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Shielding assessment in three diagnostic X-ray facilities in Asaba, South-South Nigeria: how compliant are we to radiation safety?

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ABSTRACT

Introduction. Shielding is an important aspect of radiation protection, intending to ensure the safe use of ionising radiation.

Aim and objectives. This study is aimed at determining the instantaneous dose rate (IDR) and annual dose rate (ADR) to occupationally exposed workers within controlled areas and other staff/persons within the supervised areas in the three X-ray units. The objective was to compare the shielding design goals (P) in both classified areas mentioned above with recommended standards.

Materials and methods. Three X-ray facilities denoted as centre A, B and C were used. The equipment used in this study was two floor-mounted X-ray systems and one mobile X-ray unit. A calibrated survey meter was positioned at about 30cm from each barrier at various points to determine the average shielded air kerma.

Results. The mean background radiation in the three facilities was 0.10μSv/hr. The mean IDR to the controlled and supervised areas in centre A was 0.254±0.15 and 0.162±0.05μSv/hr, centre B: 0.524±0.73 and 0.154±0.05μSv/hr, and centre C: 0.322±0.20 and 0.147±0.07μSv/hr respectively. The mean shielding design goal (P) to the controlled areas in centre A, B and C was 0.712±0.42, 1.466±2.04 and 0.901±0.56mSv/yr, respectively. Similarly, the mean shielding design goal (P) for the supervised areas for centre A, B and C was 0.455±0.15, 0.431±0.15 and 0.410±0.19mSv/yr, respectively. The ADR to a radiographer behind the mobile screen in centre A, B and C was 1.394, 4.480 and 1.341mSv/yr, respectively.

Conclusion. The mean ADR and shielding design goals in the controlled and supervised areas from the three studied X-ray units were within acceptable limits for occupationally exposed staff and the public.

Keywords controlled areas, supervised area, shielding design goal, personnel, dose rate

LAY ABSTRACT

A study was done to determine whether radiation workers and the public are safe.

INTRODUCTION

Radiation protection and the use of appropriate shielding materials have become necessary in recent year, going by the rise in the number of cancer patients globally.[1-3] Studies have shown that occupationally exposed workers are at risk of getting cancer due to the stochastic effect of radiation.[4-7] This has made it necessary that the shielding design of diagnostic X-ray facilities be adequate to forestall the danger associated with radiation.

From a survey within this region, where the study was conducted, it was noticed that care and attention were accorded to computed tomography (CT) shielding design units; less attention was paid to conventional and digital X-ray systems. This was because of the high radiation risk involved with the use of CT compared to conventional X-ray.

More than any other imaging equipment, conventional or digital imaging is the most frequently used imaging modality globally.[8-10] In order to aid diagnosis and treatment, it is often among the first requests by most physicians in the management of their patients, since it is non-invasive.[11] Globally, it accounts for the highest contribution to man-made radiation.[12,13]

According to the Nigerian Nuclear Regulatory Authority (NNRA) regulation 2003 and 2006, it is recommended that diagnostic X-ray facility be purpose-built.[14,15] A pilot study shows that most X-ray facilities either have a purpose-built control console (cubicle) or a lead screen is used in lieu, which is positioned as the control booth.[16] In this situation, shielding may be compromised due to the scatter effects of radiation in all directions, which will greatly depend on patient size and other surfaces. In most facilities, rooms and work areas are usually designated as controlled or supervised.

According to the radiological protection institute of Ireland (BIR 2000 RPII) a controlled area is a place in which a worker is liable to receive an effective dose of greater than 6mSv in a period of 12 months or an equivalent dose greater than 3/10 of any relevant dose limit or an area where any person who enters must follow a specified system of work. A supervised area in this case, is any place in which a worker is liable to receive an effective dose of greater than 1mSv in a period of 12 months or an equivalent dose greater than 1/10 of any relevant dose limit or an area where it is necessary

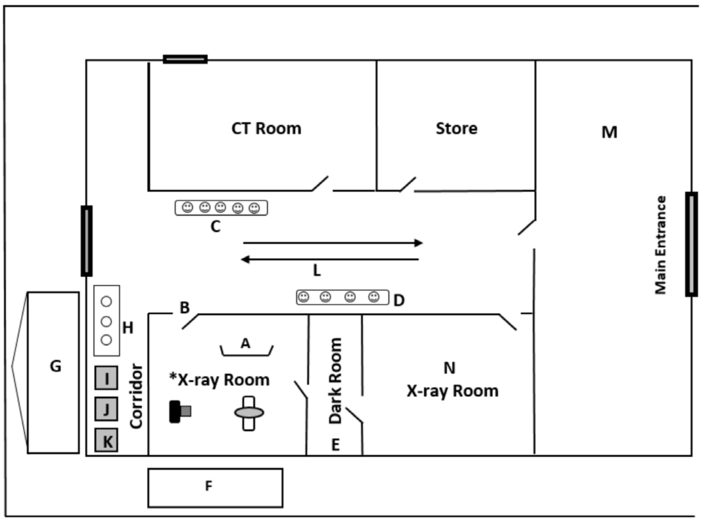

Figure 1. Schematic diagram of the X-ray centre "A" and other area close to it.

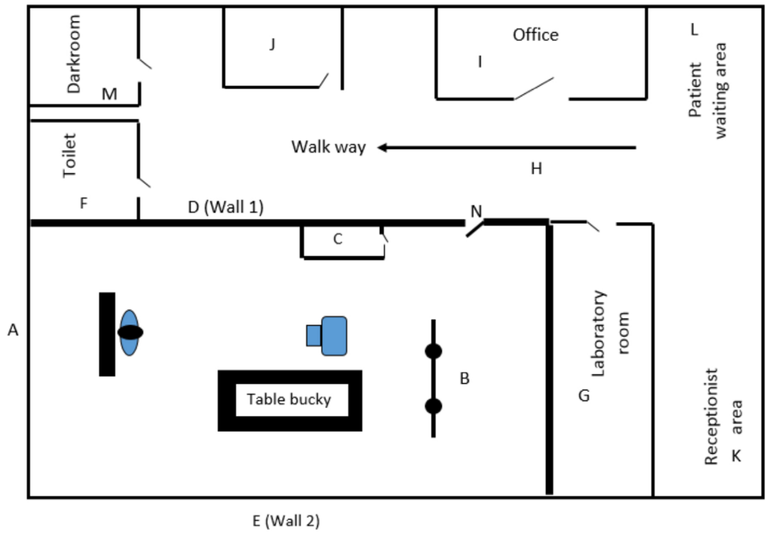

Figure 2. Schematic diagram of the X-ray centre "B" and other area close to it.

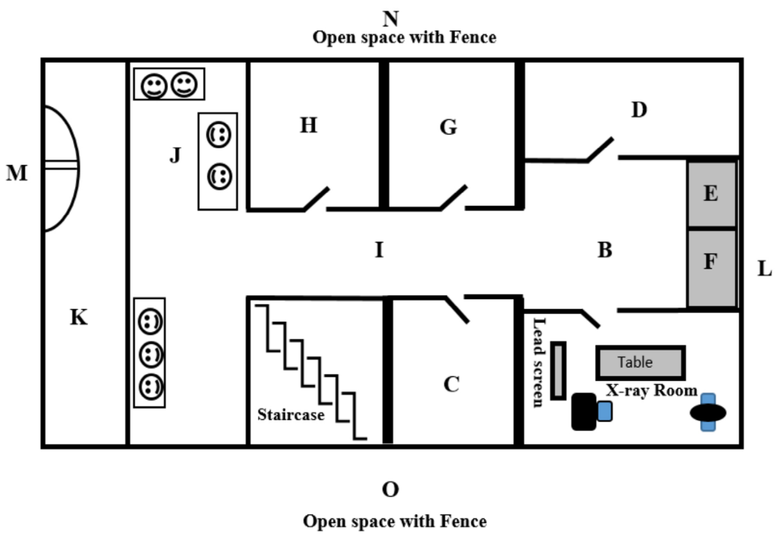

Figure 3. Schematic diagram of the X-ray centre "C" and other area close to it.

Table 1. Machine specification for the three X-ray units

Machine information	Centre A	Centre B	Centre C
Manufacturer	General Electric (GE)	LISTEM Corp	Dean G.E.C Medical
Type	U-arm (fixed) Unit	fixed Unit	Mobile Unit
X-ray machine model	Brivo XR575	CMS-21	-
Model No	5331186	-	-
Serial No	128154BC2	618	-
Maximum kVp	150	125	130
Maximum mAs	625	200	200
Maximum Power (kW)	50	30	32
Total filtration	3.3	2.3	2.7
Generator type	High frequency 3 Phase [Ø]	Single Phase [Ø]	Single phase [Ø]
Year of manufacturer	2017	2003	-
Country of make	China	Korea	USA

to keep the conditions of the area under review to determine whether it should be designated as a controlled area.[17] The NCRP-147 report puts the shielding design goal (P) for the controlled areas as 5mSv/yr and supervised areas as 1mSv/yr, which can also be expressed in term of mSv/week.[18]

The purpose of this study was to estimate IDR and ADR to places within the controlled areas and the public within supervised areas and, to determine whether radiographers' ADR is within the International Commission on Radiological Protection (ICRP) recommended limits. This study also determined whether the shielding design goals (P) in both areas are within the National Council on Radiation Protection and Measurements (NCRP) Report 147 recommended limits. This study compared patient workload among the three facilities and compared the mean IDR obtained with CT studies.

MATERIALS AND METHODS

This study was conducted over three months and it made use of three X-ray facilities, denoted as centre A, B and C, within the Asaba Metropolis in Delta State (Figures 1-3). This study involved two medical physicist and three radiographers from each individual facility. The technical specifications are represented in Table 1. The three privately owned diagnostic X-ray centres used in this study were lead-lined, with existing block walls as barriers. One of the requirements of the Nigerian Nuclear Regulatory Authority (NNRA) is to make sure that shielding design goals are met. Prior to undertaking measurements the dimensions and workload for each room were determined. All areas were marked and were classified based on their occupancy factors and their distances from the X-ray source. Adjacent X-ray rooms, entrance door leading to the X-ray room, offices areas, and laboratories close to the X-ray room were classified as controlled areas. Other areas were classified as supervised areas based on their occupancy factor.

A radiation alert inspector USB survey meter was used for radiation measurements. Background measurements were made to determine if there were any environmental factor that could influence the measurements. The inspector USB survey meter (S.E. International, Inc. USA) is a health and safety instrument that is operated to detect low levels of radiation. The energy response for photon beam with the end window was 10keV - >1MeV and the side wall was 40keV - >1MeV, respectively. The instrument is designed to measure ionising radiation such as alpha (α), beta particles (β), gamma rays (γ), and X-ray radiation. The measurement from the survey meter can be taken in milliroengens per hour (mR/hr) and count per minute (cpm) or S.I. units' microsievert per hour (µSv/hr) and count per seconds (cps) with operating range of 0.01 to 1000µSv/hr or 0 to 350,000CPM (Figure 4). Technical parameter of 100kV on 60mAs was used as indicated in NCRP report No. 147. The radiographers indicated that they hardly use the above parameter for daily routines. A rectangular 20cm thick polystyrene phantom was positioned at the chest stand and on the bucky table to mimic patient density. The survey meter was positioned 30cm

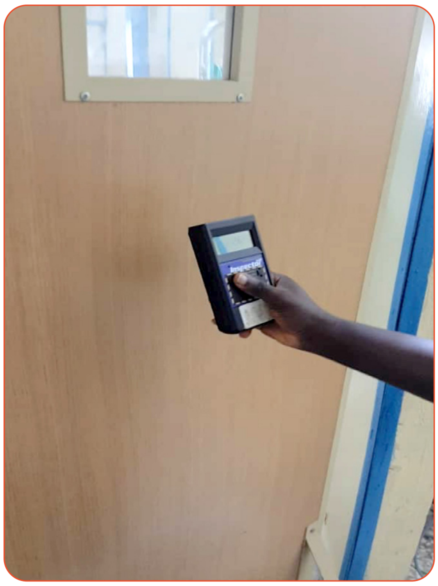

Figure 4. Shielded air kerma rate behind the lead screen.

away from the barrier to take measurement in all designated areas. Also, the shielded air kerma was obtained by positioning the same meter at 30cm after the barrier of the console, which was practically the place where a radiographer stands to take exposures. Three measurements were made per position at 100kV on 60mAs and the average values were noted. All measurements were made by setting the survey meter to start measurement within a time frame of 60 seconds, which is the minimum recorded time for the detector. Since exposure time is less than a second, to compensate for this error, we determined the normal background radiation at 60 seconds (one minute) and deducted it from the value gotten during exposure. The unit of measurements was made in count per

Table 2. Room dimensions and workload of the X-ray units

Facility information	Centre A	Centre B	Centre C
Room size (m^2)	20.7	13.44	13.52
Room height (m)	3.01	2.86	2.68
Mean workload (mA-min/week)	80	40	35

Table 3. Mean background radiation in the X-ray facilities

Centre	Average background (µSv/hr)
A	0.14
B	0.11
C	0.12

Table 4. IDR and ADR for X-ray centre A

Point	Point of measurement	IDR (µSv/hr)	ADR (mSv/yr)
A	*Control console & lead screen	0.498	1.140
B	*Entrance door to X-ray room	0.157	0.360
C	*Patient waiting area 1	0.131	0.300
D	*Patient waiting area 2	0.190	0.434
E	*Darkroom	0.295	0.677
F	Generator house	0.311	0.712
G	Residential area	0.125	0.287
H	Server room	0.131	0.300
I	Toilet	0.138	0.315
J	Toilet	0.125	0.285
K	Bathroom	0.131	0.315
L	Walkway	0.192	0.439
M	Main reception	0.157	0.360
N	X-ray room	0.170	0.390
O	Floor above the X-ray room	0.157	0.360
P	Corridor	0.150	0.344

IDR = Instantaneous dose rate, ADR = Annual dose rate, classification were made as *controlled and supervised area

minutes (CPM) for this purpose because of the chance of getting more decimal figures by applying the calibration factor (3340CPM/mR/hr); it practically gives the same value in the mR/hr mode and can be converted to other units (mSv/hr or µSv/hr). Also, estimated ADR was calculated, by multiplying the IDR by eight (8) working hours per day and 50 weeks per year. The relationship between CPM and mR/hr is given by the relation:

$$mR/hr = \frac{x\ CPM}{3340 \frac{CPM}{mR/hr}} \quad [1]$$

Where x = count recorded by the survey meter in CPM.

In addition, the workload (W) (mA-min/week) for the X-ray unit was calculated using the relation:

$$W = Number\ of\ patient \times \frac{Number\ of\ days}{Week} \times \frac{Number\ of\ exposure}{Patient} \times \frac{mAs}{Exposure} \times \frac{1\ min}{60\ sec} \quad [2]$$

RESULTS

The respective room size for centre A, B and C was 21, 13 and 14m^2 ; room height was 3.01, 2.86, and 2.68m; and workload of 80, 40 and 35mA-min/week, respectively. There was no correlation between the workload and the mean dose rate in the controlled areas (P = 0.576) and supervised areas (P = 0.244) respectively (Table 2).

The mean background in centres A, B and C was 0.14, 0.10 and 0.12µSv/hr, respectively (Table 3). The mean IDR and ADR from five points in centre A in the controlled areas were 0.254±0.15 µSv/hr and 0.712±0.42mSv/yr, respectively, while the mean IDR and ADR from 11 points in the supervised area was 0.162±0.05µSv/hr and 0.455±0.15mSv/hr, respectively. There was no statistically significant difference in the IDR and ADR (P = 0.086) between the controlled and supervised area in centre A (Table 4). The mean shielding design goal (P) in the controlled and supervised areas was below NCRP 147 limits in centre A (Figure 5).

The mean IDR and ADR from four points in centre B in the controlled areas were 0.524±0.73 µSv/hr and 1.466±2.04mSv/yr, respectively. The mean IDR and ADR from 11 points in the supervised area were 0.147±0.07µSv/hr and 0.431±0.15mSv/hr, respectively. There was no statistically significant difference in the IDR and ADR (P = 0.097) between the controlled and supervised area in centre B (Table 5). The mean shielding design goal (P) in the controlled and supervised areas was below NCRP 147 limits in centre B (Figure 6).

The mean IDR and ADR from three points in centre C in the controlled areas was 0.322±0.20 µSv/hr and 0.901±0.56mSv/yr, respectively. The mean IDR and ADR from 12 points in the supervised area were 0.147±0.07µSv/hr and 0.410±0.19mSv/hr, respectively. There was a statistically significant difference in the IDR and ADR (P = 0.018) between the controlled and supervised area in centre C (Table 6). The mean shielding design goal (P) in the controlled and supervised areas was below NCRP 147 limits in centre C (Figure 7).

DISCUSSION

A study to estimate the IDR, ADR, and shielding design goals (P), in three X-ray facilities in Asaba Delta State was carried out. The ADR in centre A, B and C at any point within the controlled areas was less than 20mSv/yr. The shielding design goal (P) was less than 5mSv/yr as recommended by NCRP Report 147. Similarly, the ADR in the three centres in all the supervised areas was less than 1mSv/yr recommended by ICRP for the public. The shielding design goals (P) were less than 1mSv/yr as recommended by NCRP Report 147.

There was no correlation in workload and the mean dose rate among the facilities studied (P =0.807). The average workload

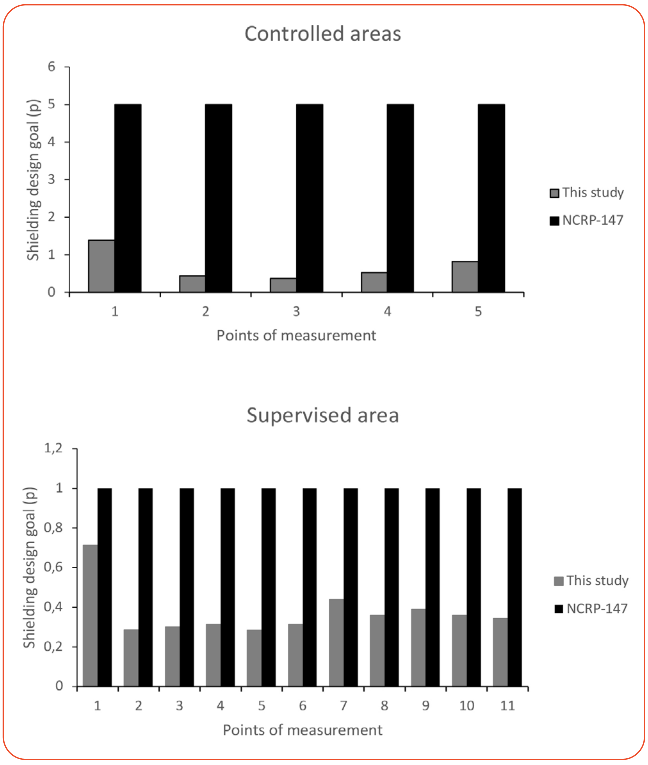

Figure 5. Comparison of this study shielding design goal with NCRP-147 limit for controlled and supervised area in centre A (The point 1-5 is A-E and 1-11 is F-P).

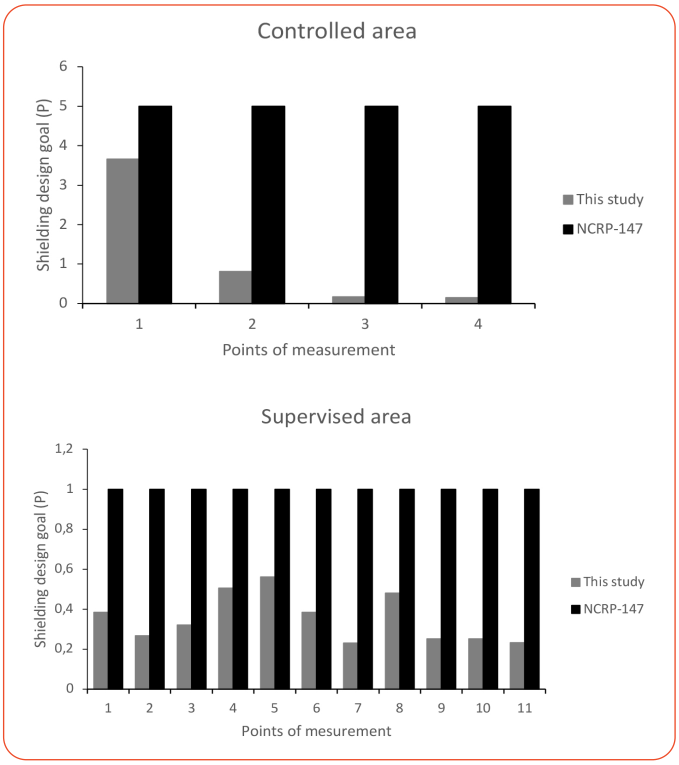

Figure 6. Comparison of this study shielding design goal with NCRP-147 limit for controlled and supervised area in centre B (The point 1-4 is A-D and 1-11 is E-O).

in this study was lower compared to a study by Omojola et al[19] whose average workload from a government facility with conventional X-ray systems was 300mA-min/Wk. Similarly, a study by Abubakar et al[20] shows that the average workload was 165mA-min/Wk. The differences in workload were as a result of the number of patients, number of exposure and the average mAs used by the individual facility.

Centre A in this study had the largest workload and also had the largest room size (21m^2). The room dimensions from the three facilities were below the recommended standards of 35m^2 as required by the International Health Facility Guideline (IHFG) for general X-ray.[21] Centre A met the requirement for room size based on the Uganda Atomic Energy Council (UAEC) guidance of ≥ 21m^2 (with at least 4m for each length) and the Atomic Energy Regulatory Board (AERB) in India, which was 18m^2.[22, 23]

The mean background values in this study were similar to those obtained by Owusu-Banhene et al[24] in Ghana, who researched on dose rate assessment in diagnostic radiology, and Joseph et al[25] and Nkubli et al,[26] who also determined background measurements in a similar study carried out in Nigeria.

Table 5. IDR and ADR for X-ray centre B

Point	Point of measurement	IDR (μSv/hr)	ADR (mSv/yr)
A	*Control console	1.600	3.661
B	*Changing room	0.356	0.815
C	*Entrance with lead door	0.072	0.165
D	*Laboratory	0.066	0.151
E	Wall behind the erect bucky	0.168	0.384
F	Wall 1 lining the X-ray room	0.117	0.267
G	Wall 2 lining the X-ray room	0.140	0.320
H	Toilet	0.221	0.506
I	Walkway	0.245	0.561
J	Office/Scan room	0.168	0.384
K	Rest room	0.101	0.231
L	Receptionist area	0.210	0.480
M	Patient waiting area	0.110	0.252
N	Darkroom	0.110	0.252
O	Floor/occupied area above the X-ray room	0.102	0.233

IDR = Instantaneous dose rate, ADR = Annual dose rate, classification were made as *controlled and supervised area.

Findings from this study show that 47, 23 and 37% of the measured IDR in centres A, B and C, at the controlled areas were close to the background values. On average, 36% of the values were seen to be close to background, which was lower compared to a study by Omojola et al[27] where the average value that was close to background, in the controlled area from two similar CTs was 59%. The cause of this was because of the use of a fabricated mobile lead screen as console in

Table 6. IDR and ADR for X-ray centre C

Point	Point of measurement	IDR (µSv/hr)	ADR (mSv/yr)
A	*Lead screen (console)	0.479	1.196
B	*Corridor (leading to X-ray room)	0.389	0.971
C	*Laboratory	0.098	0.247
D	Ultrasound room	0.114	0.284
E	Toilet	0.111	0.277
F	Store	0.132	0.329
G	Darkroom	0.171	0.336
H	Phlebotomy lab	0.102	0.254
I	Corridor 1	0.165	0.411
J	Reception	0.105	0.262
K	Veranda	0.168	0.418
L	Occupied area (furniture workshop)	0.349	0.798
M	Unoccupied area 1	0.114	0.284
N	Unoccupied area 2	0.120	0.299
O	Unoccupied area 3	0.108	0.270

IDR = Instantaneous dose rate, ADR = Annual dose rate, classification were made as *controlled and supervised area.

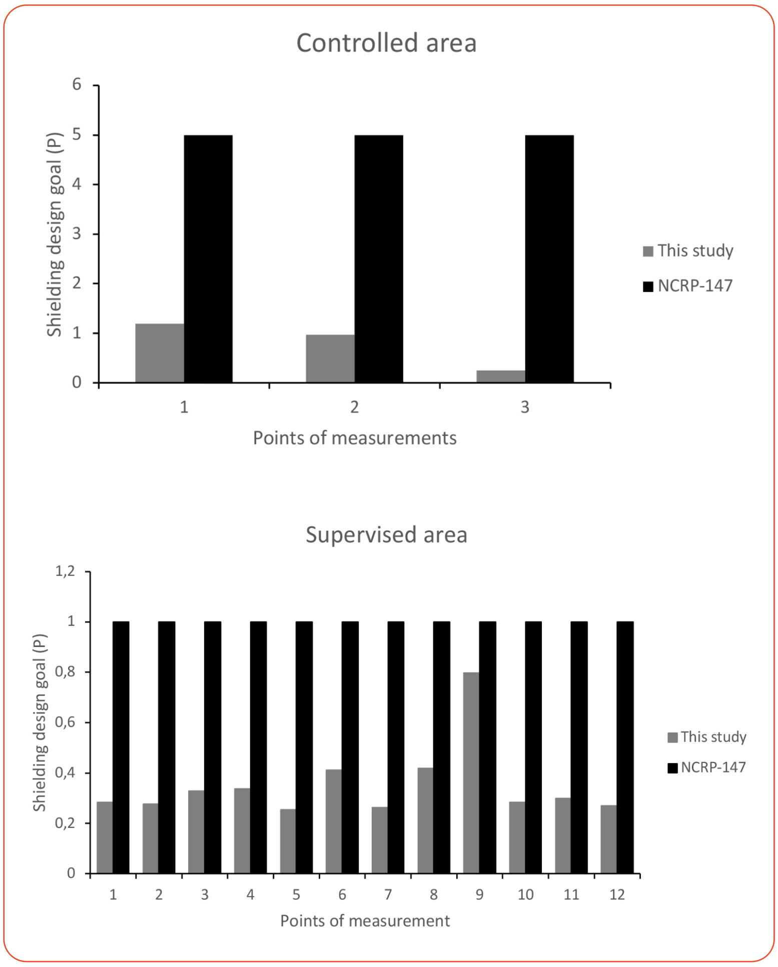

Figure 7. Comparison of this study shielding design goal with NCRP-147 limit for controlled and supervised area in centre B (The point 1-3 is A-C and 1-12 is D-O).

the 3 X-ray units, indicating that a radiographer can receive side scatter radiation. The CT console room in the study by Omojola et al[27] was enclosed compared to the 3 facilities from this study, where a lead screen was used. Similarly, 74, 78 and 80% of the IDR in centres A, B and C, at the supervised areas were close to the background. These values were comparable to the IDR in the supervised area reported in the CT study by Omojola et al.[27]

The average shielded dose in the control console in this study (0.86µSv/hr) was ~5 times higher than the study by Omojola et al[27] where the average shielded dose in the control console was 0.18µSv/hr. The findings indicated that less attention was paid to the radiation aspect and shielding design of conventional X-ray compared to that for CT.

Also, the shielding design goal in this study was based on the NCRP Report 147 document. The standards in this document are relevant for all medical imaging facilities. The shielding design goal (*P*) in our study, in the controlled areas from centres A, B and C, was higher (0.0102, 0.0209 & 0.0129mSv/wk) compared to a study by Nkubli et al.[26] They used a Radalert 100X survey meter to determine the shielding design goals from four X-ray facilities. Their design goals ranged from 0.00152-0.00496mSv/week.[26] The variation from the above values could be as a result of the parameters used, the sensitivity of the meter and barrier thicknesses. The shielding design goal from our study (centre A = 0.0199mSv/Wk; centre B = 0.064mSv/Wk and centre C = 0.0192mSv/Wk) was higher compared to that of Okon et al.[28] They used thermoluminescent dosimeters (TLDs) in Kaduna State Nigeria in two radiography facilities (first facility = 0.017mSv/Wk; second facility = 0.0116mSv/Wk), where XRAYBARR calculator software was used. The technical parameters, shielding thicknesses, distance of the source to the points of measurements and detector responses (electronic meter versus TLD) may have affected the dose rates that were measured.[28]

LIMITATIONS

Communication with the radiographers to know when exposure would commence at a point not within the X-ray room was a challenge in the absence of an intercom.

RECOMMENDATIONS

1. A control booth with adequate shield and height is preferred to a lead screen.

2. Highly sensitive survey meters should be used for shielding assessment.

CONCLUSION

Assessment of three diagnostic X-ray facilities was successfully done. The shielded air kerma rate to the control console where a radiographer stands was adequate, but the contribution of side scatter was noticed to have increased their dose because of the use of a lead screen, which in most cases does not completely shield the right and left side of a radiographer. It is imperative that shielding in diagnostic radiology be taken as seriously as that of CT shielding. The control console should be made to completely shield personnel to avoid unnecessary scatter radiation

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CONFLICT OF INTEREST

None.

CONTRIBUTIONS OF AUTHORS

AO (F.M.C Asaba) covered design of study, data collection and analysis, editing of manuscript; MA (CMUL Lagos) assisted in design of the study, contributed to the write up and editing of manuscript; SA (CMUL Lagos) did the literature search and critical review; AA (F.M.C Asaba) made sure all materials were available and was involved in data collection; and IA (LASUTH) assisted in the preparation of the manuscript.

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