basis of the machine's workload. 180mA-min in one hour is taken as the maximum workload of a diagnostic machine. Hence, leakage in one hour will be:

**Maximum leakage (mR/60min) x 180mA-min in one hour / Applied mA**

#### 3.3.3 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 installation are within the permissible limits mandated by the Competent Authority (AERB). A pressurized ion chamber-based survey meter is used to measure the radiation levels.

# 4 Observation

## 4.1 Time Accuracy

Table 2: Time accuracy

| **Timer Accuracy** | | |
|---|---|---|
| **Set time (ms)** | **Observed Time (ms)** | **% Error** |
| 1000 | 1008 | 0.8 |
| 1500 | 1508 | 0.53 |
| 500 | 508 | 1.6 |

- **Tolerence:** $\pm 10\%$

## 4.2 Measurement of Operating Voltage

Table 3: Measurement table of Operating Voltage

| **Measurement of Operating Potential** | | | | |
|---|---|---|---|---|
| **Set kV** | **mA station-1 (50 mA)** | **mA station-2 (100 mA)** | **mA station-3 (200 mA)** | **mA station-4 (350 mA)** |
| 100 | 101.94 | 101.67 | 101.38 | 100.89 |
| 120 | 125.89 | 125.61 | 125.21 | 124.78 |
| 140 | 144.44 | 144.19 | 143.72 | 143.39 |

- **Tolerence:** $\pm 2KVp$

## 4.3 mAs Linearity

Table 4: mAs Linearity table

| **mAs Linearity** | | | | | |
|---|---|---|---|---|---|
| **Output (mGy)** | | | | | |
| **mAs** | **i** | **ii** | **Avg.** | **Mean (X) (mGy/mAs)** | **COL** |
| 50 | 2.87 | 2.871 | 2.8705 | 0.0574 | 0.00810 |
| 100 | 5.71 | 5.715 | 5.7125 | 0.0571 | |
| 200 | 11.38 | 11.38 | 11.38 | 0.0569 | |
| 400 | 22.59 | 22.6 | 22.595 | 0.0565 | |

## 4.4 Output Consistancy

Table 5: Output Consistancy table

| Output Consistency (mAs = 120) | | | | | | |
|---|---|---|---|---|---|---|
| **kVp** | **Output (mGy)** | | | **Mean (X)** | **COV** | **HVL (mm Al)** |
| 80 | 2.597 | 2.595 | 2.598 | 0.0216 | 0.505 | 5.57 |
| 100 | 4.557 | 4.555 | 4.557 | 0.0380 | | 6.69 |
| 120 | 6.849 | 6.844 | 6.848 | 0.0571 | | 7.58 |
| 140 | 9.469 | 9.462 | 9.466 | 0.0789 | | 8.36 |

**Tolerance:** Tolerance of COV <0.05

## 4.5 Radiation Protection Survey

Max $KV_P$= 140 Volt
Max mA= 50 A

Table 6: Table of Radiation Protection Survey

| Area | Max. Radiation Level (uR/hr) | Max. Radiation Level (mR/week) |
|---|---|---|
| **Console Gantry Door** | **29** | **0.01740** |
| **Lead glass** | **29** | **0.01740** |
| **Console Operator** | **23** | **0.01380** |
| **CT entrance door** | **30** | **0.01800** |
| **Console entrance** | **27** | **0.01620** |

$$max\ Radiation\ level/week = \frac{1800mA - min/week \times maxradiation\ mR/hr}{60 \times mA\ used\ for\ measurment} \tag{12}$$

Maximum radiation level in location of radiation worker = 0.01740 mR/week
Maximum radiation level in location of public = 0.01620 mR/week

**Tolerance:**

- 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)

## 4.6 Measurement of CTDI

Table 7: CTDI data

| CT Phantom Type | Position | CT exposure (mGy-cm) | CTDI (mGy) | Mean Dose (mGy) |
|---|---|---|---|---|
| Body | (A) centre | 53.37 | 106.7 | 106.7 |
| Body | (B) 12 'o' clock | 104.3 | 208.7 | 232.025 |
| Body | (C) 3 'o' clock | 117.2 | 234.5 | |
| Body | (D) 6 'o' clock | 117.9 | 235.7 | |
| Body | (E) 9 'o' clock | 124.6 | 249.2 | |
| | | | | |
| Head | (A) centre | 95.36 | 190.7 | 190.7 |
| Head | (B) 12 'o' clock | 128.5 | 257.1 | 215.75 |
| Head | (C) 3 'o' clock | 98.36 | 196.7 | |
| Head | (D) 6 'o' clock | 88.68 | 177.4 | |
| Head | (E) 9 'o' clock | 115.9 | 231.8 | |

$$CTDI_w = \frac{2}{3}CTDI(Perifery) + \frac{1}{3}CTDI(center)$$

$$For\ Head\ Phantom,\ CTDI_{whead} = 207.4mGy$$

$$For\ body\ Phantom,\ CTDI_{wphantom} = 190.25mGy$$

## 4.7 Low Contrast Resolution

Operating potential, kVp = 120 V
mAs = 477
Slice thickness = 2.5 mm
Low contrast resolution: 2.5 mm at 0.5% contrast
2 mm at 1% contrast
Tolerance: 5.0 mm at 1% contrast difference (minimum)
2.5 mm at 0.5 % contrast difference (expected)

Figure 5: Observed low contrast part of the phantom

## 4.8 High Contrast Resolution

Operating potential, kVp = 120 V
mAs = 477
Slice thickness = 2.5 mm
Size of the smallest resolvable bar/hole pattern: 5 lp/cm.
Tolerance: At 10% contrast difference, the 1.6 mm (6.25 lp/cm) bar/hole pattern should be resolved.

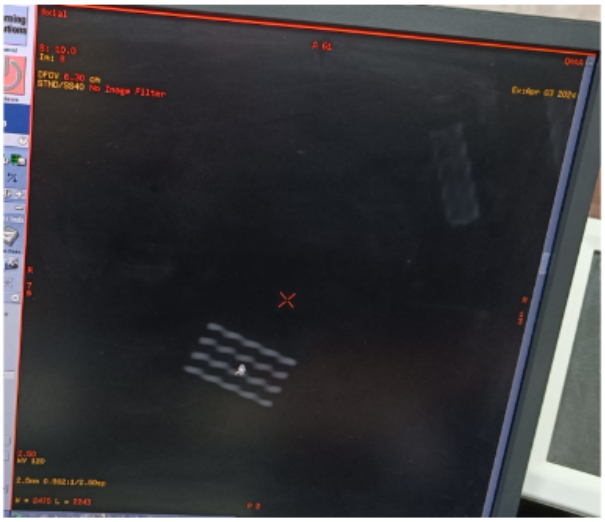

Figure 6: Observed high contrast part of the phantom

## 4.9 Radiation Leakage Levels from X-ray Tube Housing at 1 m from the Focus

Operating potential, kVp = 140 V
mAs = 350
scan time = 1s

Table 8: leakage tabulated data

| **Location** | **Air Kerma Rate (uGy/h)** | **Radiation Leakage level (mR/h)** | **Max. Leakage (mR in 1 hr)** |
|---|---|---|---|
| Right (tube at 90) | 232.9 | 26.59 | 0.63 |
| In front of Cathode (in front of gantry) | 2425 | 276.83 | 6.59 |
| Right (tube at 180) | 55.44 | 6.33 | 0.15 |
| Left( tube at 180) | 55.44 | 6.33 | 0.15 |
| In front of anode (behind gantry) | 3196 | 364.84 | 8.69 |

Upper limit: Leakage radiation level at 1 meter from the focus should be $< 115$ mR in one hour.

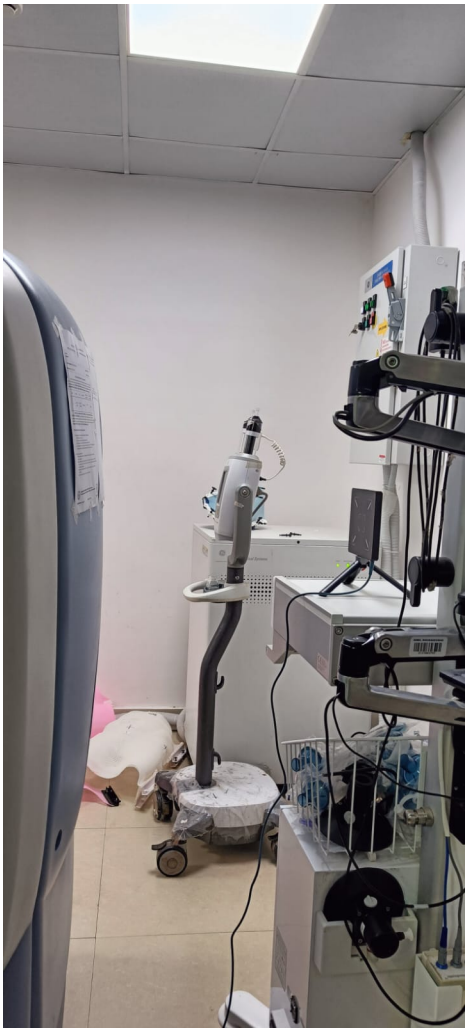

Figure 7: Measurement at the Right (tube at 90)

Figure 8: Measurement at the Right (tube at 180)

Figure 9: Measurement at the In front of Cathode (in front of gantry

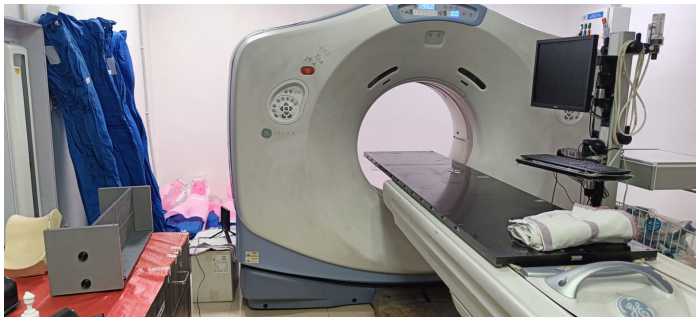

Figure 10: Measurement at the Left( tube at 180)

Figure 11: Measurement at the In front of anode (behind gantry)

# 5 Results

All CT quality assurance tests conducted are well within their respective tolerance limits.

# 6 Conclusion

Regular quality assurance testing of the CT simulator equipment is necessary to guarantee the security of the patients or members of the public who are close to the equipment, as well as the employees running it. When it comes to medical exposure, CT scans provide patients the maximum dose, so it's critical to confirm ensure exposure settings preserve image quality while staying within bounds.

# 7 References


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3. Report of AAPM Task Group 23, (REPORT NO. 96)The Measurement, Reporting, and Management of Radiation Dose in CT

4. User manual Pro-CT mini phantom

5. CMRP lab manual, semester 4