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Shielding Adequacy of Conventional X-ray Facilities in Kano Metropolis, Nigeria using RadShield Software

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Abstract

Over time x-ray department gains more patient throughput compared to when it was established, this may lead to changes in room usage, workload and occupancy factor. Therefore, it becomes imperative to re-evaluate the shielding adequacy of the facilities to ensure the appropriate shielding design goal is accomplished. The study was aimed at assessing the shielding adequacy of conventional x-ray rooms in ten radio diagnostic centres in Kano Metropolis using RADSHIELD software. This was a prospective, cross-sectional study. RadShield software version 1.1 was used in the study, parameters such as distances of each wall from a radiation source (D), the average number of patients per week (N), occupancy factor (T), and use factor (U) were inserted into the software together with the shielding design goal (P). Once the result was generated, the design and shielding variables were saved in .xml format. The data were analyzed using Excel 2016. Ten facilities were studied involving 14 x-ray rooms. Room III had the largest room size of 49.2 m^2 while room X had the least room size of 12.8 m^2. Room II had the longest source image distance (SOD) of 180cm while room IV had the shortest (120cm). The design barrier thickness was thickest (47 cm) in room II and thinnest (1.5 cm) in barrier 5 of room III. All the x-ray rooms had the ideal room size except facilities G and H. The design barrier thickness in the radiology department of all the conventional x-ray rooms involved in the study was adequate.

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1. Introduction

Radiation shielding refers to the deliberate insertion of materials between the radiation and objects to reduce the radiation intensity and damage to the object with the sole aim of reducing non-deterministic and preventing deterministic effects [1-2]. The harmful effects of ionizing radiation used in medicine result from the non-deterministic effect which is cancer and heritable effects involving either cancer development in exposed individuals owing to mutation of somatic cells or heritable disease in their offspring owing to mutation of reproductive cells [1]. The common shielding materials used for interior walls ranged from sheet lead, Gypsum wallboard, concrete block, clay brick and tiles [3]. The adequate shielding thickness must provide at least the attenuation required to reduce the air kerma (E) to the shielding design goal [4]. Shielding design goals (P) are levels of air kerma (E) used in the design calculations and evaluation of barriers constructed for the protection of people in controlled and uncontrolled areas [4]. The weekly shielding design goal for a controlled and uncontrolled area is an air kerma value of 0.1 mGy and 0.02 mGyweek^{--}1 respectively.

The parameters to consider before computing the shielding thickness of any facility includes; distance to the occupied area (D), occupancy factors (T), workload, workload distribution (W), and use factor (U). The distance (d) to the occupied area of interest should be taken from the source to the nearest likely approach of the sensitive organs of a person to the barrier [5]. For a wall, this may be assumed to be not <0.3m [5]. The occupancy factor (T) for an area is the average fraction of time that the maximally exposed individual is present while the x-ray beam is on Ref. [5]. The workload (W) of a medical imaging x-ray tube is the time integral of the x-ray tube current over a specified period, while the normalized workload (Wnorm) is the average workload per patient. Thus, the product of Wnorm and the average number of patients per week (N) is the total workload per week (Wtot) [5]. For shielding design, the distribution of workload as a function of kVp is much more important than the magnitude of the workload since the attenuation properties of barriers exhibit a strong kVp dependence [5]. The use factor (U) is the fraction of the primary beam workload that is directed toward a given primary barrier. The NCRP recommended U = 1 for primary barriers and U = 0 for secondary barriers for radiographic rooms.

RadShieldsoftware is a java based Graphical User Interface (GUI) that is designed to be used through a series of ordered steps based on the NCRP report 147, American Association of Physicist in Medicine (AAPM)Task Group Report 180 and the British Institute of Radiology's publication: Radiation Shielding for Diagnostic Radiology [5]. It was developed by Matthew DeLorenzo at the University of Oklahoma Health Sciences Center. The GUI will permit the user to enter an image of the x-ray room floor plan from disk in .png, .jpg, .gif or gif format to be overlaid on the workspace. This enabled the user to adapt the floor plan to match the correct dimension of the examination room.

Initially shielding calculations were done manually by medical physicists based on the mentioned guidelines, to recommend the minimum required barrier thickness to reduce the primary and secondary radiation to their room-specific design goal [6], however, the medical physicist typically approximate the nearest prefabricated slabs of lead thickness in 0.079m [6]. Doug Simpkin developed XRAYBARR software based on NCRP report 147. The advantages of XRAYBARR over manually hand spreadsheets calculations include multiple workload distributions, outputs organized results [6]. However, the disadvantages include, the calculation of air-kerma rate and barrier thickness at only one point, for which the user must manually locate, it doesn't take into account the entire floor layout and line of sight geometry when performing calculations [6]. RadShield overcomes all these limitations, as it computes required barrier thickness using an iterative method for multiple points and reports the maximum values for each barrier.

To the best of the researcher's knowledge, only two government-owned x-ray facilities were evaluated for shielding thickness adequacy using a software-based study. The software used in the aforementioned study was XRAYBARR. Furthermore, most of the facilities under study were not evaluated since when established and there has been an increment in patients' throughput to the hospitals due to increased population size and awareness. This may lead to more increment of the workload distribution, however, changes are not made in the shielding materials to suit the current situation. The findings of this study will be used as a baseline for making recommendations to the relevant authorities regarding the optimization of radiation protection for workers and other members of the public. The study was aimed at assessing the shielding adequacy of conventional x-ray facilities in Kano metropolis, Nigeria using RadShield software version 1.1.

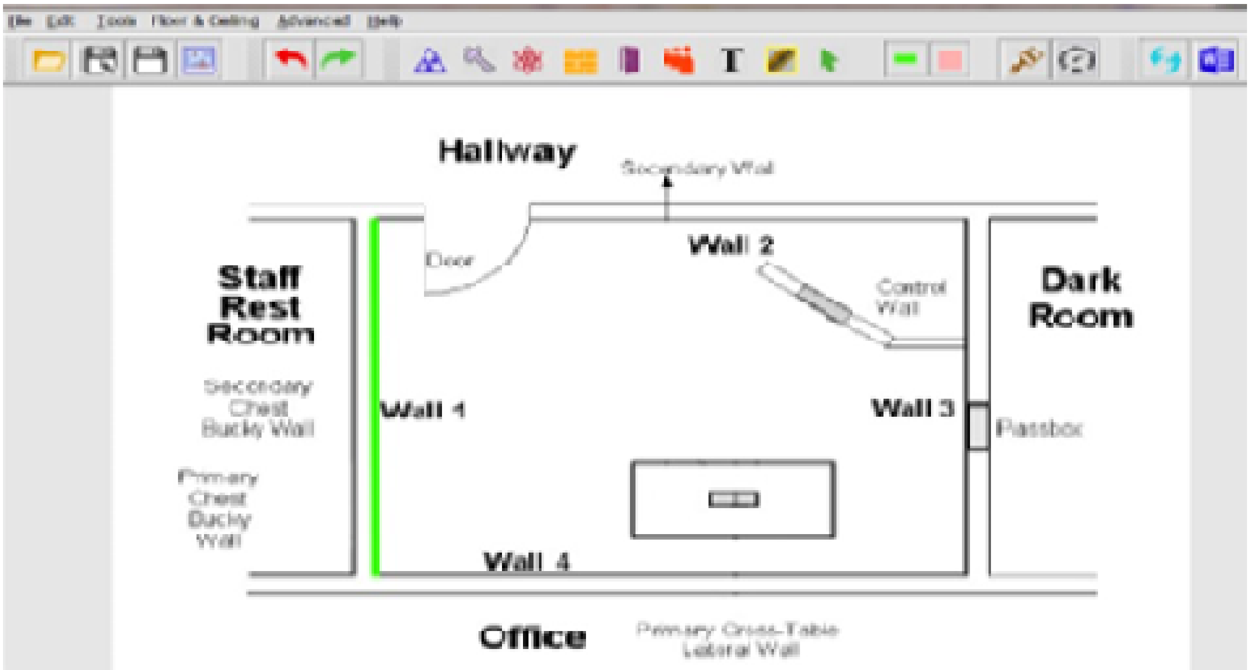

Figure 1. An illustration of RadShield workspace.

2. Materials and methods

This study was prospective and cross-sectional. A convenient sampling technique was adopted to select ten radio-diagnostic facilities from January 2020 to June 2022. The facilities were named A-J. Facilities, A, G and J were private radio-diagnostic facilities while B, C, D, E, F, H and I were government-owned facilities, among which facilities C, D and F were tertiary facilities while facilities B, E, H and I were secondary. All facilities or rooms with inactive conventional x-ray machines were excluded from the study. Thus in facilities A, B, D, G, H and J only single rooms were considered named, room I, room II, room V, room X, room X, room XI and room XIV respectively. While in facilities C, E, F and I, only two rooms were considered named room III and IV, room VI and VII, room VIII and IX and room XII and XIV respectively. Ethical clearance was obtained from the Research and Ethics Committee of the Kano State Ministry of Health prior.

A stretchable measuring tape was used to measure all the room's dimensions, the distances from the x-ray tube to the barriers and the barrier thickness. The room sketch was drawn using a computer app 'paint' and saved in the .png format as an image. The scale of the image was set in terms of pixels per meter which served as a template over which the researcher drew barriers, region of interest and source-to-patient distance (SOD) in their appropriate locations. The stored scale image file was imported into RadShield software (Figure 1) using either the picture button, file menu > load floor plan or by pressing the image icon provided on the top toolbar (Figure 2). All the calculation plans were done within the workspace provided by the software. The scale of the floor plan was set by measuring the distances of the walls from the x-ray sources using a ruler button at the top toolbar. Distances from every source to a given calculation point are automatically found using the coordinates of the image area and Pythagorean's theorem. With the help of a green arrow sign icon at the top toolbar, a line was created by dragging the mouse on the workspace from the upper point of a barrier to the lower point. Fine adjustments sometimes were made by right-clicking near the ends of the line to place the ends where appropriate. All objects drawn on the workspace were added and managed in the object list editor window. Regions were created by either selecting the top toolbar button or the Tools pulldown menu (Figure 3). Then the cursor was dragged and released on the workspace to make a rectangle. Fine adjustments and resizing were sometimes made using the right mouse button and grabbing a corner of the region.

The design goal, use factors and occupancy factor for the selected regions and barriers were generated from the

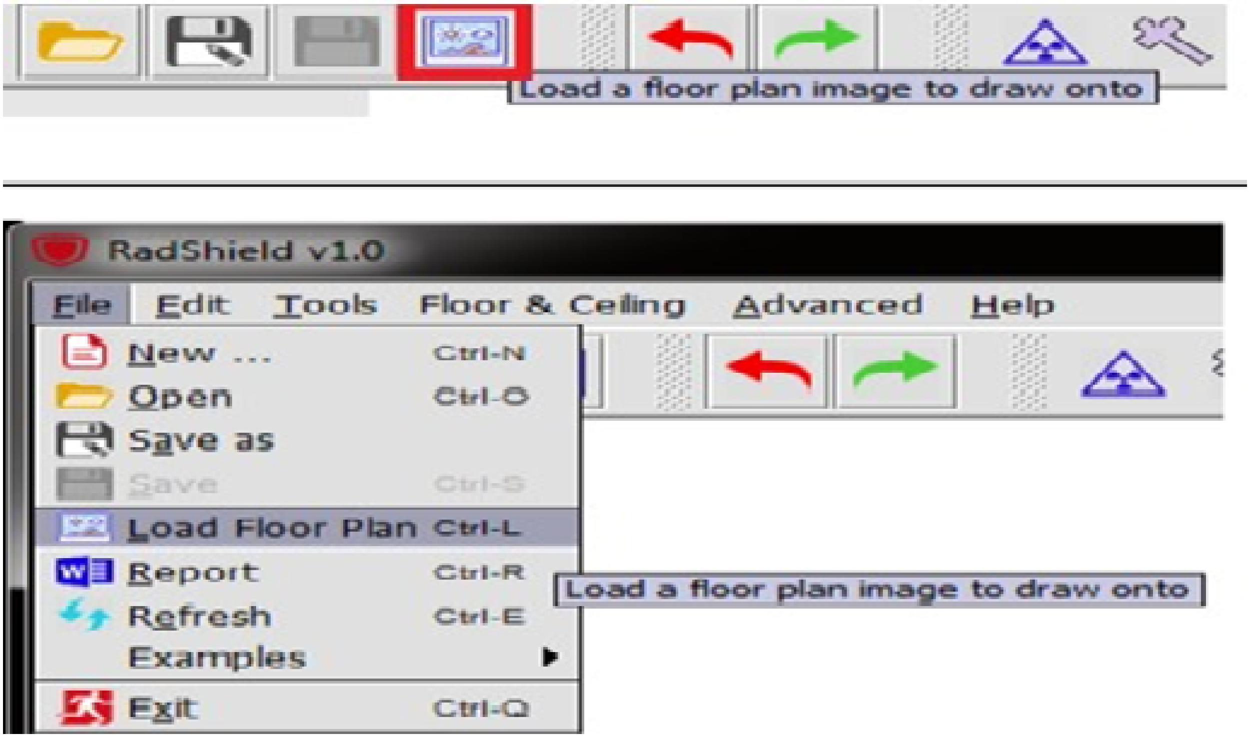

Figure 2. Loading a floor plan.

formatted lookup table based on the NCRP 147 recommendations provided by the software (Figure 4). The x-ray tube sign was drawn by selecting a radiation sign button on the top toolbar or in the tools menu and clicking on the screen where appropriate. A green cursor was clicked to make sure the tube was highlighted on the object list editor (Figure 5) which was labelled as tube 1. All patients' locations were represented by an ellipse sign within the workspace. Properties of the x-ray tube such as the number of exams, SOD, primary radiation direction (in degrees) and direction of primary radiation direction were assigned by highlighting tube 1 on the object list editor. Walls were drawn as straight lines on the workspace. A wall button icon was selected at the top toolbar then click on the starting point of the wall, then dragged and released at the ending point. The shielding properties assigned to the wall were workload distribution and material used as barriers appropriate for each room. Walls, where the x-ray tubes were directed, were considered primary walls. Doors were created by a door icon on the top toolbar which was pressed and drawn from the starting point of the door and released at the ending point of the door. The separation distance for sampling kerma between calculation points and walls or doors was set at default (0.3 meters) in all the rooms as recommended by NCRP 147 reports. When all required information has been entered, the user presses a final button to run the calculations. Once the result was generated, the design and shielding variable was saved in .xml format. The data collected was analyzed using descriptive statistics by Excel 2016 and presented in tables.

3. Results

Table 1 indicated that Room III had the largest room size of 49.2 m^2 while room X had the least room size of 12.8 m^2. Room II had the longest SOD of 180cm while room IV had the shortest SOD of 120 cm as seen in Table 1. Tables 2 and 3 indicated that 14 barriers were primary and 48 were secondary. The design barrier thickness was thickest (47 cm) in room II and thinnest (1.5 cm) in barrier 5 of room III as seen in Tables 2 and 3. Tables 2 and 3 indicated that the calculated thickness in all the rooms was less than the design barrier thickness and the ratio of the design barrier thickness to the calculated barrier thickness was less than 1 in all the rooms.

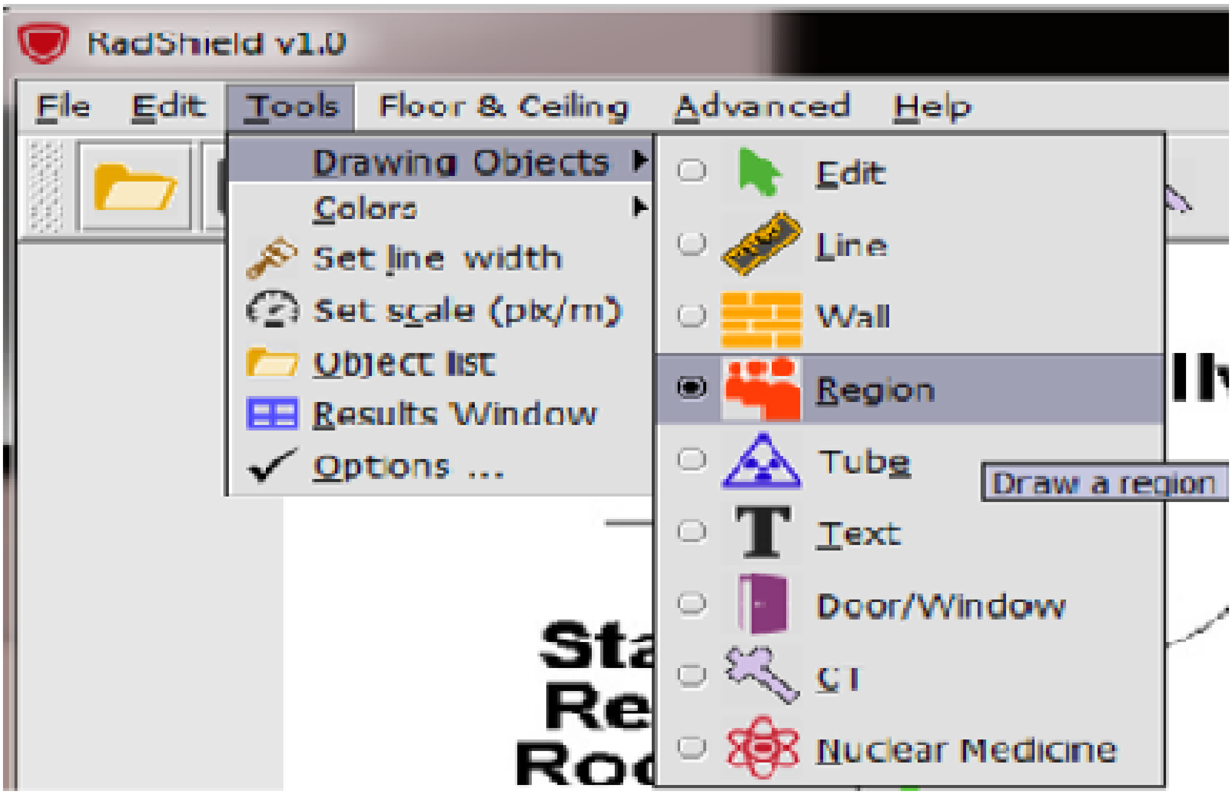

Figure 3. Inserting regions locations.

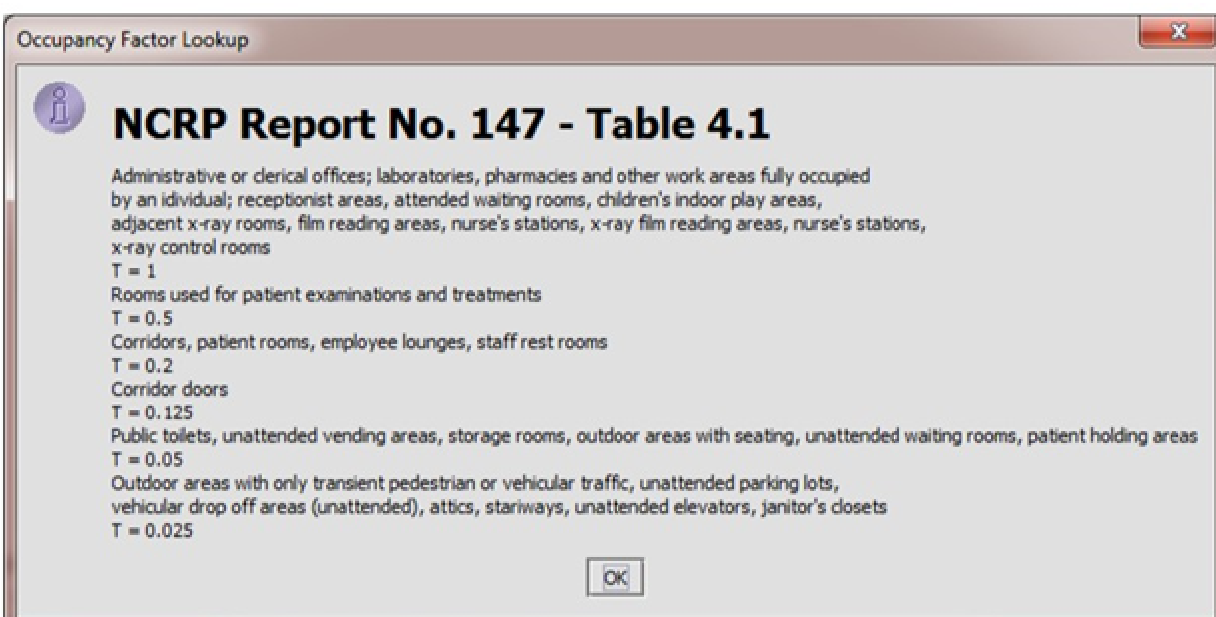

Figure 4. Formatted lookup table based on the NCRP 147 recommendations.

Figure 5. Object list editor.

Table 1. Facilities Description.

Facility Name	Rooms number	Room Dimension (m^2)	SOD (cm)
A	Room I	25.2	150
B	Room II	23.8	180
C	Room III	49.5	140
	Room IV	29.2	120
D	Room V	37.1	150
E	Room VI	30.1	150
	Room VII	30.1	180
F	Room VIII	35.2	150
	Room IX	33.4	150
G	Room X	12.8	150
H	Room XI	22.6	150
I	Room XII	33.5	150
	Room XIII	44.2	150
J	Room XIV	13.4	150

KEY: A= Providian; B=Muhammadu Buhari Specialist hospital (MBSH); C= National Orthopedic Hospital (NOHD); D= Nigerian Airforce Base Hospital (NAF); E= Muhammad AbdullahiWase Hospital (MAWSH), F= Aminu Kano Teaching Hospital (AKTH); G= Mecure; H= Sheik Khalifa Isyaka Rabiu Pediatric Hospital (SKIRPH); I= Murtala Muhamad Specialist Hospital (MMSH); J= DSM. SOD: Source Object Distance.

4. Discussion

The findings of the current study as shown in Table 1, indicated that the majority8 (80%) of the facilities met the requirements of the standard in terms of minimum x-ray room dimensions. This is similar to the findings in Ref. [7]. The possible reasons for the similarities could be because the majority of the hospital within this category were

Table 2. Number and type of barriers, design barrier thickness (cm), calculated thickness (cm), and the ratio of calculated to design barrier thickness for barrier shielding estimated from RadShield for all the facilities.

Rooms	Number of Barriers	Type of Barriers	Design barrier thickness (cm concrete)	Calculated thickness (cm)	Ratio of calculated to design barrier thickness
Room I	1	Primary	42.5	7.28	0.17
	2	Secondary	42.5	0.28	0.01
	3	Secondary	42.5	1.51	0.04
	4	Secondary	42.5	0.82	0.02
Room II	1	Primary	47.0	4.21	0.09
	2	Secondary	47.0	1.56	0.03
	3	Secondary	47.0	0.21	0.00
	4	Secondary	42.0	0.39	0.01
Room III	1	Primary	30.0	3.23	0.12
	2	Secondary	30.0	5.31	0.18
	3	Secondary	30.0	0.08	0.00
	4	Secondary	30.0	0.28	0.01
	5 (CR)	Secondary	1.50	1.19	0.79
Room IV	1	Primary	27	2.90	0.11
	2	Secondary	27	0.27	0.01
	3	Secondary	27	0.30	0.01
	4	Secondary	27	0.59	0.02
	5 (CR)	Secondary	25	0.45	0.02
Room V	1	Primary	30	0.61	0.02
	2	Secondary	30	1.44	0.05
	3	Secondary	30	0.38	0.01
	4	Secondary	30	0.19	0.01
	5 (CR)	Secondary	18	0.06	0.00
Room VI	1	Primary	37	8.85	0.24
	2	Secondary	30	1.82	0.06
	3	Secondary	37	3.87	0.10
	4	Secondary	37	1.18	0.03
Room VII	1	Primary	25	3.30	0.13
	2	Secondary	25	2.55	0.10
	3	Secondary	25	0.02	0.00
	4	Secondary	25	0.82	0.02

CR: Control room

government-owned facilities or might be due to the involvement of regulatory authorities during the establishment of such facilities. In the current study 2 (20%) facilities did not meet the minimum standard of x-ray room dimension as seen in Table 1. These violated the minimum room size recommendations of $16m^2$ – $24m^2$ given by the Nigerian Nuclear Regulatory Agency (NNRA), International Atomic Energy Agency (IAEA) and World Health Organization (WHO) [2, 7, 8]. These findings are similar to the study conducted by Nkubli *et al*. [9]. The possible reason for the similarity is related to the fact that all the facilities are privately owned. It is a known fact that the majority of private facilities were not initially built for medical services. Secondly, most likely regulatory bodies such as NNRA were not involved during the establishment of the facilities.

In the current study, as seen in Table 1, the SOD in 1 (10%) of the facilities was less than the recommended distance for a standard SOD of 140 cm - 200 cm. The finding is in accordance with the study conducted by [9]. This might leads to radiation dose increment, as the intensity of radiation is inversely proportional to the square root of the distance, probably additional shielding may require in the room. Secondly, it could lead to poor representation of the true anatomical structures as they might be magnified.

Table 3. Number and type of barriers, design barrier thickness (cm), calculated thickness (cm), and the ratio of calculated to design barrier thickness for barrier shielding estimated from RadShield for all the facilities.

Rooms	Number of Barriers	Type of Barriers	Design barrier thickness (cm concrete)	Calculated thickness (cm)	Ratio of calculated to design barrier thickness
Room VIII	1	Primary	25	6.46	0.26
	2	Secondary	29	2.61	0.09
	3	Secondary	4.5	1.23	0.27
	4	Secondary	25	2.75	0.11
Room IX	1	Primary	30	3.81	0.13
	2	Secondary	30	0.57	0.02
	3	Secondary	12	0.65	0.05
	4	Secondary	30	0.67	0.06
Room X	1	Primary	43.6	3.21	0.07
	2	Secondary	43.6	0.76	0.02
	3	Secondary	43.6	0.08	0.00
	4	Secondary	43.6	0.77	0.02
Room XI	1	Primary	43	2.47	0.06
	2	Secondary	43	0.41	0.01
	3	Secondary	43	0.99	0.02
	4	Secondary	43	0.16	0.00
Room XII	1	Primary	30	8.12	0.27
	2	Secondary	30	0.68	0.02
	3	Secondary	30	1.21	0.04
	4	Secondary	30	1.08	0.04
	5(CR)	Secondary	13	2.58	0.09
Room XIII	1	Primary	24	5.48	0.23
	2	Secondary	24	1.74	0.07
	3	Secondary	13	0.99	0.08
	4	Secondary	24	2.35	0.10
	5(CR)	Secondary	26	4.43	0.17
Room XIV	1	Primary	21	2.20	0.10
	2	Secondary	21	1.21	0.06
	3	Secondary	21	0.18	0.01
	4	Secondary	21	1.06	0.05

CR: Control room

In all the facilities, 65% of the primary beam was directed to the primary barriers and 35% of the radiation produced as a result of scattering and (or) leakage was directed towards the secondary barriers as depicted in Table 2A and 2B. Thus the U factor used in all the rooms was 1 and 0 for the primary and the secondary barriers respectively which is in line with the recommendation of NCRP report 147. Aminu and Sidi [10], reported similar findings. The possible reasons might be because all the studies used the NCRP report 147 recommendations.

In the current study, as seen in Table 2A and 2B, the existing barrier thickness in all the rooms studied was less than the calculated barrier thickness with a ratio of less than 1, indicating that the shielding barrier thickness at different positions was enough to attenuate the primary and secondary radiation to design goal of 0.1 mGy/wk and 0.02 mGy/wk for the controlled and uncontrolled areas respectively. The findings are in agreement with the studies conducted by Refs. [4-6]. The Possible reasons for the similarity might be because of the involvement of experts during the construction of the x-ray room or overestimation of the shielding calculations. However, findings from this study are dissimilar to that of Ref. [11]. The possible reasons for the dissimilarities might be related to the shortage of qualified experts for room design or the absence of supervision and regulatory authority in the establishment of such an x-ray room.

5. Conclusion

Based on the parameters studied, all the x-ray rooms had the ideal room size except Facility G and H. Relative distances from the x-ray tubes to the nearest chest wall were optimized in all the rooms except in-room IV. The ratio of the calculated to the design dose limits was less than one. We hereby conclude that based on NCRP recommendations, the design barrier thickness in the radiology department of all the conventional x-ray rooms involved in the study was adequate. Further studies should consider imaging facilities such as computed tomography, Angiography, fluoroscopy units and mammography units.

Acknowledgments

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