EAS Journal of Radiology and Imaging Technology
Abbreviated Key Title: EAS J Radiol Imaging Technol
ISSN: 2663-1008 (Print) & ISSN: 2663-7340 (Online)
Published By East African Scholars Publisher, Kenya

OPEN ACCESS

Volume-3 | Issue-1 | Jan-Feb-2021 | DOI: 10.36349/easjrit.2021.v03i01.003

Research Article

Evaluation of the Effectiveness of the Structural Shields of X-Ray Facilities in Asaba, Delta State

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Article History
Received: 08.02.2021
Accepted: 20.02.2021
Published: 26.02.2021

Journal homepage:
https://www.easpublisher.com

Quick Response Code

Abstract: ***Introduction***: Radiation in medicine has brought improvements in quality of diagnosis as well as treatment of patients notwithstanding its deleterious side effects. The study is aimed at evaluating the effectiveness of structural shields in X-ray facilities. ***Materials and method:*** This was a prospective cross-sectional study aimed at assessing the adequacy of the existing structural shields in the selected facilities using NCRP 49 methodology. The target population for this study was selected X-ray facilities in Asaba, designated centre A to F. Ethical approval was granted by the Ethical and Research Committee of Federal Medical Centre Asaba. The dimensions six X-ray rooms were measured using a 7.5m/25ft measuring tape. Average technical parameters of 100kVp and 60mAs at a distance of 180cm from the tube head to the erect bucky with 30cmx30cm collimation were used. A well calibrated Inspector USB survey meter was used to measure dose rate in mR/hr and a NT6200 electronic dosimeter to measure the equivalent dose (mSv). To validate the result, three exposures were taken and the mean readings recorded. The data was analysis using SPSS for Windows, Version 22.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics was used to determine mean values. ***Result:*** The average workload in this study was 42mA-min/week. The barrier lead thickness for X-ray centre A and F for the primary barrier was 0.5 mm, and 1.3mm while the secondary beam for the entrance door into the x-ray room was 0.38mm and 0.47mm respectively. The X-ray room dimension measurement for A, E and F were 20.16m^2, 20.68m^2 and 25.96m^2 respectively. ***Conclusion:*** The lead thickness in this study was adequate for all secondary barriers. However, the primary barriers for X-ray Centres B and C were inadequate and lower than NCRP 49 specification.

Keywords: X-ray structural shields, X-ray, lead thickness, dosimeter, and primary barrier.

INTRODUCTION

Radiation in medicine is a wonderful tool that has brought about amazing improvements in diagnostic capability, great curing capacity and invaluable palliative treatments. It is generally classified as ionizing and non-ionizing radiation with known amplitude, frequency and wave-length [1, 2].

The need for radiation protection exists because, exposure to ionizing radiation can result in deleterious effects that could manifest not only in the exposed individual but in his descendants as well. These effects are called somatic or genetic effect [3]. In order to minimize the potential risks of biological effects associated with ionizing radiation, various advisory and regulatory bodies at the international and national levels have been established to regulate and recommend guidelines for radiation protection purposes. The International Commission on Radiological Protection (ICRP) and the National Council for Radiation Protection and Measurements (NCRP) are both advisory bodies which collect and analyze data and put forward recommendations on radiation protection. Recommendations are utilized by regulatory groups to develop policies. The regulatory body in Nigeria is the Nigerian Nuclear Regulatory Authority (NNRA)[4].

In the planning of any x-ray facility, the main priority is to ensure that persons in the vicinity of the facility are not exposed to levels of radiation which surpass the current regulatory exposure limits of 5mSv/year for occupationally exposed persons and 1mSv/year for members of the public [5, 6].

Adequate shielding of radiographic rooms plays a key role in reducing the absorbed dose to personnel, patient and the public. Standards for shielding of Radiographic facilities are listed in the National Council on Radiation Protection and Measurements (NCRP)[5] guidelines in the reports (1976a, 1993b, 2004c) which form the basis in most countries in designing radiographic rooms and shielding[7].

The sources of radiation that must be shielded in a diagnostic x-ray room are the primary radiation and secondary radiation (which consist of scatter radiation and leakage radiation). With the variation of workload and replacement of X-ray machines it necessary to re-evaluate the primary and secondary shielding thickness periodically [1, 8]. Even though there are dose limits, it is of great importance to keep radiation doses well below these limits by applying the ALARA concept (an acronym as low as reasonably achievable). The ALARA concept is an integral part of all activities that involve the use of radiation. This includes the design, construction and operations of existing and future facilities [6, 9].

A few studies have evaluated primary and secondary barriers with different recommendations [10-13] with the aim of setting standards that will help determine the thickness of materials needed for a particular X-ray room based on where it is sited, radiographic workload, use factor and occupancy factor.

Figure 1 shows a diagrammatic description of a typical medical imaging X-ray room layout and major points of measurement of primary and secondary radiation [11]. However, it is worth mentioning; that the design rules and calculations related to shielding has not been generally observed in most radiographic rooms in Nigeria. Studies have shown high proliferation of X-ray machines and conversion of rented apartments to diagnostic X-ray facilities [14].

A pilot study based on visit to the X-ray facilities within Asaba, Delta state showed that most of the centres were not purpose built; hence no information on shielding calculations is available. As a result there may be high compromise of standards particularly the shielding specification, requirements and goal.

The study provides data on the adequacy of radiation protection available in the various X-ray facilities in Asaba, Delta state, improving on the safety of staff, patients and the public. It promotes the credibility of the department and makes recommendations on how shielding could be improved in these facilities.

MATERIALS AND METHODS

The study was a prospective cross-sectional design aimed at assessing the adequacy of the existing structural shields in the selected facilities and determining the required thickness for each barrier using NCRP 49 methodology based on workload, distances and occupancy of the adjoining areas. The target population for this study was all X-ray facilities in Asaba, Oshimili-South Local Government Area of Delta State. A purposive sampling method was used. A sample size of six (6) X-ray facilities that met the inclusion criteria of having a functional X-ray unit, having a radiation shielding in place, and availability of X-ray erect bucky were used for the study.

Ethical approval for the study was granted by the Ethical and Research Committee of Federal medical Centre Asaba and permission was obtained from the authorities of the X-ray facilities where the study was carried out.

A data collection checklist which includes machine specification, room size, number of patients, attenuated dose and un-attenuated dose, X-ray machine (floor mounted and mobile unit), A calibrated (Cesium-137) Inspector USB survey meter (with energy response of 10keV-2.0MeV, which is capable of measuring alpha, beta, gamma and X-ray, with unit of measurement in CPM, CPS, mR/hr, μSv/hr, Bq, or DPM. The accuracy is ±10%, typically ±15% maximum in mR/hr, μSv/hr and count per minute (CPM) modes; manufactured in 2013 by S.E. International, Inc. USA) calibration factor (3340cpm/mR/hr).

NT6200 personal dosimeter (with energy response of 40keV-3.0MeV), which has the capable of measuring gamma and X-ray, with unit of measurement in μSv/hr, Sv, mSv/hr mSv and Sv/hr. The accuracy is ±10% or less; manufactured in 2014 by China coal, China).

All the X-ray rooms studied were general purpose x-ray rooms. The X-ray room dimensions and distances from tube head to the primary and secondary barriers were measured using a 7.5m/25ft measuring tape. Similarly, a Vernier Caliper was used to measure existing lead thickness in a few centers. The unshielded and shielded air kerma were measured for the primary and secondary barriers of the X-ray rooms studied, using the calibrated digital survey meter and the dosimeter. The radiation meters was positioned on the erect bucky and exposure was made to get unshielded air kerma. It was again positioned at about 0.3m away from the primary wall/barrier to determine the shielded air kerma. Similarly, the radiation meter was positioned at various points like the entrance door, adjacent walls and control console to estimate scatter radiation. To minimize error, all measurements were taken three times and the mean values documented.

Five of the facilities were located at the floor of a building, while one was located at the top floor of a storey building. Three of the X-ray facilities were not purpose built rather they were converted from existing structures that were designed for other purposes. All the facilities used had existing protective barriers/shields which were factored in the determination of the barrier thicknesses using NCRP 49 methodology.

The specification of the X-ray facility were written out in a workbook, the six facilities are referred to as centres 'A', 'B', C, D E and F. Five of the centres did not have operational manuals for their machines so, the specification of each machine was written out from the body of the X-ray machine.

The dimensions of the six X-ray rooms were measured using a 7.5m/25ft measuring tape, for centre A-F, Similarly, measurement at five points to the X-ray tube head was done. The points taken for measurement were: wall behind the image receptor (primary barrier), entrance door (secondary barrier), control console (secondary barrier), adjacent wall 1 (secondary barrier), and adjacent wall 2 (secondary barrier), were taken in A-F. Chest bucky secondary wall was not included in this study.

Average technical parameters used were: 100kVp and 60mAs at a distance of 180cm from the tube head to the erect bucky, with collimator dimension of 30cmx30cm. While other measurements were done using a calibrated Inspector USB survey meter which is able to measure dose, dose rate in mR/hr, Count Per Minute (CPM) and Count Per Seconds (CPS) to the five various points of study. Similarly, a NT 6200 electronic dosimeter was used, which was able to measure equivalent dose (mSv) and dose rate (mSv/hr) to validate our result. For each point of measurement three exposures and readings were taken, the final readings were mean values.

Data analysis was performed using SPSS for Windows, Version 22.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics was used to determine mean values of workload for facility/centre and thickness of the barriers. Independent Sample t-test was used for comparison of the leakage radiation. The relative difference was used to compare the differences between the centres.

RESULT

The workload spectra for the six facilities studied are as expressed in the Table 1 below. The highest workload (145mA-min/week) was noted in Centre F, which is a government based hospital. The average workload in this study is 42mA-min/week.

The use of NCRP 49 methodology was involved computing the primary barrier thickness (wall behind the erect bucky) and the secondary barrier thickness (control console, main entrance door, adjacent walls). Lead requirement in X-ray centre A for the primary barrier (wall behind the image receptor) was 0.35 mm, the secondary barrier thickness for the entrance door was 0.00 mm, control console (scatter (d_s) + leakage (d_l)) was ~0.00 mm, and adjacent wall 1 and 2 was ~0.00 mm and ~0.00 mm respectively. Whereas the requirement for Centre B for the primary barrier was 0.40 mm, the secondary barrier thickness for the entrance door was ~0.00 mm, control console was 0.10 mm, and adjacent wall 1 and 2 were ~0.00 mm and ~0.00 mm respectively (table 2.1).

As illustrated in table 2.1, the lead requirement in X-ray Centre D for the primary barrier was 0.38 mm, while that for the secondary barrier thickness for the entrance door, control console and adjacent wall 1 and 2 were ~0.00mm, 0.10mm, ~0.00mm and ~0.00 mm respectively. Lead requirement in X-ray Centre F for the primary barrier (wall behind the image receptor) was 0.70 mm, the secondary barrier thickness for the entrance door was ~0.00 mm, control console (scatter + leakage) was 0.4 mm, and adjacent wall 1 and 2 was 0.15mm and 0.00mm respectively as also shown in Table 2.1 and 2.2.

The calculated lead thickness for X-ray centre A for the primary barrier (wall behind image receptor) was 0.5 mm, secondary beam for the entrance door into the X-ray room was 0.38 mm, control console which was the addition of scatter and leakage radiation was 0.88 mm, and adjacent wall 1 and 2 were 0.72mm and 0.84 mm respectively (Table 3). It was also shown that lead thickness for X-ray centre B for the primary barrier (wall behind image receptor) was 0.3 mm, secondary beam for the entrance door into the X-ray room was 0.17 mm, control console which was the addition of scatter and leakage radiation was 0.50 mm, and adjacent wall 1 and 2 were 0.17 and 0.30 mm respectively (Table 3).

Lead thickness for X-ray centre D for the primary barrier was 1.1 mm, secondary beam for the entrance door into the X-ray room was 0.23 mm, control console which was the addition of scatter and leakage radiation was 0.43 mm, and adjacent wall 1 and 2 were 0.7 and 0.97 mm respectively as shown in table 3.

According to table 3, lead thickness for X-ray centre F for the primary barrier was 1.3 mm, whereas the secondary beam for the entrance door into the X-ray room was 0.47 mm, control console which was the addition of scatter and leakage radiation was 1.11 mm, and adjacent wall 1 and 2 were 0.40 and 0.87 mm respectively as seen in Table 3.

Table 4 showing the x-ray room dimension comparison with NNRA and WHO recommendations reveal that centres A, E and F had dimensions that are within the recommended ranges. They had 20.16m^2, 20.68m^2 and 25.96m^2 for centres A, E and F room diameters respectively.

DISCUSSION

An investigation whether a facility was purpose built was determined. Only two out of the six facilities used were specifically built as a radiology department/complex. Others were from existing rented apartments which were converted for radiographic use. None of the centres were concrete based; rather they were a combination of hallow blocks, lead (mostly 0.25mm in thickness) and ply boards which was used to cover the entire surface of the wall. The workload ranged from 16.8-145 mA-min/Weeks, the highest workload in the study was seen in Centre F, which was the only government hospital used. Total Workload (W_{tot}) in this study was below NCRP 147 recommendation [15] for average (240) and busy (320 mA-min/Weeks) radiography room (all barriers).

This study average workload (42 mA-min/Weeks) was lower than Pesianian *et al*. [8] whose average workload value was 172 mA-min/Weeks. In another related study carried out in Nigeria, where three conventional X-ray facilities in Makurdi and Gboko in Benue State [1] revealed values above that obtained in the index study. In addition, Anikoh *et al*. [16], conducted a study to determine the workload, primary and secondary shielding barrier in Jos Teaching Hospital (JUTH), Nigeria using XRAY BARR mathematical software. The average workloads in his study [16]; from two X-ray rooms were 60.44 and 20.5mA-min/week respectively. They were both seen to be lower when compared to centre F (145 mA-min/week) in our study. Workload for X-ray room 2 from Anikoh's study was the same as centre B and D from our study.

The schematic diagrams of the X-ray facilities are shown in Appendix 1 to 6. Only Centres A, E and F room sizes met the recommendations of NNRA [4] and WHO [2]. Centres B, C and D room sizes were below the recommended size. Similarly, this study's room dimension for centre A-F was larger than room Y (11.88m^2) in the study by Nkubli *et al*. [17].

This study assumed radiographic field sizes for radiographic room (chest bucky) and (all barriers) was 1,505 cm^2. This value was adapted from Tsalafoutas *et al*. [18] who used similar assumed value. Our reason was because most facility field size was either erased from the collimator control and/or unavailability of specification manuals to justify field dimensions. In like manner, Shahid *et al*. [19] lead thickness of barrier for leakage radiation from NCRP 49 in one of the conventional X-ray room studied was 0.00mm for distances of 2.15-3.56m (target to secondary barrier). This was similar to our study whose lead thickness was 0.00mm for distances of 1.99-3.30m. The reason for 0.00mm of lead may be largely due to the workload spectral which has been shown to have effect on barrier thickness. A comparison of scatter radiation between Shahid *et al*. [19] and this study using NCRP 49 showed that no lead thickness was required as barrier (0.00mm) for the secondary walls.

The primary barrier thickness in this study (0.3-1.1mm) based on NCRP 49 was within Agba *et al*. [1]; who's primary shielding was in the range of 0.00-1.1mm of lead (Pb). Although the average workload were between both studies were reported as 42 and 246 mA-min/Weeks respectively. In addition, the secondary barrier thickness in Agba *et al*. [1] was 0.00mm of Pb for the three facilities used. This study also followed similar trend with the exception of Centre B and E having 0.1mm of Pb thickness at the control console, and Centre F having a thickness of 0.4 and 1.5mm of lead at the control console and adjacent wall (1). NCRP 147 graph approach used by Refaat 2014 [20] with the following parameters: d_{pri} =1.5m, U = 1 and T = 0.2 to estimate the lead thickness required for case of without shielding and pre-shielding of a primary barrier in one of the three facilities studied. The results obtained were 1.8 and 0.98mm of Pb respectively with the first facility. The above results were not in line with this study. The following parameters were used in our study as: d_{pri} =1.8m, U = 1 and T=0.2, which was quite similar except for the primary distances. Results without shielding and pre-shielding of a primary barrier were in ranges of 0.4-1.1mm and 0.00-0.32mm of Pb. A comparison NCRP 49 between Refaat [20] and our study reveal a large difference in the lead thickness. In Refaat's [20] study the study primary barrier thickness was 2.2mm of Pb while the three secondary barrier were 1.5/0.3/0.93 mm of Pb. Our study mean primary thickness was 0.44mm of Pb and secondary barrier was approximately 0.00 mm of Pb.

The lead thickness based on NCRP 49 for Centre A for wall behind the primary barrier was lower than the value obtained in this study, with a relative difference (R.D) of 35.3%. This Points to the fact that the lead thickness towards the primary beam was adequate. It was also noticed from our study that due to the small workload, only the primary barrier thickness was comparable to this study. The secondary barrier, which comprises the main entrance door, control console, adjacent wall 1 (distal from the tube head) and adjacent wall 2 (proximal to the tube head) were approximately 0.00mm based on NCRP 49.

A look at Centre B shows that there was close comparison between the primary barrier thickness with NCRP 49 methodology and this study. The lead thickness for this study was below NCRP 49 by a relative difference of 28.6%. Also lead equivalent thickness for the control console (D_s +D_l) was adequate since it was above NCRP 49 thickness of 0.10mm.

Other secondary barrier based on this study was adequate.

Centre C lead thickness based on NCRP 49 (0.78mm) was higher than this study (0.35mm). The control console barrier thickness of this study (0.58mm) was adequate when compared to NCRP 49 (0.1mm) value. The lead thickness for the main entrance door and the two adjacent walls for this study were higher than those of NCRP 49 which were approximately zero (0.00mm). Also, the lead thickness of this study for centre D and E were adequate for all barrier studied when compared to NCRP 49. Similarly, all barrier thickness for Centre F was adequate except for the primary barrier of this study that was 0.2mm less in thickness compared to NCRP 49.

CONCLUSION

The lead thickness in this study was adequate for all secondary barriers. However, the primary barriers for X-ray Centres B and C were inadequate and lower than NCRP 49 specification. The study also revealed that some of the X-ray facilities were not purpose built for a radiologic facility, hence no information concerning shielding calculations is available and workplace monitoring program are suboptimal.

RECOMMENDATION

Based on the findings the study recommends that prior to construction/design/use, of a radiographic facility, regulatory bodies such as the Nigerian Nuclear Regulatory Authority (NNRA) should be aware and the employer must seek authorization, similarly a qualified expert should be contacted during the above processes.

Existing structures used for radiographic purpose should involve a qualified expert in the shielding design and other radiation safety/protection matters. In the advent of replacement of X-ray machines, shielding evaluation should be carried out before replacing the machine as well as adequate workplace monitoring program should be implemented, to detect leakages

Table-1: Workload spectra for Centre A-F

Centre	Average number of patient/week (N)	Workload (mA- min/week)
A	35	23.33
B	30	20.1
C	37	24.7
D	25	16.8
E	30	20.1
F	128	145

*Workload = (mAs/film) × (patients/day) × (films/patient) × (days/week)

Table-2.1: Lead thickness using NCRP 49 49 methodology for centre A, B and C

Centre	ocation	P	U	T	a	F	D	*d(m)*	W	K(R/mAmi)	Thickness (mm)
	Wall behind EB	0.002	1	0.025	-	1505	-	2.72	23.33	2.54×10^{-2}	0.35
A	Main entrance	0.04	0.02	0.2	0.0015	1505	5.6	1.8	23.33	27.56	0
	Control console	0.04	0.02	1	0.0012	1505	4.7/-	1.8/3.3	23.33	5.78/1.95	0
	Adjacent wall 1	0.04	0.02	1	0.0013	1505	2.7	1.8	23.33	12.37	0
	Adjacent wall 2	0.002	0.02	0.2	0.0013	1505	3.2	1.8	23.33	82	0
B	Wall behind EB	0.002	1	0.025	-	1505	-	2.1	20.1	1.76×10^{-2}	0.40
	Main entrance	0.04	0.02	0.2	0.0012	1505	3.2	1.8	20.1	73.12	0
	Control console	0.04	0.02	1	0.0015	1505	4.0/-	1.8/1.99	20.1	21.09/0.82	0.1
	Adjacent wall 1	0.04	0.02	1	0.0013	1505	3.2	1.8	20.1	13.5	0
	Adjacent wall 2	0.002	0.02	0.025	0.0013	1505	2.8	1.8	20.1	20.67	0
C	Wall behind EB	0.04	1	1	-	1505	-	1.8	24.7	5.25×10^{-3}	0.78
	Main entrance	0.04	0.02	0.2	0.0015	1505	3.05	1.8	24.7	43.24	0
	Control console	0.04	0.02	1	0.0012	1505	3.03/-	1.8/2.05	24.7	10.67/0.7	0.1
	Adjacent wall 1	0.04	0.02	1	0.0013	1505	3	1.8	24.7	9.65	0
	Adjacent wall 2	0.002	0.02	1	0.0013	1505	3.8	1.8	24.7	15.49	0

N= Number of patient, T= Occupancy Factor, *P* = Maximum permissible weekly exposure (R/Week) = Shielding design goal, *d (meters)* = Distance from the X-ray tube to the occupied area. K value was normalized to 1m, d = target to secondary barrier, I = tube current in mA (on average 200mA), D = scattered to secondary barrier, a = ratio of scatter to incident radiation

Table-2.2: Lead thickness using NCRP 49 methodology for centres D, E and F

Centre	Location	P	U	T	A	F	D	*d(m)*	W	K (R/mAmin)	Thickness (mm)
D	Wall behind EB	0.002	1	0.025	-	1505	-	2.1	16.8	2.1×10^{-2}	0.38
	Main entrance	0.04	0.02	1	0.0015	1505	3.05	1.8	16.8	12.72	0
	Control console	0.04	0.02	1	0.0015	1505	4.1/-	1.8/2	16.8	22.98/0.99	0
	Adjacent wall 1	0.04	0.02	0.05	0.0013	1505	3.23	1.8	16.8	329.1	0
	Adjacent wall 2	0.002	0.02	0.05	0.0013	1505	1.9	1.8	16.8	113.87	0
E	Wall behind EB	0.04	1	0.025	-	1505	-	2.2	20.1	3.85×10^{-1}	0.05
	Main entrance	0.04	0.02	1	0.0012	1505	2.38	1.8	20.1	8.09	0
	Control console	0.04	0.02	1	0.0012	1505	2.1	1.8	20.1	0.673	0.1
	Adjacent wall 1	0.002	0.02	1	0.0013	1505	3.23	1.8	20.1	6.87×10^{-1}	0
	Adjacent wall 2	0.04	0.02	0.05	0.0013	1505	2.28	1.8	20.1	274.1	0
F	Wall behind EB	0.04	1	0.2	-	1505	-	2.2	145	6.68×10^{-3}	0.70
	Main entrance	0.04	0.02	0.2	0.0013	1505	2.8	1.8	145	7.163	0
	Control console	0.04	0.02	1	0.0012	1505	4.55/-	1.8/3	145	4.1/0.25	0.4
	Adjacent wall 1	0.002	0.02	1	0.0013	1505	4.1	1.8	145	1.54×10^{-1}	0.15
	Adjacent wall 2	0.04	0.02	1	0.0013	1505	2.6	1.8	145	1.24	0

N= Number of patient, T= Occupancy Factor, *P* = Maximum permissible weekly exposure (R/Week) = Shielding design goal, *d (meters)* = Distance from the X-ray tube to the occupied area. K value was normalized to 1m, d = target to secondary barrier, I = tube current in mA (on average 200mA), D = scatterer to secondary barrier, a = ratio of scatter to incident radiation

Table-3: Calculated barrier thickness for the index study

Centre	Location	Thickness (mm)
A	Wall behind Erect Bucky	0.50
	Entrance door	0.38
	Control console	0.88
	Adjacent wall 1	0.72
	Adjacent wall 2	0.84
B	Wall behind Erect Bucky	0.30
	Entrance door	0.17
	Control console	0.50
	Adjacent wall 1	0.17
	Adjacent wall 2	0.30
C	Wall behind Erect Bucky	0.35
	Entrance door	0.30
	Control console	0.58
	Adjacent wall 1	0.25
	Adjacent wall 2	0.22
D	Wall behind Erect Bucky	1.10
	Entrance door	0.23
	Control console	0.43
	Adjacent wall 1	0.70
	Adjacent wall 2	0.97
E	Wall behind Erect Bucky	0.92
	Entrance door	0.05
	Control console	0.30
	Adjacent wall 1	0.90
	Adjacent wall 2	0.05
F	Wall behind Erect Bucky	1.30
	Entrance door	0.47
	Control console	1.11
	Adjacent wall 1	0.40
	Adjacent wall 2	0.87

$$Transmission\ factor\ (B) = \frac{Shielded\ air\ kerma}{Unshielded\ air\ kerma\ \left(\frac{D1}{D2}\right)^2}$$

D_1 = Distance of source to shielded area
D_2 = Distance of source to occupied area

Table-4: X-RAY Room dimension: comparison of study with nnra and who recommendations

Centre	This study (R.D)m^2	NNRA (R.D)m^2	WHO (R.D)m^2	This study ceiling height (m)
A	20.16	≥16	16-24	2.7
B	13.63	≥16	16-24	2.9
C	12.96	≥16	16-24	2.7
D	15.6	≥16	16-24	2.7
E	20.68	≥16	16-24	2.5
F	25.96	≥16	16-24	3.3

R.D = Room Dimension

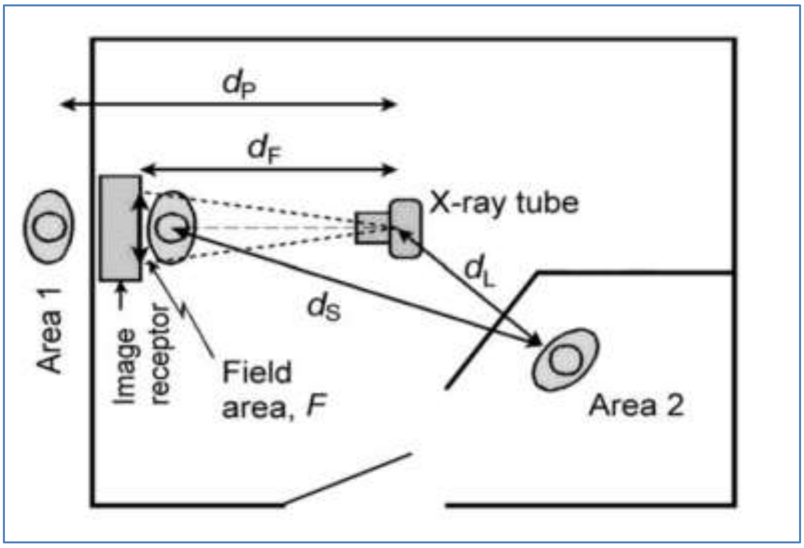

Fig-1: A typical medical imaging X-ray room layout and major points of measurement of primary and secondary radiation (Adapted from NCRP 147 Document)[11]

$_{dp}$ =Source to shielded area 1 $_{df}$ = Source to image receptor

$_{ds}$ =scatter radiation distance $_{dL}$ =leakage radiation distance

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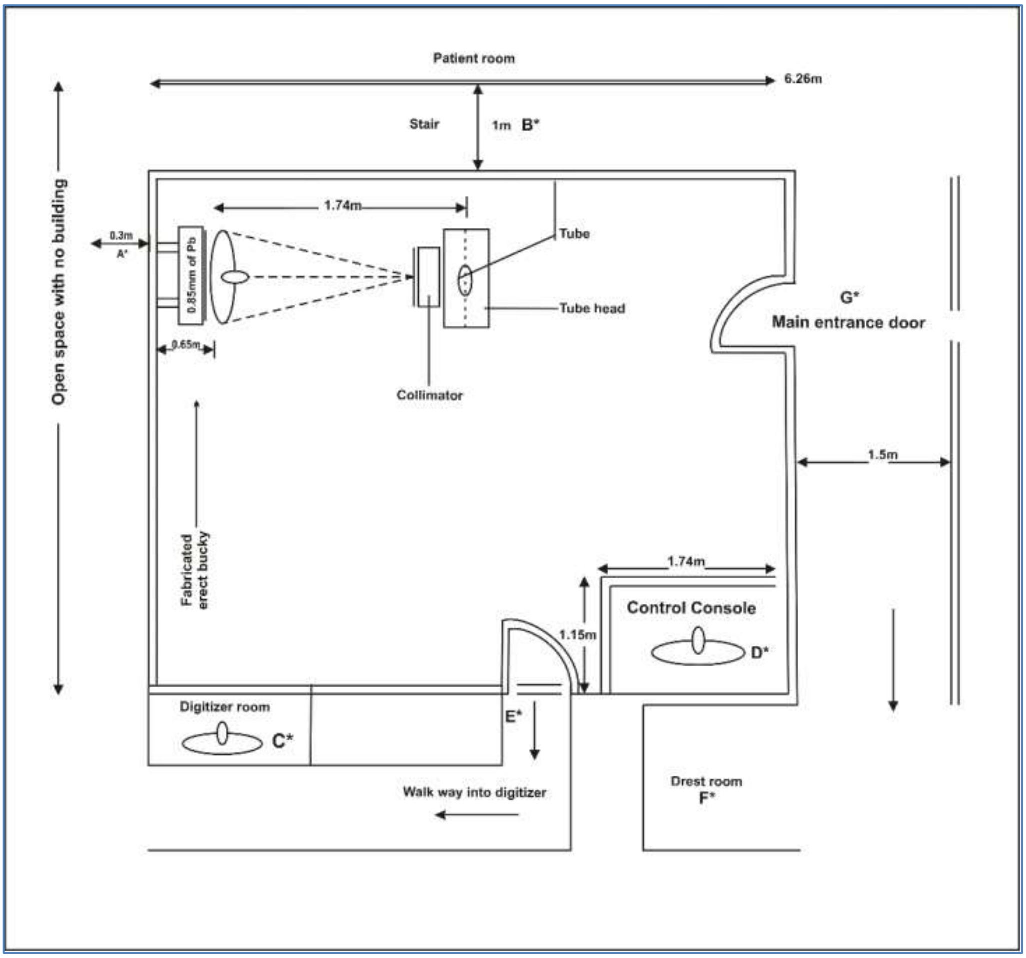
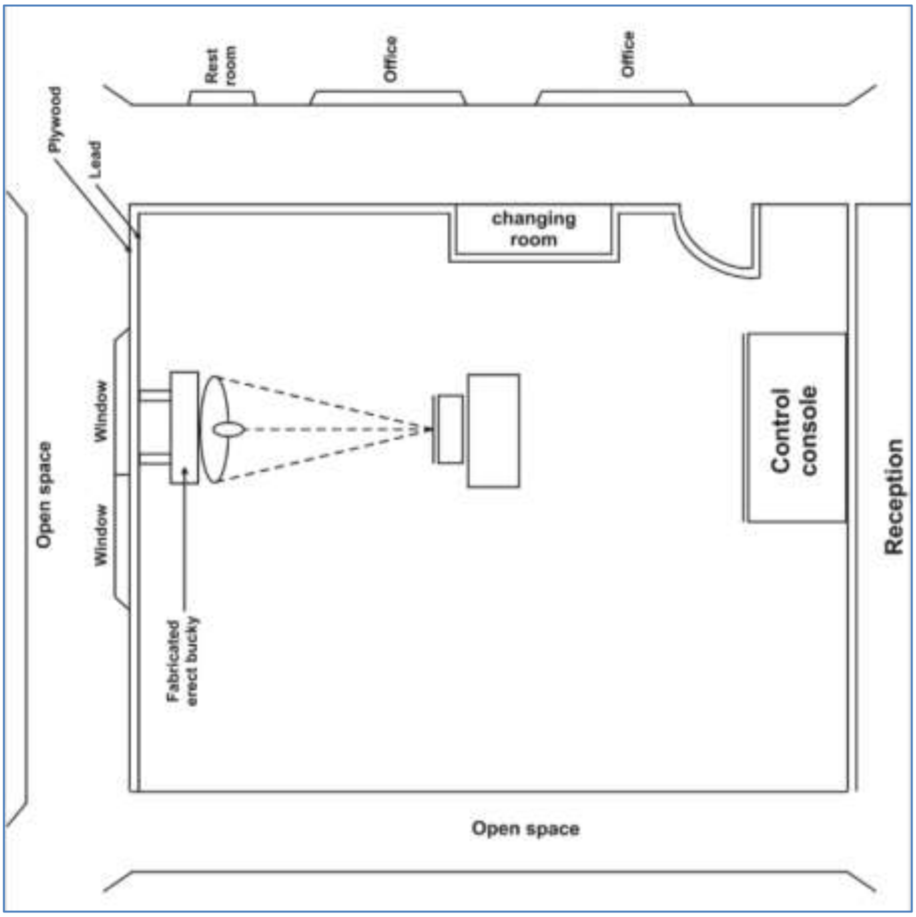
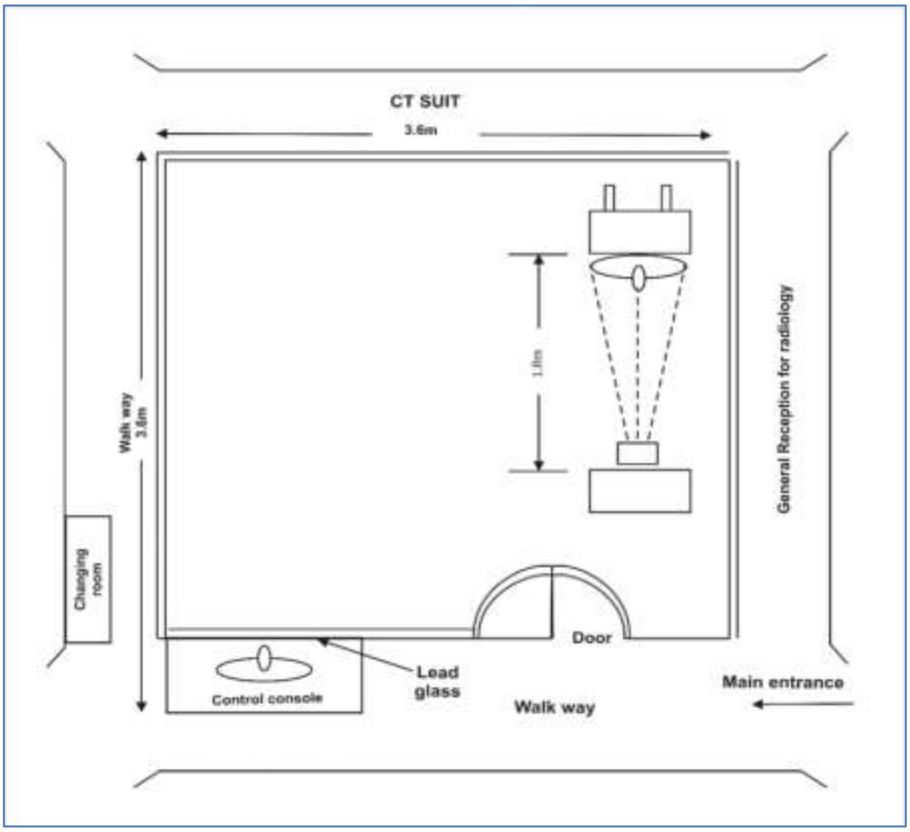


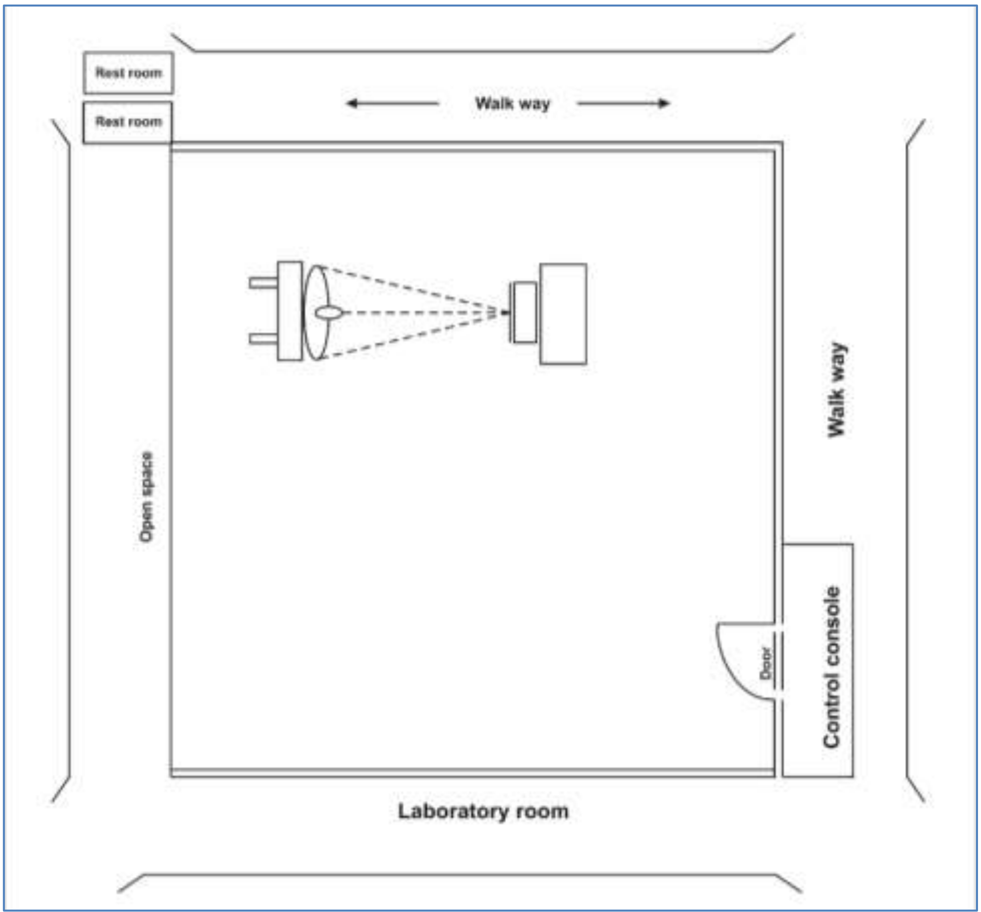
Appendix-1: X-ray room dimension for centre A



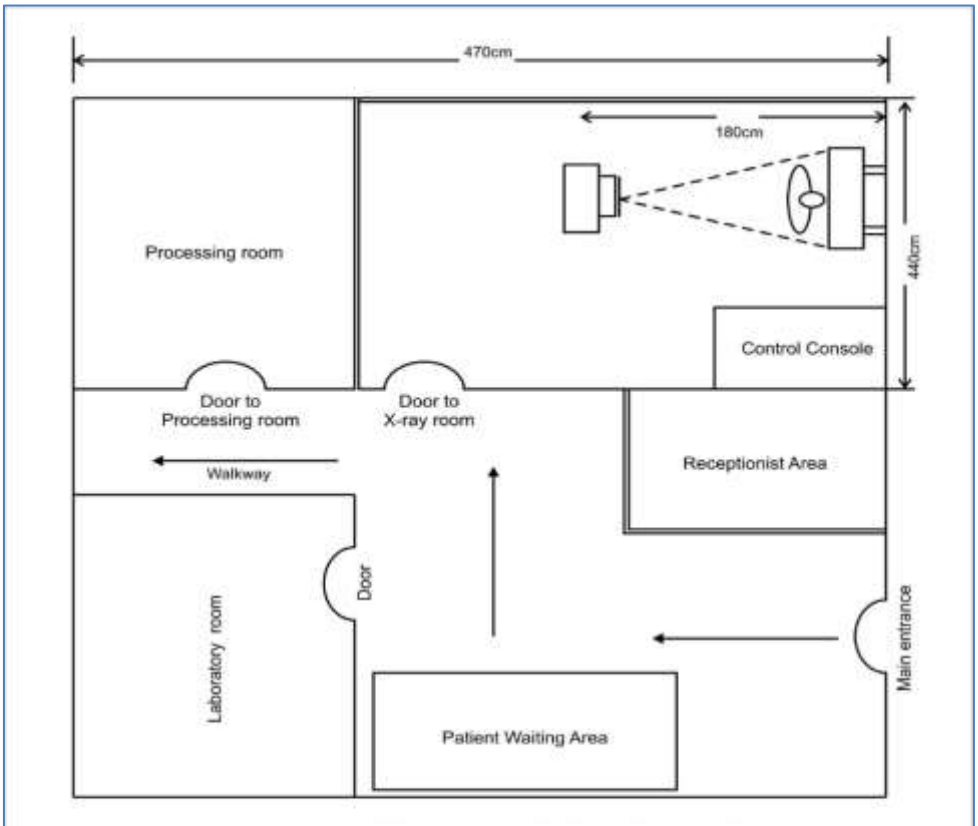
Appendix-2: X-ray room layout for centre B



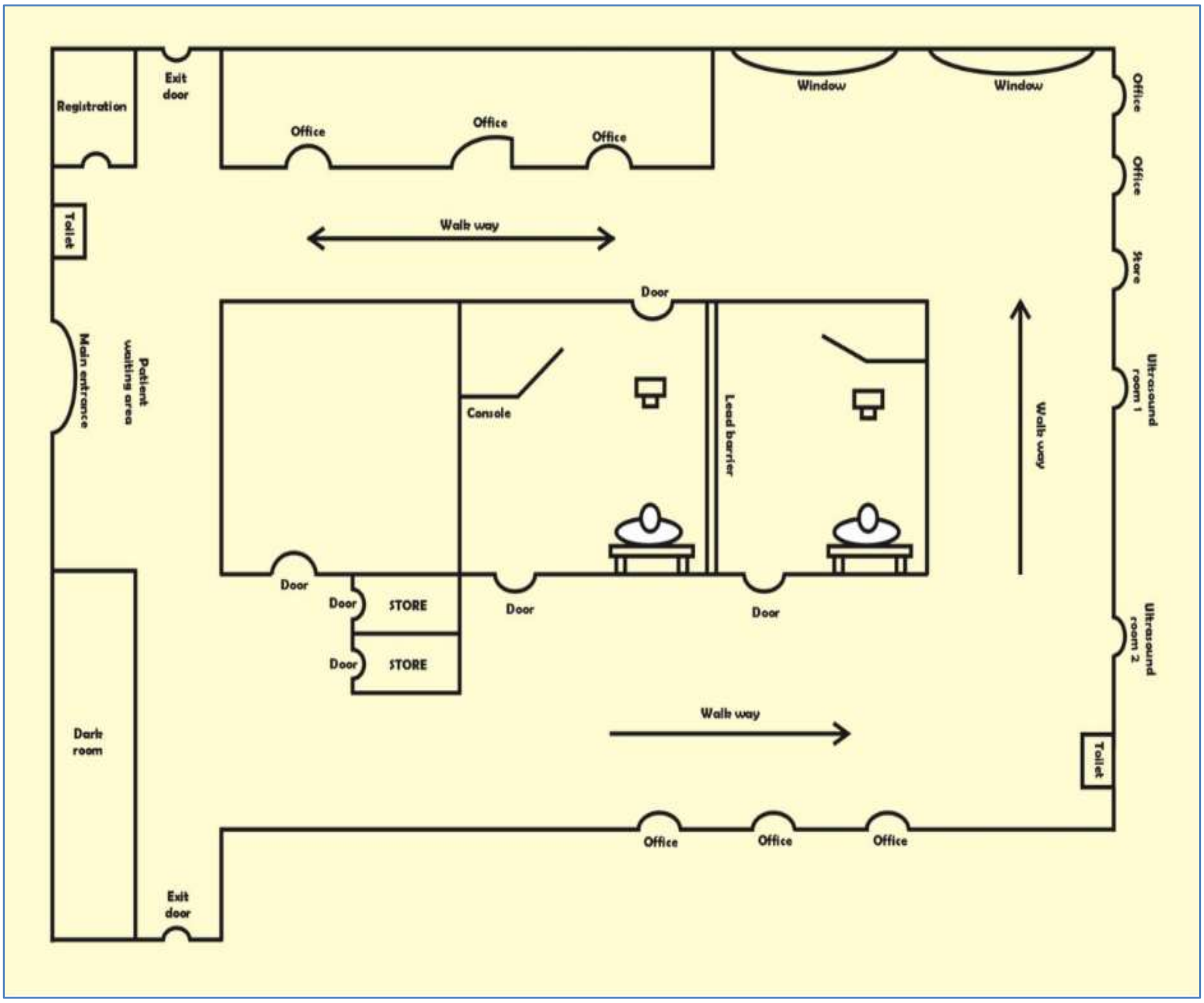
Appendix-3: X-ray room dimension for centre C



Appendix-4: X-ray room layout for centre D



Appendix-5: X-ray room for centre E



Appendix-6: X-ray room layout for centre F

Cite This Article: Anizor *et al* (2021). Evaluation of the Effectiveness of the Structural Shields of X-Ray Facilities in Asaba, Delta State. *EAS J Radiol Imaging Technol*, *3*(1), 6-16.