# X-RAY OUTPUT DOSE ASSESSMENT OF SOME X-RAY FACILITIES IN JOS PLATEAU STATE

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## ABSTRACT

*The use of x-ray machines in both private and government hospitals in Jos Plateau state are on the increase. Adequate quality control measures of such equipment are of particular importance to prevent unwanted radiation exposure and to ensure dose optimization. In this study, the dose reproducibility, exposure linearity and coefficient of variation of five x-ray units were investigated using a well calibrated Unfors Mult-o- meter 710l. The results indicated that of the five P1, P2, P3, P4 and P5 x-ray machines studied, 80% (P2, P3, P4andP5) had tolerable dose reproducibility,100% (P1, P2, P3, P4 and P5) exposure linearity and 80% (P2, P3, P4 and P5) coefficient of variation. 80% of all the studied x-ray units had acceptable deviation with tolerance limit of5%. The study, therefore concluded that monitoring of the performance characteristics of the x-ray equipment will enhance quality practice and radiation safety for patients and staff and should be carried out at least annually and when major parts are replaced or fixed.*

**Keywords:** *exposure linearity, dose reproducibility, coefficient of variation and x-ray machine*

## INTRODUCTION

Radiation is all around us and when exposed to high enough amount it can present health hazard if it is not properly controlled (Oladele et al 2018). Radiation can be categorized into non-ionizing or ionizing depending on the radiated particle's energy. X-rays is a form of ionizing radiation which is generated in an x-ray tube and its applications in medical field is widely documented (ICRP 2006). The use of X-rays in the medical field is one way to improve public health (Martins, 2020). X-ray examination using X-rays can provide information about the human body without the need for surgery (Ratnawati et al 2019). In the use of radiation technology, it is realized that in addition to its use for radio diagnostics, X-rays harm the environment and living things around them, especially radiation workers. The impact that can result in cancer due to the accumulation of radiation dose exposure received by the body exceeds the specified threshold dose (Ratnawati et al 2019). Medical x-ray contributes to the increase of human exposure to ionizing radiation. Maintaining human exposures in radiology, as low as reasonably achievable, taking social and economic factors into account, without altering the quality of the images is a challenge of radiation protection (Kramer et al 2006, UNCLEAR 2000, ICRP 2006). This desire to optimize doses to professionals and patients is dependent on human and material factors.

The first quality control test of diagnostic X-ray units in the world was carried out in England in 1966. American Association of Physicist in Medicine (AAPM) developed a comprehensive quality assurance program for diagnostic radiology units in 1977 (Khoshnazar et al; 2013). The International Atomic Energy Agency (IAEA) is charged to establish the guidelines for the use of the ionizing radiations, as well as to issue recommendations to ensure the nuclear safety and radiation protection. In diagnostic radiology and more specifically, the quality control in x-rays machines, the IAEA published the paper" Dosimetry in diagnostic radiology: an international code of practice" that explains the necessary tests to measure the parameters for the proper functioning of the equipment, and how to make the dosimetry depending on the study (IAEA 2007, Torres et al., 2019).

The World Health Organization (WHO), due to widespread use of radiology unit, published a guideline for quality control tests in 1982. Thereafter, a comprehensive quality assurance program was developed by National Council of Radiological Protection and Measurement (NCRP) in 1988. As stated in AAPM report of 1994, "Designing and supervising a quality assurance program is the prime responsibility of medical physicist ". Guidance for quality control of diagnostic units was published by European commission of protection against ionizing radiation in 1997 (Khoshnazar et al., 2013). AAPM explained the main components of quality control program in its report named "Quality Control in Diagnostic Radiology" in 2002 (AAPM 2002). In Nigeria, the use of x-ray machines is regulated by the Nigerian Nuclear Regulatory Authority (NNRA) governed by the Nuclear Safety and Radiation Protection Act 19 of 1995.Quality control checks on x-ray machine are mandatory yet only but a few radiological centers carry out QC test on their x-ray machines (AAPM 2002).

The quality control techniques in radiological practice have to ensure an adequate system of protection for people exposed to x-radiation (Ike-Ogbonna et al 2020). These techniques form part of a quality assurance program for radiological examinations and are designed to correct problems relating to equipment and radiological practices, to obtain radiological information of high quality and to reduce the unnecessary exposures. In such a quality assurance program in medical diagnostic radiology, the medical physicist has a major role to assure the proper functioning of the equipment and work methodologies and to constantly seek to obtain a sensible benefit-risk report in radiological procedures. Evaluation with a good accuracy of radiation dose in radiological procedures is of great importance in radiation protection. Performance assessment of radiographic equipment cannot be over-emphasized. A little shift in any radiographic parameter has a significant impact on the patient absorbed dose (Achuka 2020), especially due to the incidence of cancer induction from radiographic examinations (Achuka 2018a, Achuka 2018b)). It is therefore important that radiographic units be assessed before usage and periodically to ensure proper functioning. Hence, this study desired to assess the output of radiographic x-ray machine in selected centers in Jos's metropolis to optimize the patient radiation doses

## METHODOLOGY

**Table 1:** Specifications of the five x-ray units and the designated facility codes

| CODE | EQUIPMENT NAME | MODEL | SERIAL NUMBER | DATE OF MANUFACTURE | YEAR OF INSTALLATION | MAX kVp/mAs |
|---|---|---|---|---|---|---|
| P1 | ECORAY | ULTRA 200 PLUS | ECO-M20-1909013 | SEPTEMBER 2019 | JULY 2020 | 125/206 |
| P2 | SIEMENS | POLY MOBILE PLUS | (240)05605022 | FEBRUARY 2021 | OCTOBER 2021 | 120/160 |
| P3 | GENERAL ELECTRIC | GE RX7201 | 164144B18 | SEPTEMBER 2021 | MARCH 2022 | 150/620 |
| P4 | ITAIRAY | X50 | 35F196 | - | 2017 | 150/800 |
| P5 | PHILIPS | PHILIPS MCD-105 | 30301 | SEPTEMBER 2020 | 2019 | 105/20 |

## METHODOLOGY

**Procedure To Determine The Dose Reproducibility Of The Studied X-Ray Machines.**

I. A lead apron was placed on the exposure table to absorb any back scatter radiation.
II. A Focus-Film-Distance (FFD) was set at 100cm.
III. The radiation detector sensitive probe was placed on the lead apron on the radiography couch along the central axis of the X-ray beam.
IV. At fixed voltage of 80kVp, 10mAs was selected from the control console.
V. X-ray exposures were performed five times for the selected exposure factors. All exposure were taken after tube warm up.
VI. Unfors Mult-O-Meter 710L Radiation detector, was used for determining the incident kerma in air in this study maintaining same technical parameters. This system has an external dose probe which designed for determining the input dose to medium. The air kerma was measured without the presence of patients for each set of exposure parameters.

Dose reproducibility of the exposure was then calculated with exposure limits, ±5% variance.

$$\text{Dose Reproducibility (\%)} = \frac{\text{Dose Maximum} - \text{Dose Minimum}}{\text{Dose Maximum} + \text{Dose Minimum}} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots\ldots 1$$

**Procedure To Determine The Linearity Of The X-Ray Machines Exposure Output.**

To determine the linearity of the exposure of the x- ray machines exposure output, (i.e., same exposure for a given mAs regardless of the mA/time station combination employed) and beam quality for radiographic systems.

I. A lead apron was placed on the exposure table to absorb any back scatter.
II. The Focus-Film-Distance (FFD) was set at 100cm.
III. The Unfors Mult-O-Meter 710L Radiation detector probe was placed on the lead apron on the radiography couch along the central axis of the X-ray beam.
IV. At fixed voltage of 80kVp, 10mAs was selected from the control console. Current (mA) and time (msec) combination were selected such that the corresponding mAs for any mA and msec selected were the same.
VII. X-ray exposures were performed five times for the selected exposure factors. All exposure were taken after tube warmup.
V. The exposures(mR) at each mA-time station combination were recorded.
VI. Carry out the required calculations for all mA/time combinations tested and record the calculated mR/mAs values.

Linearity of the exposure was then calculated with the exposure limits,±5% variance.

$$\text{Linearity of the exposure } = \left( \frac{(\frac{mR}{mAs})_{max} - (\frac{mR}{mAs})_{min}}{(\frac{mR}{mAs})_{max} + (\frac{mR}{mAs})_{min}} \right) x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

where $(mR/mAs)_{max}$ and $(mR/mAs)_{mjn}$ are the maximum and minimum values of the calculated mR/mAs as recorded.

**Procedure To Determine The Coefficient Of Variation Of The X-Ray Tube Output.**

I. The Unfors Mult-O-Meter was placed on a lead apron which was placed on the exposure table to absorb any back scatter.
II. The x-ray beam with the central ray was positioned at a focus-meter distance of 100cm, perpendicular to the center of the meter sensor (probe).
III. The beam was collimated to the size of the detector.
IV. Exposure was made using set parameters of 80 kVp and 10mAs.
V. The exposure (mR) readings on the radiation detector were recorded.
VI. This process was repeated five (5) times using the same set of parameters and the mean meter reading was recorded.
VII. The coefficient of variation (COV) can be determined using the following equation:

$$\text{COV} = \frac{S}{\bar{x}} = \frac{1}{\bar{x}} \left( \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \right)^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where Xi= ith exposure measurement, $\bar{x}$ = Mean value of exposure measurements n= Number of exposure measurements, S = The estimated standard deviation, COV = The coefficient of variation

## RESULTS

**TABLE 1:** Dose Reproducibility Of The Studied X-Ray Machines

| DOSE (µGy) | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| 1ST READING | 518.8 | 449.1 | 398.9 | 433.3 | 501.9 |
| 2ND READING | 488.6 | 459.7 | 397.5 | 478.1 | 501.2 |
| 3RD READING | 528.3 | 462.2 | 388.4 | 439.0 | 494.1 |
| 4TH READING | 476.7 | 458.9 | 394.6 | 441.9 | 466.3 |
| 5TH READING | 467.3 | 460.0 | 379.7 | 449.4 | 498.2 |
| **MEAN READING** | **495.9** | **458.0** | **391.8** | **448.3** | **492.3** |
| **MAXIMUM** | **528.3** | **462.2** | **398.9** | **478.1** | **501.9** |
| **MINIMUM** | **467.3** | **449.1** | **379.7** | **433.3** | **466.3** |
| **REPRODUCIBILITY** | **6.13%** | **1.44%** | **2.36%** | **4.91%** | **3.68%** |

**TABLE 2.** Exposure Linearity Of The Studied X-Ray Machines

| FACILITIES | VOLTAGE (kVp) | CURRENT (mA) | TIME (mSec) | mAs | EXPOSURE (mR) | mR/mAs | LINEARITY OF EXPOSURE (%) |
|---|---|---|---|---|---|---|---|
| **P1** | 80 | 6 | 1.65 | 10.0 | 59.14 | 5.91 | **3.00** |
| | 80 | 5 | 2.00 | 10.0 | 55.70 | 5.57 | |
| **P2** | 80 | 9 | 1.17 | 10.5 | 51.20 | 4.88 | **1.17** |
| | 80 | 7 | 1.50 | 10.5 | 52.41 | 4.99 | |
| **P3** | 80 | 6 | 1.65 | 10.0 | 45.47 | 4.55 | **1.45** |
| | 80 | 5 | 2.00 | 10.0 | 44.18 | 4.42 | |
| **P4** | 80 | 10 | 1.00 | 10.0 | 51.68 | 5.17 | **2.66** |
| | 80 | 7 | 1.40 | 10.0 | 54.50 | 5.45 | |
| **P5** | 80 | 8 | 1.50 | 12.0 | 57.22 | 4.77 | **1.69** |
| | 80 | 6 | 2.00 | 12.0 | 55.31 | 4.61 | |

**TABLE 3:** Coefficient Of Variation (Cov) Of The Studied X-Ray Machines

| DOSE (µGy) | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| 1ST READING | 518.8 | 449.1 | 398.9 | 433.3 | 501.9 |
| 2ND READING | 488.6 | 459.7 | 397.5 | 478.1 | 501.2 |
| 3RD READING | 528.3 | 462.2 | 388.4 | 439.0 | 494.1 |
| 4TH READING | 476.7 | 458.9 | 394.6 | 441.9 | 466.3 |
| 5TH TEADING | 467.3 | 460.0 | 379.7 | 449.4 | 498.2 |
| **MEAN READING** | **495.9** | **458.0** | **391.8** | **448.3** | **492.3** |
| **COV** | **5.35 %** | **1.12%** | **2.01%** | **3.93%** | **3.02%** |

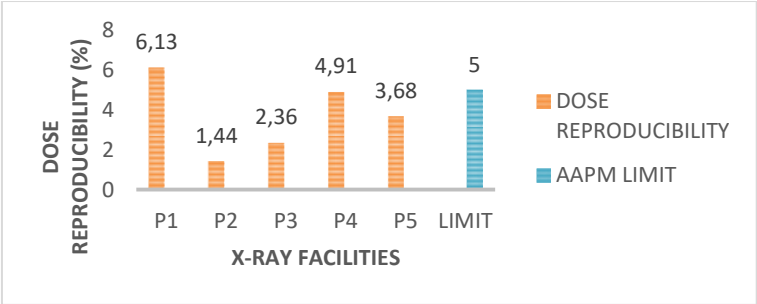


**FIGURE 5:** Comparison Of The Dose Reproducibility Of The Studied X-Ray Machines To Aapm Standard.

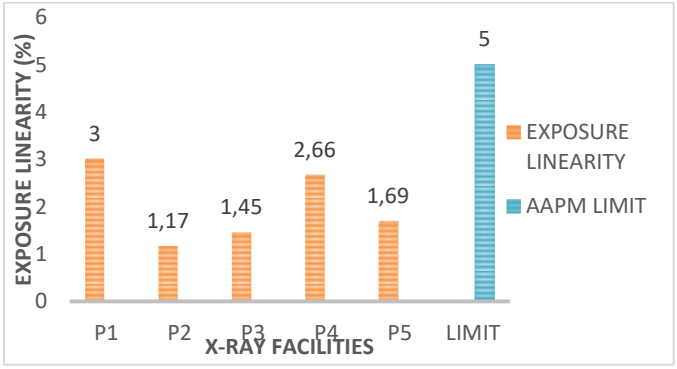


**FIGURE 6:** Comparison Of The Exposure Linearity Of The Studied X-Ray Machines To Aapm Standard.

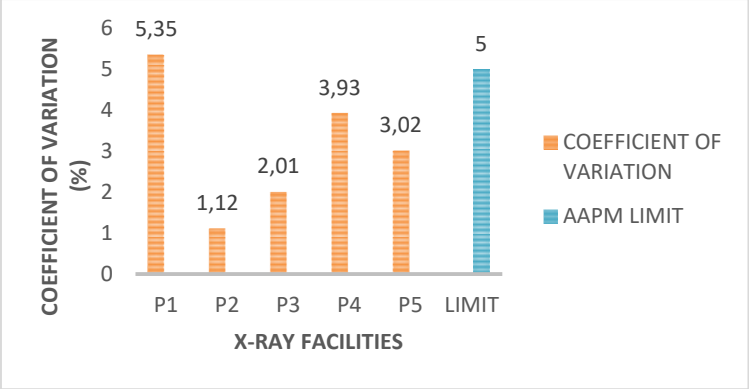


**FIGURE 7:** Comparison Of The Coefficient Of Variation Of The Studied X-Ray Machines To Aapm Standard**.**

## DISCUSSION

From the results presented above in Table1 and Figure 5, the dose reproducibility of the studied x-ray machines (P1, P2, P3, P4 and P5). The maximum dose readings were, 528.3, 462.2, 398.9, 478.1 and 501.9 µGy while the minimum dose readings observed were, 467.3, 449.1, 379.7, 433.3 and 466.3µGy corresponding to dose readings from P1, P2, P3, P4 and P5 respectively. The observed mean doses were 495.9µGy a dose registered by P1 which was the highest dose recorded, this was followed accordingly by 492.3, 458.0, 391.8, and 448.3µGy recorded by P5, P2, P4 and P3. The dose reproducibility corresponding to P1, P2, P3, P4 and P5 were, 6.13%, 1.44%, 2.36%, 4.91% and 3.68% respectively. The American Association of Physicist in Medicine (AAPM) set limits for x-ray machine dose reproducibility is 5% and by this, the x-ray machines were assessed of their ability to maintain dose variations within set limit. As shown in figure 5, P1 failed this test and does not conform to international best practice. P2, P3, P4, and P5 passed this test resulting in an 80% passed rate. The radiation dose output should be constancy reproducible to within 5% of variation for a given fixed exposure parameter this is an indication of safe radiological practice. Dose variation above 5% only indicates excess radiation dose to the patient and subsequently the radiation worker. It is recommended that the dose reproducibility test should be carried out annually on every x-ray unit and any time the major component of the x-ray machine such as the generator or the tube head is repaired or replaced (AAPM 2002).

The exposure linearity was determined from a combination of two different mA and ms stations having the same mAs values. The exposure linearity of the x-ray machines determine in this study were, 3.00, 1.17, 1.45, 2.66 and 1.69%, these represents the exposure linearity to P1, P2, P3, P4 and P5 respectively as shown in Table 2 exposure linearity ranges from 1.17% to 3.0% and from observations conformed with set AAPM set limit of 5% as represented in Figure 6 which shows the comparison of the exposure linearity of the studied x-ray machines to standard. P1, P2, P3, P4 and P5 all having exposure linearity values below 5%, hence, passed the test recording a 100% passed rate.

Table.3 shows the coefficient of variation of the studied x-ray machines. From this table, P1, P2, P3, P4 and P5 were observed to have coefficient of variation of 5.35 %, 1.12%, 2.01%, 3.93% and 3.02% respectively. Only one of the studied x-ray machines, P1, has a coefficient of variation value above 5%. This x-ray unit failed this test resulting in a 20% railed rate and 80% passed rate as four (4) x-ray units, P2, P3, P4 and P5 have coefficient of variation values below 5% as shown in Figure 7.

The x- ray units that failed the exposure tests were most likely due to the following reasons:
Power failure , Inadequate power supply to the x- ray generator and miscalibration or poor calibration of the kVp on the control console. To reduce these failures and ensure that these units pass the exposure tests, power supply to the generator in the x- ray tube should be stabilized. This can be achieved using either an Uninterrupted Power Supply (UPS) or an Automatic Voltage Regulator (AVR) (AAPM 2002).

## CONCLUSION

Quality control checks can reveal information concerning the operation safety of the x-ray unit. The QC tests carried out in x-ray facilities in Jos to measure the stability of the x-ray machine parameters during exposure show most of the x-ray equipment (P2, P3, P4 and P5) performance to be sufficiently within recommended limits except for P1 where out-of-range performance was observed. The study, therefore, concluded that monitoring of the performance characteristics of the x-ray equipment will enhance quality practice and radiation safety for patients and staff and should be carried as specified.

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