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A Quality Control Test for General X-Ray Machine

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ABSTRACT

The aim of a quality assurance program is to assist a radio-diagnostic facility in consistently obtaining adequate radiological information with a minimum of dose and a minimum of cost. An integrated part of a quality assurance program is quality control ascertaining quality by measurements and other procedures. When procuring equipment, a specification is worked out taking into account all aspects of the performance of the equipment including the desired tolerances of technique factors. In this study the seven tests (beam alignment, beam collimation, reproducibility, accuracy of kv, time accuracy, half value layer (HVL) and leakage) were carried out for the newly installed General X-Ray machine at Nuclear Malaysia and were in the acceptable limits. Such a test will be the responsibility of a qualified physicist or engineer. The status test is carried out in order to establish the functional status of the equipment. The test is performed immediately after the acceptance test or as an integrated part of it. The test will be repeated when repair influencing the functional status has taken place like the acceptance test; the status test will comprise absolute measurements and will likewise be the responsibility of a qualified physicist or engineer.

***Keywords*:** Quality Control, X-Ray Machine, Quality Assurance

1. INTRODUCTION

The World Health Organization (WHO) defines a quality assurance (QA) programme in diagnostic radiology as an organized effort by the staff operating a facility to ensure that the diagnostic images produced are of sufficiently high quality so that they consistently provide

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adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient. The nature and extent of this programme will vary with the size and type of the facility, the type of examinations conducted, and other factors. The determination of what constitutes high quality in any QA programme will be made by the diagnostic radiology facility producing the images. The QA programme must cover the entire X-ray system from machine, to processor, to view box.

Quality assurance actions include both quality control (QC) techniques and quality administration procedures. QC is normally part of the QA programme and quality control techniques and those techniques used in the monitoring (or testing) and maintenance of the technical elements or components of an X-ray system.

The quality control techniques thus are concerned directly with the equipment that can affect the quality of the image i.e. the part of the QA programme that deals with instrumentation and equipment. An X-ray system refers to an assemblage of components for the controlled production of diagnostic images with X-rays. It includes minimally an X-ray high voltage generator, an X-ray control device, a tube-housing assembly, a beam-limiting device and the necessary supporting structures. Other components that function with the system, such as image receptors, image processors, automatic exposure control devices, view boxes and darkrooms, are also parts of the system. The main goal of a QC programme is to ensure the accuracy of the diagnosis or the intervention (optimizing the outcome) while minimizing the radiation dose [1-22].

To achieve that objective in a typical diagnostic radiology facility, QC procedures may include the following:

- **a.** Acceptance test and commissioning Acceptance test is performed on new equipment to demonstrate that it is performing within the manufacturer's specifications and criteria. Commissioning is the process of acquiring all the data from equipment that is required to make it clinically useable in a specific department. This commissioning test will give the baseline values for the QC procedures.
- **b.** Constancy tests are performed at specific intervals to check on the performance of some key parameters. The frequencies reported for the control of constancy may be with a tolerance of ±30 days.
- **c.** Status tests are normally performed with full testing at longer periods, e.g. annually.
- **d.** Performance tests are specific tests performed on an X-Ray system after a pre-determined period of time.
- **e.** Verification of radiation protection (RP) and QC equipment and material.
- **f.** Follow up of necessary corrective actions taken in response from previous results of QC procedures. This is important because simply performing QC measurements without documentation of corrective actions and a follow ups are not sufficient. On the other hand, quality administration procedures are those management actions intended to guarantee that monitoring techniques are properly performed and evaluated and that necessary corrective measures are taken in response to monitoring results. These procedures provide the organizational framework for the quality assurance programme. A diagnostic radiology facility as used in this sense refers to any facility in which an X-Ray system(s) is used in any procedure that involves irradiation of any part of the human or animal body for the purpose of diagnosis or visualization.

1. 1. PRINCIPLE OF A QUALITY CONTROL PROGRAM

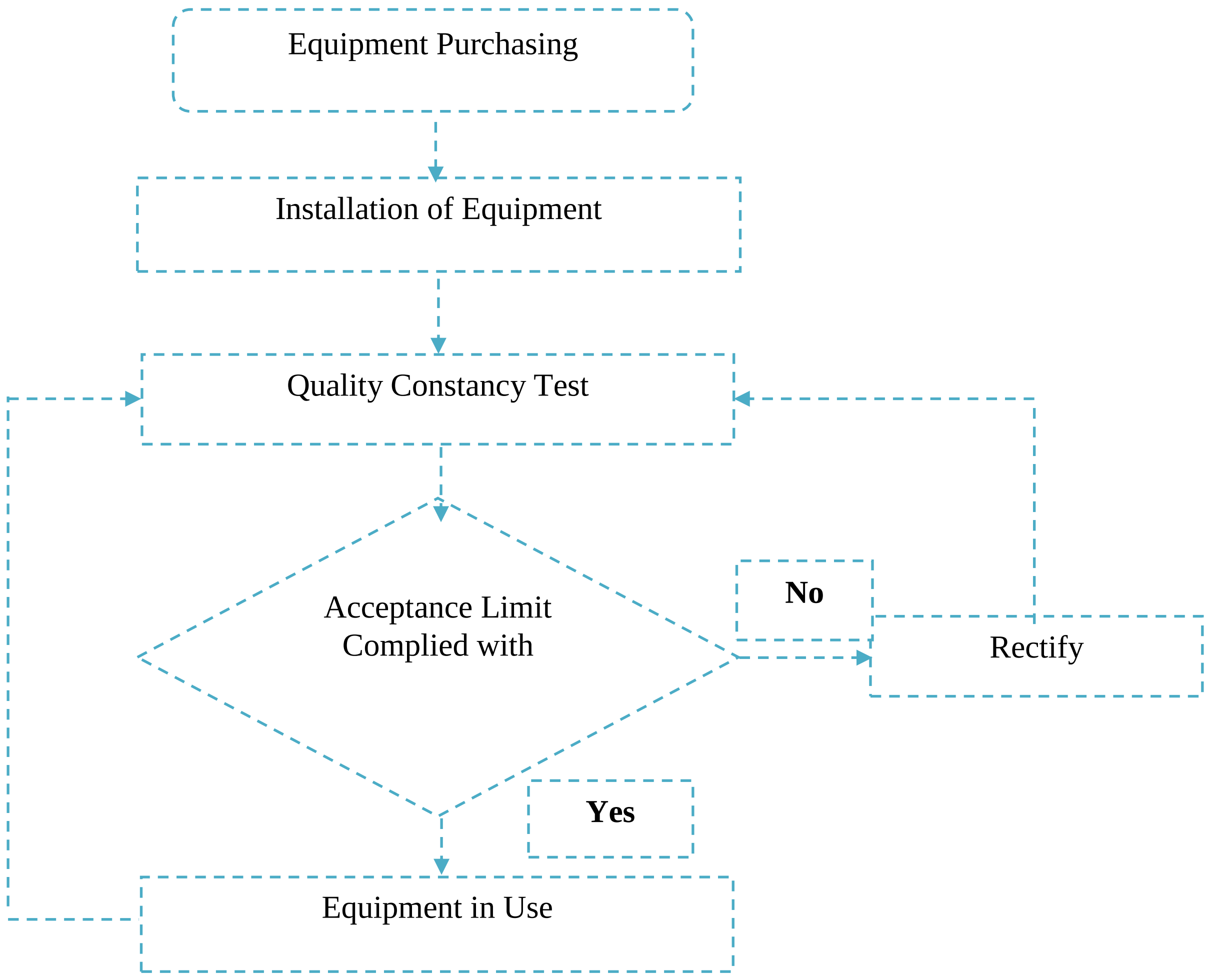


Figure 1. QC of general X-Ray machine.

2. X-RAY PRODUCTION

2. 1. PRODUCTION OF X-RAY

X-Rays for medical diagnostic procedures or for research purposes are produced in a standard way: by accelerating electrons with a high voltage and allowing them to collide with a metal target. X-Rays are produced when the electrons are suddenly decelerated upon collision with the metal target; these X-Rays are commonly called brehmsstrahlung or "braking radiation". If the bombarding electrons have sufficient energy, they can knock an electron out of an inner shell of the target metal atoms. The electrons from higher states are drop down to fill the vacancy, by emitting x-ray photons with precise energies determined by the electron energy levels. These X-Rays are called characteristic X-Rays.

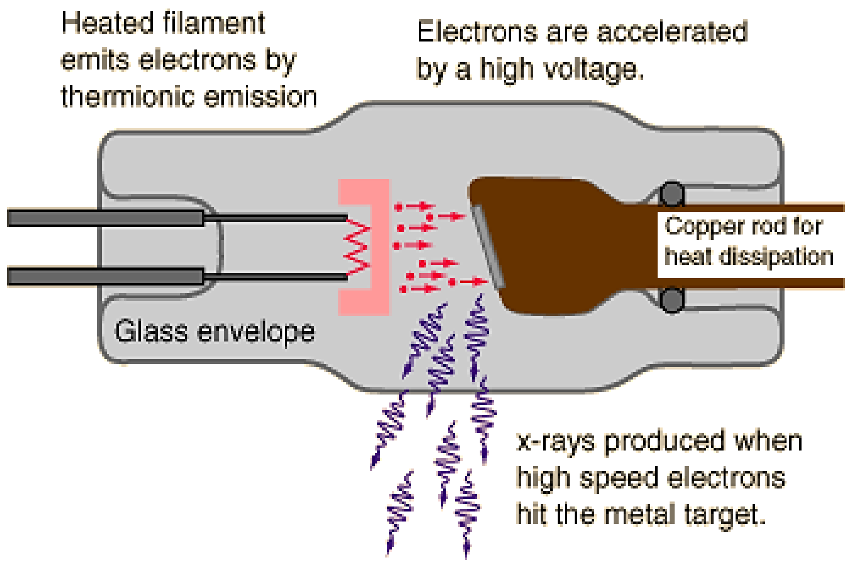


Figure 2. Production of X-Rays.

2. 2. COMPONENTSOF X-RAY TUBE

The basic components of an x-ray tube are:

a. A sealed glass tube envelope is made of glass or metal-ceramic having high melting point to withstand the intense heat generated at the anode. A high vacuum environment for the tube elements is necessary; to prevent oxidation of the electrode materials, to permit ready passage of the electron beam without ionization of gas within the tube, to provide electrical insulation between the electrodes.

b. A source of electrons i.e. heated tungsten filament (cathode).

c. A metal target (anode).

2. 2. 1. DESIGN CONSIDARATIONS FOR EQUIPMENT

Focal spot size is as small as possible to produce sharp image. The major parameter for image quality is the dimension of the focal spot. A small focal spot size is used to obtain x-ray image with minimum blur. Small focal spot tends to concentrates heat and gives load on focal spot area. If the quantity of heat delivered during an individual exposure exceeds the track capacity, the anode surface can melt. Appropriate material, area and angulations of the anode are required to produce X-Ray efficiently. Choose of rotating and stationary anodes to avoid excessive heat production. Efficient heat dissipation system is required to cool the target.

Sufficient filament current is required to minimize exposure times. The light beam must be congruent with the x-ray beam. Additional & variable filtration should be available.

2. 2. 2. TUBE HOUSING AND COLLIMATOR

Tube housing has aperture to allow useful X-Ray beam to emerge but it is also shielded to restrict unwanted radiation. Leakage radiation must comply with standards. Tube housing contains oil, for electrical insulation and heat dissipation. Useful beam is directed at the patient through an adjustable collimator to control the size and shape of the X-Ray.

2. 3. X-RAY GENERATOR

The generator powers the X-Ray tube. It provides the potential difference to accelerate electrons from cathode towards the anode. Transformers supply electrical power needed to generate X-Rays. Some mobile X-Ray units use a capacitor to store the required electrical energy.

2. 4. CONTROL CONSOLE

Three primary controls in control console, voltage (kVp), current (mA) and Time (s). Voltage control the quality of the X-Ray while current and time control the quantity. Layout and functions on the control console depend on the system and the functions implemented (Fig. 3).

Figure 3. Control Console.

3. QUALITY CONTROL TESTS OF GENERAL X-RAY MACHINE

3. 1. LIST OF QC TESTS FOR GENERAL X-RAY MACHINE

1.Congruence of radiation and light field	13.Tube output Variation of µGy/mAs with mA
2.Beam alignment	14.Tube output Variation of µGy/mAs with time
3.Field size at 1 m from focus	15.Measured Leakage Radiation
4.Minimum focus to skin distance	16.Evaluation of total filtration of x ray tube
5.Light Beam Illumination	17.Total radiographic system check for image quality

6.Determination of focal spot size using focal spot test tool	18.Calibration Distance and scale
7.Tube voltage accuracy	19.Constancy of film density for all chambers in one AEC
8.Exposure time accuracy	20.Detector matching
9.Constancy of output µGy/mAs	21.Satisfactory operation of the fine density control
10.Constancy of kVp	22.Constancy of film density with kV
11.Constancy of exposure time	23.Constancy of film density for various patient thicknesses
12.Tube output Variation of µGy/mAs with kV^2	24.Measurements of scatter radiation

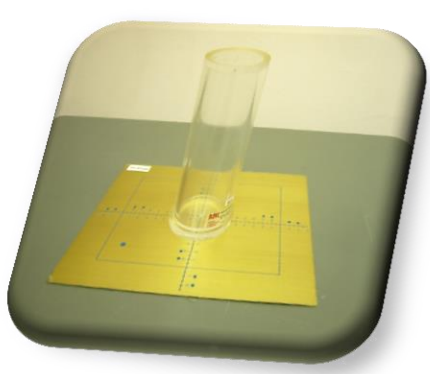
3. 2. SCOPE OF LIMITATION OF THIS PROJECT

Since the time limitation for this work, only the following tests were carried out to fulfill the requirement of this project.

1. Beam Alignment	5. Time Accuracy
2. Beam Collimation	6. Half Value Layer (HVL)
3. Reproducibility	7. Leakage Test
4. kVp Accuracy	

3. 2. 1. BEAM ALIGNMENT

If the beam center is not coinciding with the light field, the radiation field may be shifted away from the area of clinical interest. This can be finding using the beam alignment test tool. If the beam alignment tests tool perpendicular to the beam, image on the cassette must be as follows. (Fig. 4)



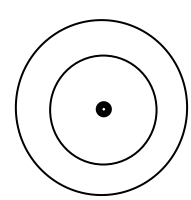


Figure 4. Beam Alignment Test Tool.

But in the normal situation the beam alignment is not always hundred percent accurate. But, if the image shows as follows, (Fig. 5)

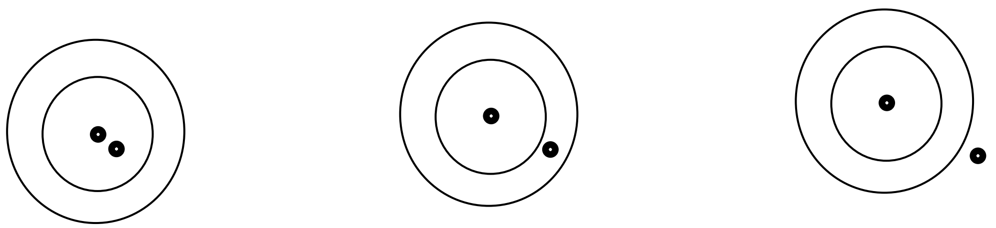


Figure 5. Possible ways of beam alignment.

If the beam alignment is less than 1.5^0 or in between 1.5^0 and 3^0 the perpendicularity (alignment) of the X-Ray beam is in the acceptable limit. If it moves beyond 3^0, it is not within the acceptable limit.

3. 2. 2. BEAM COLLIMATION

If the X-Ray beam is not coinciding with the light field, the radiation field may be shifted away from the area of clinical interest, which will contribute unnecessary dose to the patient. This can be found by using the collimation test tool. If the collimation test tool perpendicular to the beam and image on the cassette must be coincided with size of the field of collimation test tool (Fig. 6).

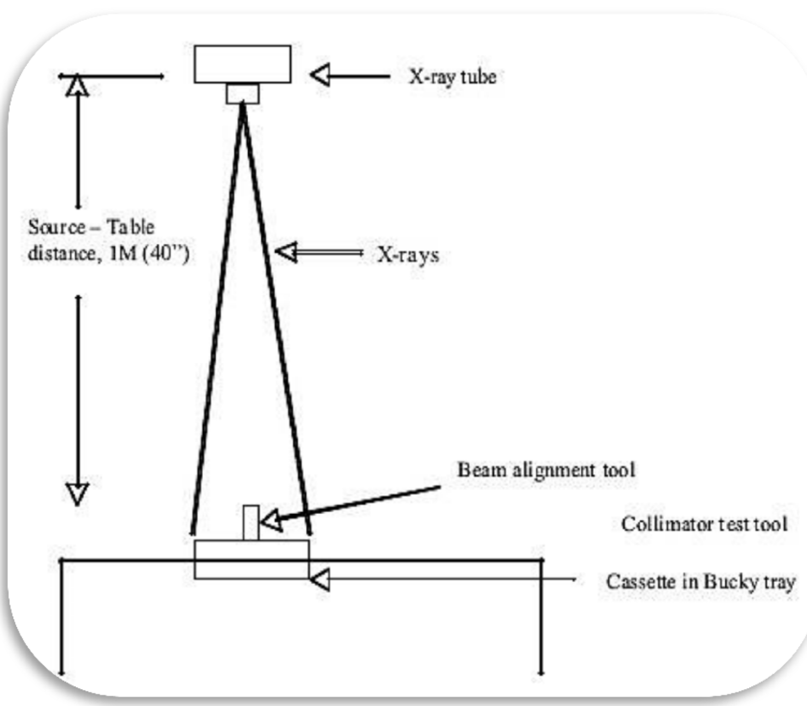


Figure 6. Collimation/ Beam alignment setup.

The alignment to the image receptor should be within 1% of the focal spot image distance.

3. 2. 3. REPRODUCIBILITY TEST

The parameters of timer, kVp output of an X-Ray machine at a given setting should be reproducible when all the other parameters are fixed. Perfect settings of the above parameters provide optimal dose to the patients and course to quality image. For kVp the coefficient of variation should be less than 2% and for time and output the coefficient of variation should be less than 5%.

$$\text{Coefficient of Variation} = \frac{\text{Standard Deviation}}{\text{Average}} \times 100\%$$

3. 2. 4. kV ACCURACY TEST

There is an optimal tube potential for each X-Ray exposure. If the peak energy of the output beam is not same as the set kVp the important details of the image can be loss and results to retake the image, which gives more doses to patient.

If the percentage of kVp error lie between $\pm 5\%$, the machine kVp value is acceptable.

$$\text{Percentage kVp error } = \frac{(V_0 - V_s)}{V_s} \times 100$$

where: V_0 - The measured value
Vs - The set value

3. 2. 5. TIME ACCURACY TEST

Time is very important parameter of an x-ray machine. Small time variation cause large dose variation which affects the patient and the image. More time gives more exposure to the patient and less time less exposure give poor quality image.

If the percentage of timer error lie between $\pm 5\%$, the machine time setting is acceptable.

$$\text{Percentage timer error } = \frac{(T_0 - T_s)}{T_s} \times 100$$

where: T_0 - The measured value
Ts - The set value

3. 2. 6. HALF VALUE LAYER (HVL) TEST

The determination of the half value layer of the x-ray beam is the acceptable method for specified quality of the X-Ray beam. For a given kVp a measurement of the HVL gives information on the total filtration in the x-ray beam. Little filtration gives unnecessary radiation to the patient (Fig. 7).

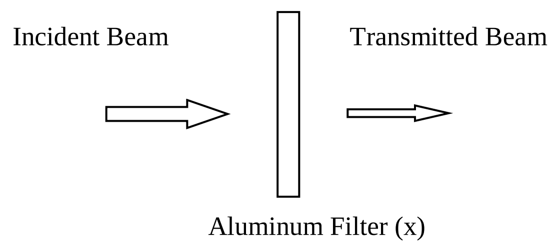


Figure 7. Set up for HVL.

$$I = I_0 e^{-\mu x}$$

where: I - Intensity of the transmitted beam.
I_0 - Intensity of the incident beam.
μ - Attenuation Coefficient.

but, Radiation Intensity, I α Radiation Dose, D

$$D = D_0 e^{-\mu x}$$
$$D/D_0 = e^{-\mu x}$$
$$\ln D/D_0 = -\mu x$$
$$\ln D = -\mu x + \ln D_0$$

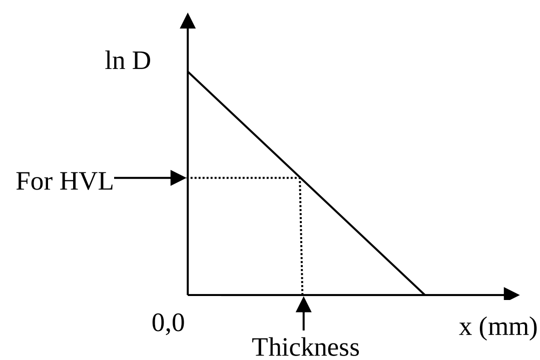


Figure 8. The graph of ln D vs x

The thickness of the HVL can be calculated from the above graph. The value from the graph is match with the given half value layer thickness. (The calculated value should be greater than the accepted value for a specific value of kVp.)

3. 2. 7. LEAKAGE TEST

Figure 9. Leak test at 1-meter distance.

Fluke survey meter features a pressurized ion chamber, providing enhanced sensitivity (μR resolution) and improved energy response to measure radiation rate and dose from x-ray and gamma sources. Originally designed to measure leakage and scatter around diagnostic x-ray and radiation therapy suites. The leakage of the x-ray machine is noted at 1 m distance from focal spot to front, back, right and left of the machine using the maximum filed size (Fig. 9).

4. MATERIALS AND METHODDS

4. 1. MATERIALS

4. 1. 1. GENERAL X-RAY MACHINE

Machine : TOSHIBA KXO-50S
Tube Type : Model DRX – 3724HD S/N :13G195
Insert Model DR-3724H S/N :3G016
Collimator Type : BLR – 1000A S/N :H1C1382166
Generator H.T : Model KXO-50S S/N :H5D1382135
Control Planel : Model KXO-50S S/N :H5D1382135
Range kV/mA/kW : 150 kV/ 320 mA/ 50kW (Fig. 10).

Figure 10. General X-Ray machine.

4. 1. 2. FLUKE SURVEY METER

Ion Chamber Survey Meter with Beta Slide measures radiation rate and accumulated dose from beta, gamma and X-Ray radiation sources above 10 keV (Fig. 11).

Figure 11. Fluke Survey Meter.

4. 1. 3. COLLIMATION/ BEAM ALIGNMENT TEST TOOL

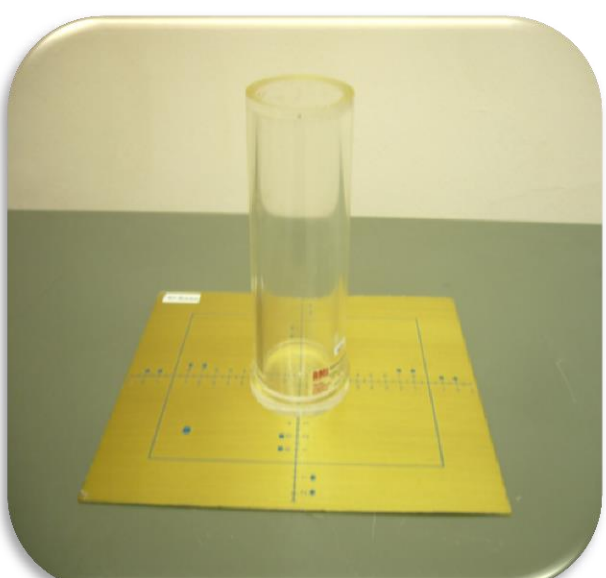


Figure 12. Collimator/ Beam Alignment test tools.

Test Tool is designed to evaluate the collimator light field and X-Ray field congruence and accurate field alignment according the Center of Devices and Radiological Health (CDRH) specifications. This device provides a simple means of determining if the x-ray beam is perpendicular to the image receptor and centered with respect to the light field. A steel ball is mounted in the center of a disc at each end of the 15 cm high clear plastic cylinder. When the balls are positioned over one another and at a right angle to the film, their images will appear as one if the central ray is truly perpendicular to the film. The approximate degree of improper angulations can also be determined.

4. 1. 4. Aluminium Filters

The Aluminum sheets used were 5.00 mm of thickness (Fig. 13).

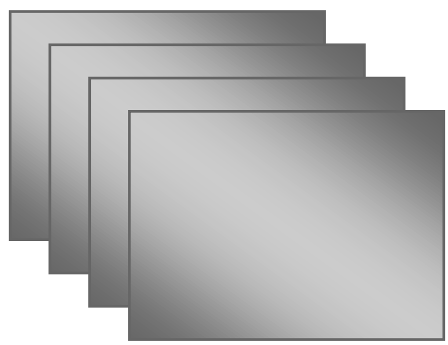


Figure 13. Aluminum Filters.

4. 1. 5. ACCU-PRO DIAGNOSTIC ION CHAMBER AND kV SENSOR COMPONENTS

Figure 14. Ion Chamber.

A - Accu-Pro Control Unit	B - Diagnostic kV Sensor
C - Ion Chamber	D - Mini Positioner Kit
E - Ion Chamber Digitizer	F - Main Cable

4. 2. METHODS

4. 2. 1. BEAM ALIGNMENT AND BEAM COLLIMATION

Cassette was placed in the bed and collimation test tool was kept over that on the table. Beam alignment test tool was kept over collimation test tool so that the middle spot of the collimation test tool, beam alignment test tool and cross line of the beam coincide with each other. The machine was adjusted to 80 kVp and 20 mAs and expose radiation to check the beam alignment and collimation of the machine.

4. 2. 2. REPRODUCIBILITY OF kV

The machine was set up to 100 mA and 0.1s. First the kV was set to 80 and noted down the readings of kV. The same procedure was repeated for the voltage of 80 to find the reproducibility of kV.

4. 2. 3. kV ACCURACY

Test was performed at lowest tube voltage, 50 kV up to 120 kV tube voltage, at the highest available tube current (200 mA) and an exposure time of 0.1s. The voltage, time and the output were noted down to find the accuracy of tube output time and kV.

4. 2. 4. TIME ACCURACY

The machine was set to 80 kV and 200 mA. The machine time was set to 10 ms. the readings for time, kV and the output were noted down. The same procedure was repeated for time 20 ms, 40 ms, 80 ms, 100 ms, 160 ms and 200 ms to find out the time accuracy.

4. 2. 5. HALF VALUE LAYER (HVL)

The machine was set up to 80 kVp and 28 mAs. The x-ray test device was placed 100 cm away from the focal spot. X rays were exposed to test device without Al filter and the reading was noted down. Then the Al sheets with different thicknesses were added one by one (increased by 5 mm) and the readings were taken to find out HVL.

4. 2. 6. LEAKAGE TEST

The specific tube output rate (mGy/s) free in air along the reference axis were measured at 1 m distance from the focal spot to front, back, right and left of the machine, by setting the machine at 100 kVp, 200 mA, time 0.2 s and using the maximum field size.

5. RESULTS

5. 1. BEAM ALIGNMENT AND BEAM COLLIMATION

Table 1. Beam Alignment/ Beam collimation results.

X-Ray Beam size Relative to light Beam: 14 cm x 18 cm	Front (cm)	Back (cm)	Left (cm)	Right (cm)	
	0.1	0.4	0.2	0.3	
%	0.1	0.4	0.2	0.3	Pass

Beam alignment - 1.5^0
The beam collimation - 0.4 %

5. 2. REPRODUCIBILITY OF kV

Table 2. Voltage Reproducibility.

Measuring Quantity	80 kV, 200 mA, 0.1 s				
Actual kV	80.85	80.89	80.90	80.82	80.94
Time (ms)	100.4	100.4	100.4	99.86	100.4
Output (mR)	130.5	130.3	130.6	130.5	130.7

The variation of kV – 1.1 %

5. 3. kV ACCURACY

Table 3. Values for kV Accuracy.

Dial kV	50	60	70	80	90	100	110	120
Actual kV	49.06	58.77	68.97	78.29	87.52	98.23	105.92	115.25
Time (ms)	93.83	94.34	94.35	94.34	94.84	94.84	94.83	94.84
Output (uGy)	32.19	54.53	80.01	104.9	133	166.6	186.9	220
Corrected kV	49.06	58.77	68.97	78.29	87.52	98.23	105.92	115.25

ΔkV	0.94	1.23	1.03	1.71	2.48	1.77	4.08	4.75
%ΔkV	1.9	2.0	1.5	2.1	2.8	1.8	3.7	4.0

Tube voltage accuracy - 4.75 V (4 %).

5. 4. TIME ACCURACY

Table 4. Values for time Accuracy Test.

mAs	2	4	8	16	20	32	40
t set (ms)	10	20	40	80	100	160	200
t measured (ms)	4.51	14.55	34.12	74.77	94.84	154.6	194.7
Actual kV	78.65	78.21	78.46	78.69	78.81	78.91	78.89
Output (mR)	10.8	21.71	43.44	86.04	107.6	170.7	212.6
Timer Accu.%	54.9	27.3	14.7	6.5	5.2	3.4	2.7

For 20 ms to 100 ms - 27.3 %
For > 100 ms - 3.4 %

5. 5. HALF VALUE LAYER (HVL)

Table 5. Half value thickness.

Added Filters (mm Al)	Dose (D)	ln D
0	181.7	5.20
1.0	138.8	4.93
1.5	124.9	4.83
2.0	112.2	4.72
2.5	101.4	4.62
3.0	92.38	4.53
3.5	85.34	4.45

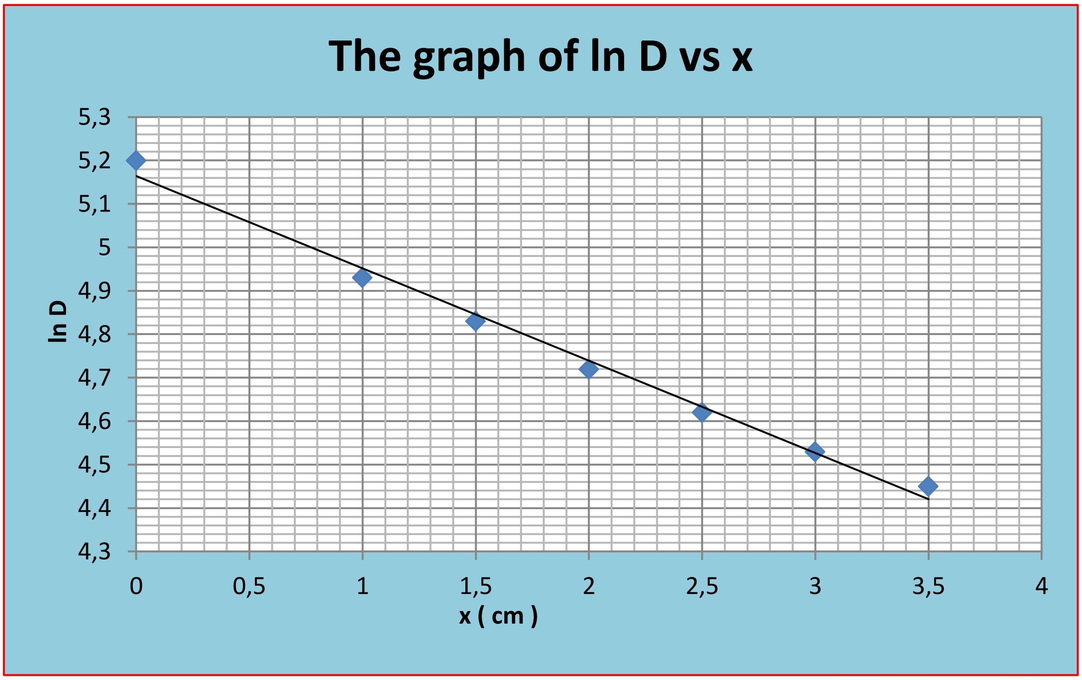


Figure 15. The graph of ln D vs x.

The half value layer - 2.5 cm

5. 6. LEAKAGE TEST

Table 6. Leakage Radiation.

kV	100	(100 kV)
mA	200	(200 mA)
Time t (s)	0.2	(0.2s)
LTF kV	150	(150 kV)
LTF mA	3.4	(3.4 mA)
Max. Dose (μR)	5	
Leakage (μR/h)	3443	
Leakage (mGy/h)	0.03	Accepted

5. 7. SUMMARY OF THE RESULTS

Table 7. Summary of the results.

Physical parameter	Tolerance Limit	Assessment	Comment
Beam alignment	$< 3^0$	1.5^0	Pass
Beam collimation	≤ 1 %	0.4 %	Pass
Reproducibility	± 5 %	1.1 %	Pass
kV Accuracy	±5 kV or 5 %	±4.75 kV or 4 %	Pass
Time accuracy	± 20 % for 10 ms ≤ t ≤ 100 ms ± 10 % for t > 100 ms	± 27.3 % for 10 ms ≤ t ≤ 100 ms ± 3.4 % for t > 100 ms	Accepted Pass
Half value layer	Between 2.5-3.5 mm Al	2.5 mmAl	Pass
Leakage	< 0.1 mGy/h	0.03 mGy/h	Pass

6. DISCUSION

Seven QC test were carried out for the newly installed General X-Ray machine at Nuclear Malaysia.

1. Beam alignment and the beam collimation were in the acceptable limit where beam alignment shows the variation of 1.5^0 and beam collimation 0.4%, well below the tolerance.
2. Reproducibility of kV of the machine was 1.1%, which is less than the tolerance ± 5%.
3. Accuracy of kV was ± 4.75 kV or 4%, which can be accepted, where the tolerance is ± 5 kV or 5%.
4. The tolerances limit for time accuracy ± 20 % for 10 ms ≤ t ≤ 100 ms. But the measured value is higher than the tolerance as shown in the table 8 (average ± 27.3 % for 10 ms ≤ t ≤ 100 ms). Although the higher value in this range can be accepted, because that is not use in the clinical procedures.

Table 8. Time accuracy for 10, 20 and 40 ms.

mAs	2	4	8
t set (ms)	10	20	40

t mesured (ms)	4.51	14.55	34.12
Actual kV	78.65	78.21	78.46
Output (mR)	10.8	21.71	43.44
Timer Accuracy%	54.9	27.3	14.7

The tolerances limit for time accuracy ± 10 % for t > 100 ms, and the measured value is ± 3.4 % for t > 100 ms, which is well within the tolerance limit.

5. Measured half value layer is 2.5 mmAl, can be accepted with the given value 2.5 - 3.5 mmAl.
6. The accepted value for leakage should be less than 0.1 mGy/h and the measured value 0.03 mGy/h which is well below the accepted value.

Assurance that equipment is operating correctly demands routine assessment with a view to standardizing performance. This can be undertaken within the context of a "Quality Assurance Program". An integrated part of a quality assurance program is Quality Control (QC) in which a series of examinations and checks on equipment performance are undertaken, so that any changes can be objectively monitored and remedies made. The purpose is to detect changes that may result in a clinically significant degradation in image quality or a significant increase in radiation exposure.

Quality Control is "The regulatory process through which the actual quality performance is measured, compared to existing standards and finally the actions necessary to keep or regain the standards" Some of the quality control tests use physical assessments and some subjective assessments.

Tests with quarterly to annual frequencies may be performed either by a diagnostic medical physicist or a well-trained QC technologist working under the supervision of a medical physicist, depending upon the complexity of the test and the competency of the technologist. Carefully maintained and calibrated standard test equipment should be used to conduct tests.

Quality begins with proper equipment selection. Equipment must be appropriate in terms of its ability to deliver the quality necessary for a particular imaging task at a cost to both patient and hospital. The medical physicist must be an integral component of the equipment selection process. Documentation of the system performance during the warranty period may become a critical issue and hence must be carefully maintained. Performance comparisons should be made routinely to assure constancy in the performance of each device as well as consistency between devices.

7. CONCLUSION

Quality control tests were performed due to replacement of new x-ray machine at Nuclear Malaysia to evaluate the performance of the equipment. kV accuracy test, kV

Reproducibility, time accuracy, X-Ray Beam Collimation, HVL/Filtration, and Leakage Radiation all these tests were done and complied with the requirements of the standards and manufacture's specifications.

Even though the tolerances limit for time accuracy is ± 20 % for 10 ms ≤ t ≤ 100 ms, the measured value is higher than the tolerance, ± 27.3 % for 10 ms ≤ t ≤ 100 ms. But this value can be accepted, because that is not use in the clinical procedures for imaging.

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