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ORIGINAL RESEARCH

A Survey of Structural Design of Diagnostic X-ray Imaging Facilities and Compliance to Shielding Design Goals in a Limited Resource Setting

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Abstract

Purpose: To survey structural designs of x-ray rooms and compliance to shielding design goals of three x-ray imaging facilities.

Methods and Materials: The survey was conducted in three radiodiagnostic centers in South East Nigeria, labeled X, Y and Z for anonymity. A stretchable non-elastic meter rule was used to measure x-ray room dimensions. A Vernier caliper was used to measure lead thickness while a calibrated digital survey meter Radalert 100x was used for radiation survey of controlled and uncontrolled areas. Simple statistical tools such as mean and standard deviation were used for analysis with the aid of Microsoft Excel version 2007.

Results: Center X had a room dimension of 2.4 m × 2.1 m, Center Y had an x-ray room dimension of 3.6 m × 3.3 m, and Center Z had two x-ray rooms with identical dimensions of 6.3 m × 3.6 m. Measured exit radiation doses for controlled areas in all the centers were: 0.00152 mSv/wk; 0.00496 mSv/wk; 0.00168 mSv/wk; 0.00224 mSv/wk respectively. Lead was the common shielding material used.

Conclusion: Based on the parameters studied, Center Z had the ideal room size and layout. Relative distances from the x-ray tubes to the nearest walls were not optimized in all the centers except in Center Z. Measured exit doses were within recommended limits except in Center Y. The location of the control consoles and measured doses were appropriate and within recommended design goals.

Introduction

THE structural design of every x-ray imaging facility is as important as the use of the facility itself (1,2). A properly designed and shielded x-ray imaging room is important for the radiation protection of the patient, staff and the general public. It is recommended that prior to equipment installation, surveys be carried out to ensure that the approved building plans have been followed and that the shielding and operating conditions in terms of design controls provide protection for all persons (3-6).

The structural design of x-ray imaging facilities will either enhance or diminish the primary objective of minimizing radiation dose to levels as low as reasonably achievable (ALARA). A well-designed x-ray imaging facility which takes into consideration design controls such as shielding and distance will minimize radiation exposure (6). This is rarely achieved in low- and middle-income

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countries with limited resources and a paucity of funds for standardized purpose-build x-ray rooms where the cost of lead shielding is also high, as noted by previous research (7,8). Unoptimized structural design of x-ray rooms and location of x-ray equipment within the x-ray room with marked variations from the recommended standard guidelines due to limited resources have been reported in studies conducted in limited-resource settings (6-8).

It is recommended that the location, structural design and equipment layout of x-ray rooms be carefully considered from a radiation protection perspective (9). The purpose of structural design of the x-ray rooms coupled with some form of shielding is to protect: the patient (when not being examined), the x-ray department staff, visitors, the public, and persons working adjacent to or near the x-ray facility (9). The x-ray room must be designed with knowledge of the location and use of all rooms which adjoin the x-ray room. This must be in consultation with a qualified expert (10). X-ray rooms are expected to be sufficiently large to reduce radiation intensity at the operator's console and to allow for free movement of persons and patients on trolleys (9,10). Time, distance and barrier are cardinal principles of radiation protection in projection radiography. Apart from the radiation protection benefit of longer distances in projection radiography, it also improves image sharpness through geometric means both in film screen and digital radiography (11,12).

It is advocated that the cost and practical implications of distance versus shielding should be considered in optimizing design solutions (8,11). This has great implications for developing countries, where the cost of shielding is very high. With maximized distance, and proper room dimensions, unnecessary costs of shielding can be reduced and radiation protection of persons at barriers adjacent to the x-ray rooms will be enhanced (10-12), since intensity of radiation decreases with distance from the source. However, there is a paucity of literature on this important subject in most developing countries (7,8). The present study is a structural survey of three x-ray imaging facilities in a limited-resource setting which assesses the structural designs of the x-ray rooms. Emphasis is placed on the x-ray room dimensions and layout, relative distance from the tube to various protective walls within the room, and location of the x-ray tube, control console and darkroom, followed by a radiation safety assessment of these areas.

Methods and materials

The survey was conducted in three radiodiagnostic centers (labeled X, Y and Z for anonymity) in a limited-resource setting in South East Nigeria. Center X had one x-ray room, Center Y also had one x-ray room and Center Z had two x-ray rooms. All the x-ray rooms studied were general purpose x-ray rooms. A calibrated digital survey meter, the Radalert 100x (International Medcom, Inc., Sebastopol, CA, USA), was used to measure transmitted radiation output from barriers.

Diagnostic x-ray room dimensions and distances were recorded with a stretchable non-elastic meter rule as shown

Figure 1. X-ray Room Layout for Center X

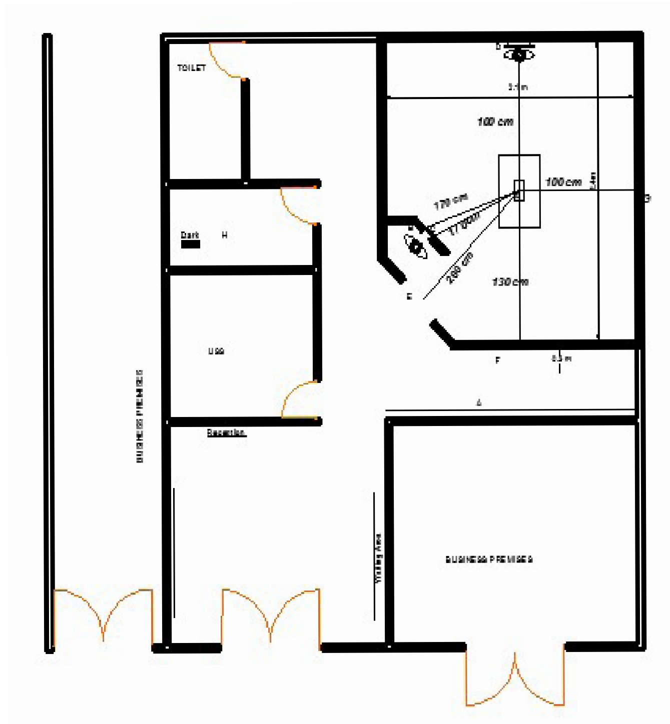


Figure 2. X-ray Room Layout for Center Y

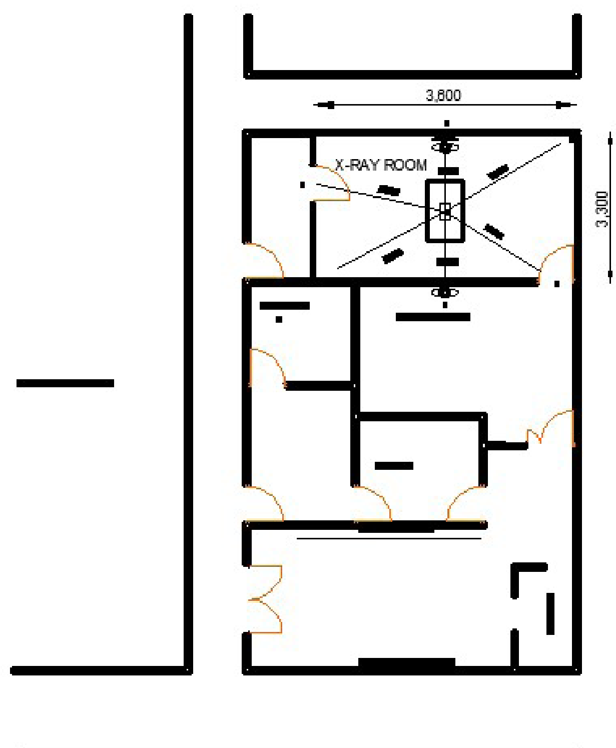
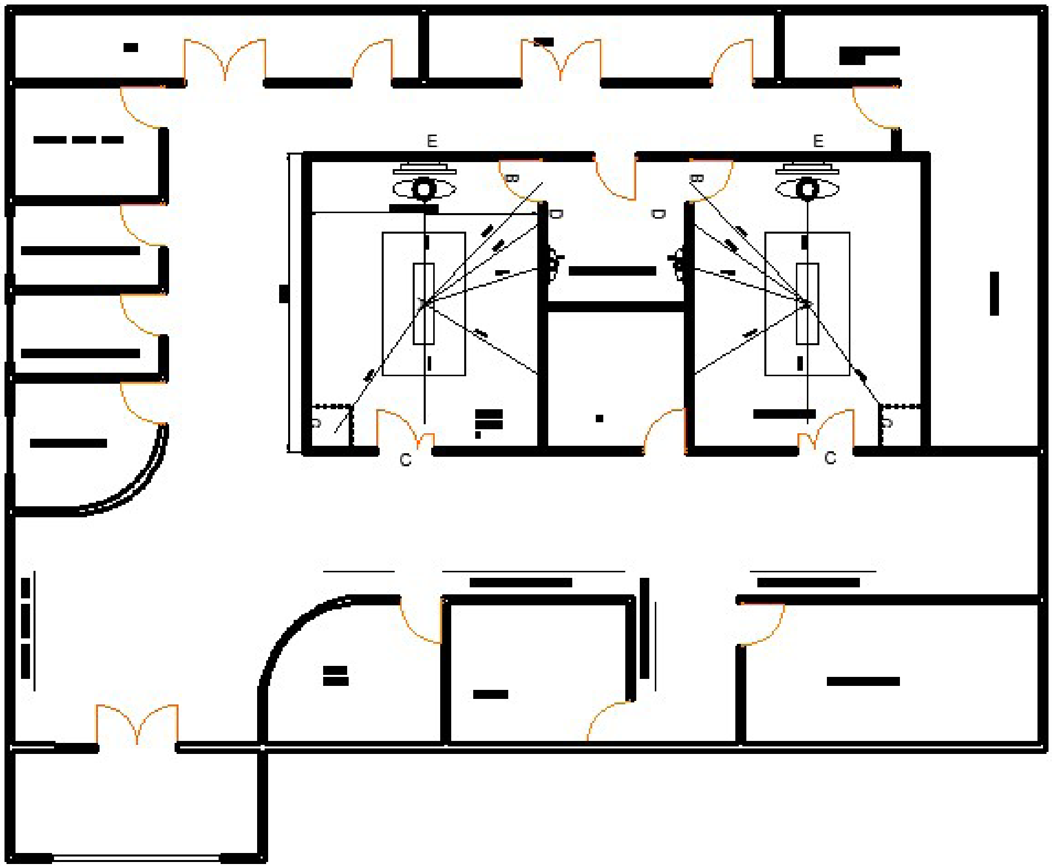


Figure 3. X-ray Room Layout for Center Z



in Figures 1, 2 and 3. Types of shielding material used in room designs were identified and thicknesses measured using a manual Vernier caliper. Measurements were interpreted from the scale by the user. The Vernier caliper has two measuring scales: a main metric scale and the hundredths of mm scale.

A radiation safety assessment by measurement of radiation transmission through the barriers was made with respect to reference shielding design goals recommended by the National Council on Radiation Protection and Measurements (NCRP) (5). This assessment tested the integrity of the shielding materials to protect from primary and secondary radiation. To minimize error, measurements were taken three times and the average documented. The digital survey meter was then zeroed for every fresh reading to avoid accumulated readings from previous measurements. All exit radiation measurements through barriers were taken at a distance of 0.3m (30 cm) from the nearest barrier as recommended by NCRP report No. 147 (5).

These measurements were grouped based on controlled areas and uncontrolled areas. Controlled areas are defined as limited-access areas, such as the x-ray room and areas directly connected to it, used by radiographers and radiologists during x-ray examination. In these areas, the occupational exposure of personnel to radiation is under the supervision of an individual in charge of radiation protection. Uncontrolled areas are areas in the vicinity of the x-ray room which are usually part of the x-ray department, and accessible to other radiation workers, hospital staff and the public (5).

The natural background radiation for each center was taken at different points while the x-ray equipment was switched off. All exposures were made from the x-ray machine using routine exposure factors. All measured exit dose values were reported as weekly shielding design goals. The data generated were analyzed with the aid of statistical software (Microsoft Excel version 2007).

Results

Findings from this study indicate that out of the three radiodiagnostic centers studied for structural designs, Center X (Figure 1) had a room dimension of 2.4 m × 2.1 m with a minimum and maximum distance of 100 cm and 280 cm from the x-ray tube to the nearest wall or protective barrier (Tables 1a and 1b). A 2.23 mm lead sheet bonded to plywood was used as the shielding material.

Center Y (Figure 2) had an x-ray room dimension of 3.6 m × 3.3 m with a minimum and maximum distance of 140 cm and 310

Table 1a. Measured Exit Dose for Controlled Areas from Center X

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose (mSv/wk)
1	Point B	Lead Glass window	170 cm	0.00152± 0.0000	0.1
2	Point C	Control Console	170 cm	0.0014 ± 0.0000	0.1
3	Point H	Darkroom	150 cm	0.00068± 0.0000	0.1

Table 1b. Measured Exit Dose for Uncontrolled Areas from Center X

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose (mSv/wk)
1	Point D	Chest Stand	100 cm	****	0.02
2	Point E	X-ray room door	280 cm	0.00056± 0.0000	0.02
3	Point F	Wall 1	130 cm	0.0176± 0.0009	0.02
4	Point G	Wall 2	100 cm	0.0076± 0.0004	0.02
5	Point I	Patient Waiting Areas	30 cm	0.00066±0.0000	0.02

****Radiation exit dose at this location could not be measured

cm from the x-ray tube to the nearest wall or protective barrier (Table 2a and 2b). Barium plaster with an unquantifiable thickness was used as the shielding material.

Center Z (Figure 3) had two x-ray rooms (Room 1 and Room 2), which shared common features structurally. Both Room 1 and Room 2 had room dimensions of 6.3 m × 3.6 m with minimum and maximum distances of 240 cm and 440 cm from the x-ray tubes to the nearest walls or protective barriers (Tables 3a and 3b; Tables 4a and 4b). The shielding material used in the x-ray rooms of this center was lead. The edges of the lead-lined walls were adequately sealed such that the lead thickness could not be measured. However, x-ray beam transmission through these walls was considered a measure of protection efficacy.

Centers Y and Z had control consoles located outside the x-ray room, while Center X's control console was located within the x-ray room. The darkrooms in Centers Y and Z were located adjacent to the x-ray room, while that of Center X was directly opposite the x-ray room, hence, its distance could not be measured (Figure 1). Of the three centers studied, only Center Z had provision for a well-designed patient changing cubicle.

Results of the radiation survey show that the average natural background for all the centers was 0.076±0.106 µSv/hr. Measured or estimated transmission doses beyond the shielded barriers show that for Center X, a maximum exit dose value of 0.00152mSv/wk was recorded for controlled areas against the recommended value of 0.1mSv/wk, while a maximum exit dose value of 0.0176mSv/wk was recorded for uncontrolled areas, against the recommended value of 0.02mSv/wk (Tables 1a and 1b).

The results from Center Y also show that the maximum exit dose for a controlled area was 0.00496 mSv/wk, against the recommended 0.02mSv/wk (Tables 2a and 2b). However, high measured radiation dose values above the recommended shielding design goals were observed at two locations in Center Y for uncontrolled areas; point C (Primary wall behind the chest stand), 0.428 mSv/week; and point F (behind x-ray room door 2), 0.321 mSv/week (Table 2b and Figure 2). The recommended shielding goal for these areas is 0.02 mSv/week. Results from the two rooms in Center Z show that the maximum measured exit dose for controlled area in Room 1 was 0.00168 mSv/wk, while maximum measured exit dose for uncontrolled areas was 0.00392 mSv/wk. The maximum exit dose at controlled and uncontrolled areas for Room 2 were also within recommended limits as shown in Tables 3 and 4.

Discussion

This study set out to survey the structural shielding design and radiation transmission through barriers of three radiodiagnostic centers in a limited-resource setting in South East Nigeria. Findings from this study concur with results in the existing body of literature that most diagnostic x-ray rooms in developing countries are not designed based on recommended standard specifications (6-8). The three radiodiagnostic centers covered in this study have given us three different structural designs of diagnostic x-ray rooms, types of shielding materials used and radiation transmission through barriers. These findings call for standardization in radiology room designs and regular radiation safety assessment as recommended by regulatory bodies (4,5).

Table 2a. Measured Exit Dose for Controlled Areas from Center Y

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose (mSv/wk)
1.	Point B	Control console	180 cm	0.00496±0.0002	0.1
2.	Point G	Darkroom	30 cm	0.00208±0.0001	0.1

Table 2b. Measured Exit Dose for Uncontrolled Areas from Center Y

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose (mSv/wk)
1.	Point C	Primary wall	310 cm	0.428±0.0214	0.02
2.	Point D	Secondary wall	200 cm	0.02416±0.0012	0.02
	Point E	X-ray room Door1	180 cm	0.01012±0.0005	0.02
3.	Point F	X-ray room Door2	140 cm	0.32144±0.0161	0.02
4.	Point H	Reception	30 cm	0.00064±0.0000	0.02

Table 3a. Measured Exit Dose for Controlled Area for Center Z1

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose (mSv/wk)
1.	Point D	Wall 1	200 cm	0.00168±0.0000	0.1
2.	Point F	Control console	220 cm	0.00044±0.0000	0.1
3.	Point G	Cubicle	300 cm	0.00072±0.0000	0.1
4.	Point H	Darkroom	360 cm	0.00052±0.0000	0.1

Table 3b. Measured Exit Dose for Uncontrolled Areas for Center Z1

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose (mSv/wk)
1.	Point B	X-ray room Door1	240 cm	0.001±0.0000	0.02
2.	Point C	X-ray room Door 2	440 cm	0.00088±0.0000	0.02
3.	Point E	Wall 2	220 cm	0.00392±0.0000	0.02
4.	Point I	Waiting Area	30 cm	0.00096±0.0000	0.02

Time, distance and shielding are well-established dose reduction strategies in radiography (12). Measurement of distances in diagnostic radiography is of great significance, as the intensity of radiation decreases as the square of its distance from the source, according to the inverse square law (12). Apart from decreasing the intensity of radiation, maximized distance also helps to minimize the cost of shielding (9), and also has clinical significance as it aids in proper patient positioning and geometric display of anatomy of interest and pathology on radiographs (11,12). If the x-ray room size is not adequate and the location of the x-ray tube to the nearest wall or chest stand is not optimized, these could lead to poor positioning and wrong diagnosis of numerous chest pathologies. For example, the recommended distance for standard chest x-ray is within the range of 140 cm to 200 cm based on the literature (11).

In this study, the distance from the x-ray tube to the chest stand in one of the centers was found to be 100 cm, which is less than the recommended distance for a standard chest x-ray of 140-200 cm (11). This implies that chest x-rays done at this distance may not reflect the true anatomical geometry of the patient's chest, since the source to image distance is not optimized. The radiation protection implication of this

Table 4a. Measured Exit Dose for Controlled Areas for Center Z2

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose (mSv/wk)
1.	Point D	Wall 1	200 cm	0.00224±0.0001	0.1
2.	Point F	Control Console	220 cm	0.00052±0.0000	0.1
3.	Point G	Cubicle	300 cm	0.00104±0.0000	0.1
4.	Point H	Darkroom	360 cm	0.00052±0.0000	0.1

Table 4b. Measured Exit Dose for Uncontrolled Areas for Center Z2

S/N	Point of Measurement	Description	Distance from the source	Measured Exit Dose	Recommended Dose
1.	Point B	X-ray room Door1	240 cm	0.00104±0.0000	0.02
2.	Point C	X-ray room Door 2	440 cm	0.00544±0.0003	0.02
3.	Point E	Wall 2	220 cm	0.00904±0.0005	0.02
4.	Point I	Waiting Area	30 cm	0.00096±0.0000	0.02

finding is that the intensity of the radiation reaching this wall will be high, hence additional shielding may be required. This finding is just one among many issues that go unnoticed in limited-resource settings.

Of the three radiodiagnostic centers covered in this study, one was owned by the Nigerian government, whereas the other two centers were owned by private practitioners. On the x-ray room layout, it was noted that only Center Z (Figure 3) had a standard, general-purpose diagnostic x-ray room size and layout, while the others were modified existing structures used for diagnostic centers. These findings are consistent with those of Muhogora and Kondoro (7), who conducted a study on secondary shielding barriers in Tanzania and noted that most of the x-ray rooms in private hospitals were not of the recommended standard sizes.

The relative position of the various points selected from the x-ray tube to the nearest walls were not fully optimized in two of the three centers, as shown in Tables 1, 2, and 3. The findings still corroborate those of an earlier study (6). If the distance from the x-ray tube to the nearest point of occupancy is not optimized and the recommended shielding materials are not used, the possibility of unintended exposure to unsuspecting staff, patients in the waiting area and the general public is high (10). Two of the three centers studied had their control console located outside the x-ray room (Figures 2 and 3), and one was situated inside the x-ray room (Figure 1).

The practice of situating the control console either within or outside the x-ray room depending on the output of the x-ray equipment is consistent with recommendations from advisory and regulatory boards (5,9,10). The locations of the darkrooms relative to the x-ray tube based on the distances measured appear appropriate by visual inspection. These were further verified by measuring the exit radiation dose to ensure that the walls were able to shield the x-rays to the recommended shielding goals or design dose for x-ray films stored in the darkroom (1,2,5).

Findings of measured radiation doses transmitted through barriers showed that two of the three centers studied were in compliance with the recommendations of the shielding design goals. Only Center Y recorded doses above the recommended design dose limits at some locations, as shown in Tables 2a and 2b. While the measured exit dose for controlled areas in Center Y was below the recommended limit, high measured values above the recommended shielding design goal were observed at two locations for uncontrolled areas; Point C (Primary wall behind the chest stand), and Point F (x-ray room door 2). Possible factors influencing the high measured radiation exposure levels at these points could be inadequate shielding and room dimensions not being optimized. It was further observed that barium plaster was used in this center for shielding, but barium is less efficient than lead in terms of shielding efficacy (9). The doors were not adequately lead-lined, which accounted for the high x-ray beam transmission. The radiation protection implication of this finding is that passersby and patients could be subjected to unnecessary radiation exposure in these areas.

Conclusion

These findings provide a picture of the progress to be made in limited-resource settings in meeting the Basic Safety Standard (BSS) for radiation protection. Of the three centers studied, our findings with respect to room sizes and layouts, relative distances from the x-ray tube to the nearest shielded walls, and location of the control consoles and the darkrooms, showed that Center Z had the recommended room sizes and layouts. Relative distances from the x-ray tube to the nearest shielded walls were not fully optimized in all the centers except in Center Z. However, the location of the control console and the measured distances from the x-ray tube were appropriate as shown by the measured x-ray transmission through the shielded barriers. Measured exit doses for all controlled areas were within recommended limits, except in one of the centers where doses above the recommended limits were observed for uncontrolled areas.

Conflict of interest

The author reports no conflict of interest.

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