Caliphate Journal of Science & Technology (CaJoST)

ISSN: 2705-313X (PRINT); 2705-3121 (ONLINE) Research Article

Open Access Journal available at: https://cajost.com.ng/index.php/files and https://www.ajol.info/index.php/cajost/index

DOI: https://dx.doi.org/10.4314/cajost.v5i3.5

Article Info

Received: 25th February 2023

Revised: 22nd July 2023

Accepted: 24th July 2023

Optimization of Shielding Barriers for Feasible Exposure to Medical X-Ray Radiation

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Cite this: *CaJoST*, 2023, 3, 280-287

Despite the importance of X-ray facilities in medical practices, adequate shielding is required to reduce exposure to patients, workers and members of the general public. The importance of adequate shielding barriers in attenuating the intensity of X-rays to recommended limits thus cannot be over-emphasized. An evaluation of the shielding barrier in a public hospital was carried out with the aim of optimizing radiation protection of the general radiology department of specialist hospital Sokoto with the X-ray facility unit of the department as a case study. XRAYBARR software was used to evaluate the primary and secondary barriers using the X-ray tube Specification, distance of the various occupied areas, workload distribution, and use factor. An area survey was carried out using thermoluminescence dosimeters (TLD). Values from XRAYBARR and measured values from TLDs, the ratio of the software calculated to the designed barrier thickness and the ratio of measured to the designed dose were all compared. The ratio of the software calculated barrier thickness to designed barrier thickness was greater than 1 except in 4 positions. Results of the study also indicated that the ratio of the measured to design dose was greater than 1 for all the positions. This indicates that the barrier put in place except at 4 positions is not adequate to protect individuals from harmful effect of radiation. The result also shows that radiation dose beyond the barrier is greater than the design dose limit at all positions. Therefore, the need for reinforcement of the existing shielding barrier.

Keywords: X-ray; Shielding; Protection barrier; XRYBARR; Workload; Radiation dose.

1. Introduction

Radiation Protection is based on three basic principles: justification, optimization and limitation. Principle of optimization states that dose should be kept As Low as Reasonably Achievable (ALARA). X-rays are playing an increasingly significant role in medical diagnosis, in which seldom in medical history has any discovery resulted in such spectacular impact as the discovery of X-rays [1]. As per the World Health Organization report, a third-to-half of crucial medical decisions are dependent of X-ray diagnosis and the early diagnosis of some diseases depends completely on X-ray examination [2]. In Nigeria where the frequency of X-ray examination is high, diagnostic X-rays are one of the major contributors to population dose among the man-made source of radiation [3]. However, there is no published data yet on the number of interventional radiology examinations in Nigeria.

Environmental safety has become a major concern in every community, society and country at large. Despite the importance of X-ray in diagnosis, the hazard caused by the use of X-ray should not be overlooked. If X-ray facility is not properly shielded and then allowed to interact with the patient, it can cause damage to the patient, workers and to the immediate members of the environment [4, 5]. Thus, various measures need to be taken to keep the Radiation hazard to "As low as reasonably Achievable (ALARA principle) in order to have safe environment considering social and economic constraint that no individual will be subjected to undue risk [6]. The fundamental parameters in radiation protection process include time, distance and shielding. Minimizing time of exposure, keeping a relatively high distance between the patient and the source of radiation and proper shielding of the radiographic room, occupational radiation workers and the people within the surrounding are believed to be important measures of protection against the risk of X-ray radiation [7].

Proper attenuation of X-rays intensities can only be achieved by proper designing and installation of shielding barriers in order to achieve the respective shielding and dose limit. This will be better attained if qualified expert (medical physicist or health physicist) is involved in the design and installation of shielding barriers [8, 9].

One of the most important consideration in any diagnostic X-ray installation is to ensure that workers and the public are adequately shielded from radiation. The provision of shielding the X-ray installation room is one of the ways in which this radiation can be controlled. That is why National Council on Radiation Protection and Measurements (NCRP) was established to ensure that any radiology room must be properly designed and verified by experts in that field and to ensure that right facilities at the right time are in the right place [10]. This can significantly help in controlling the amount of effective dose to be absorbed by any individual.
Specialist hospital Sokoto is an old established hospital. The hospital was recently renovated with new X-ray machine installed and the shielding barriers of the installation room were tempered during the renovation work. In view of this, there is need to undergo a performance assessment (Radiation survey) by a qualified expert (Medical Physicists or Health Physicists) to confirm that the shielding provided will achieve the respective shielding and dose limit. In line with that, an assessment of the shielding barriers of radiology departments of this hospital need to be evaluated to see whether they meet the requirements as stated and designed by NCRP. Shielding barrier evaluation had not been done previously at Specialist hospital Sokoto. However, work of this kind had been done somewhere else in Nigeria [11]

2. Materials and Methods

2.1. X-ray facility unit

The X-ray facility of Sokoto Specialist Hospital houses an X-ray machine manufactured by Toshiba (Model SMS-CM-N), made in U.K. in the year 2012 and installed in the year 2015. The X-ray field covers 2.5 m x 3.0 m and field size of 1000 cm^2. The specifications of the X-ray machine are summarized in Table 1.

Table 1: Specifications of X-ray Machine.

Items	
Manufacturer	Toshiba (Ecoray)
Model/type	SMS-CM-N
Year of manufacture	2012
Year of installation	2015
Inherent filtration	1.2 mmAL
Added filtration	0.8 mmAL
Type of unit	Static
Generator type	1-phase
Maximum kVp	125
Maximum mAs	80

2.2. X-ray tube and XRAYBARR Software

The radiology department of Sokoto Specialist Hospital has an estimated area of 650 m^2. The department comprises corridor with attached offices and reception room. There is also an X-ray room of an estimated area of 100 m^2 and height of 2.8 m. Attached to the X-ray room is the dark room. The shielding barrier in the whole department is concrete of thickness 100 mm. Figure 1 is the layout design of the case study radiology department.

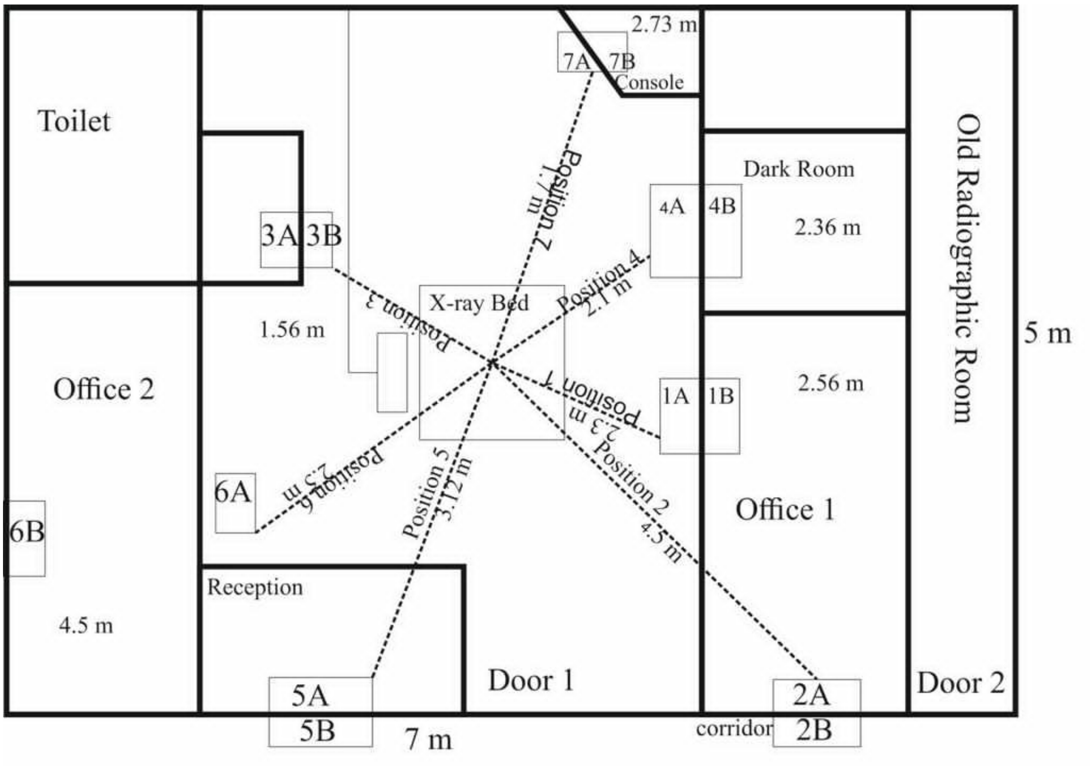

Figure 1: The Layout of Radiology Department of Specialist Hospital Sokoto.

The Program XRAYBARR was designed by Douglas J. Simpkin [12] to fully evaluate the shielding barrier of any radiographic installation. The program is used to calculate the barrier thickness of various shielding materials required to shield the diagnostic X-ray installation at the study areas with the annual dose limit (p) and occupancy factor (T) to the specified area to be shielded. The program also uses the following parameters such as workload, use factor, distance from the occupied area and the X-ray tube information to calculate the barrier thickness required for various shielding materials such as glass, lead, gypsum etc. to reduce the total annual dose to the recommended dose. The interface of the program is shown in Figure 2.

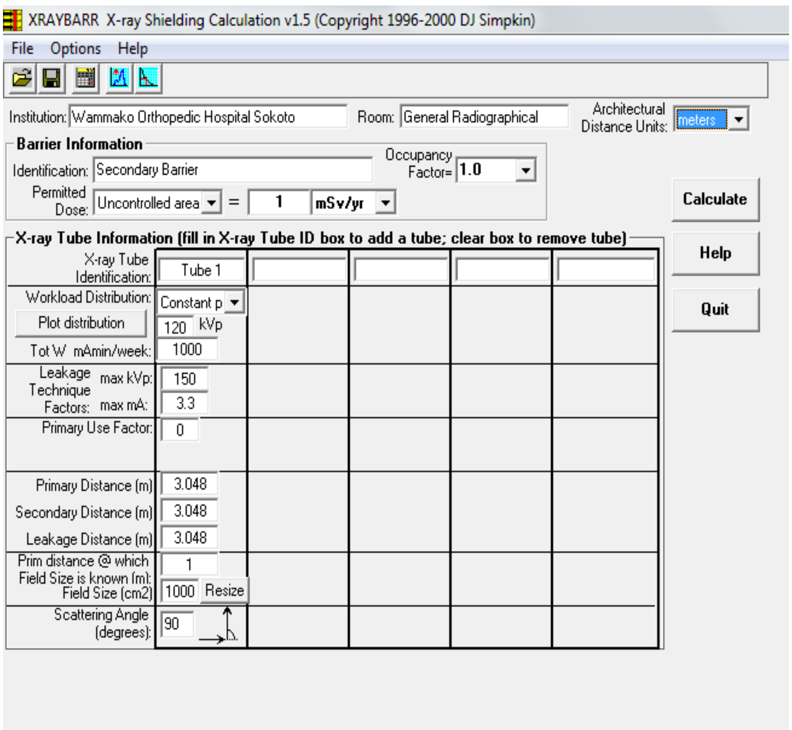

Figure 2: XRAYBARR Software Interface [11].

2.3. Thermoluminescence Dosimeter (TLD) and Area monitoring Survey

The TLD's used in this study were obtained from the Centre for Energy Research and Training, Ahmadu Bello University, Zaria. The TLDs are lithium fluoride (LiF) chips of 3.8 mm x 3.8 mm x 2.5 mm in size originally supplied by RISQ Laboratories in Denmark. The calibration of the TLD's was carried out at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria. These chips were first annealed and then calibrated to determine their dose responses by exposing them at a distance of 8 cm to a ^{137}Cs gamma source (from Austria) with a dose rate of 0.4 mSv/hr at 0.5 hours, 1 hour, 1.5 hours, 2 hours, 2.5 hours, 3 hours, 3.5 hours and 4 hours. The TLD Processor Model 680 Solaro by Vinten Analytical Systems Limited, United Kingdom was employed to read the TLDs with its sensitivity level being 99.9% [13]. The TLD reader was set at a preheat temperature of 1600 ℃, for 10 s, read temperature of 260 ℃ read time of 16 s, anneal temperature of 300 ℃, anneal time of 16 s and calibration factor of 1.

Monitoring areas inside the X-ray room and beyond the barrier was carried out for the period of four calendar weeks using calibrated TLDs. A pair of TLD was placed in different positions of the radiographic department. One is placed inside the X-ray room and named as Position 1A, and the other TLD is placed outside the X-ray room directly behind the other TLD and named Position 1B. The placement of the TLDs was done based on the importance of such barriers to the adjacent occupied areas. The position of the TLD chips is shown in Figure 1.

2.4. Determination of Workload

The Total workload distribution for the general Radiographic room was surveyed over four calendar weeks. Workload *W* is very important in calculating the amount of barrier thickness required. It is the total amount of work done by the X-ray machine in a week [14]. It is the time integral of the X-ray tube current measured in milli ampere-minutes (mA-min). The total workload per week is given by equation 1.

$$W = NW_{norm} \quad 1 \quad (1)$$

~~W~~here W_{norm} is the average Workload per-patient and N is the number of patients examined in a week.

3. Results and Discussion

The following~~s~~ show the results obtained from the study of evaluation of shielding barrier of radiology department of Specialist Hospital Sokoto, using parameters and data obtained from the software and survey area monitoring respectively.

Table 2: Workload distribution for Sokoto Specialist Hospital.

X-ray	Average patient per week	Workload (mAmin/week) 50 kVp – 120 KVp
General radiography room	75	76.5

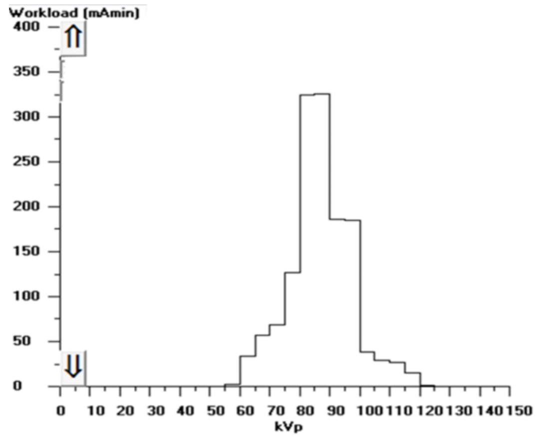

Figure 3: Workload distribution for Specialist hospital Sokoto.

Table 2 above shows the total workload distribution and the average number of patients examined per week at the general radiography room of Specialist Hospital Sokoto, Figure 3 represent the workload against the kilovolt (kVp). The kVp values ranges from 50 kVp to 120 kVp as seen from figure 3 and this kVp depends on the type of X-ray protocol offered to the patients.

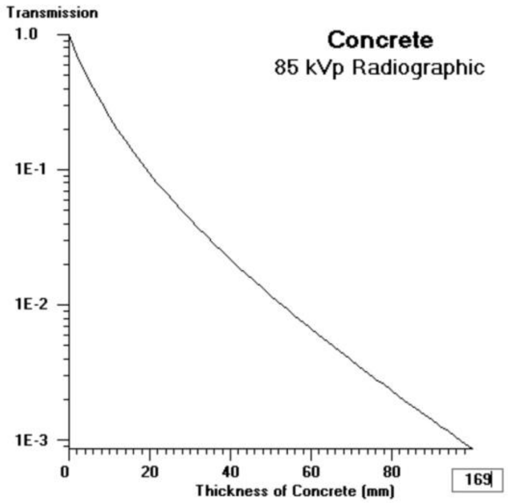

Figure 4: Attenuation curve for console of Specialist hospital Sokoto (Generated from the XRAYBARR).

Table 3: Software calculated dose and barrier thickness required for Specialist Hospital Sokoto

S/No.	Position	Unshielded Dose (mSv/week)		Shielded Dose (mSv/week)		Zone	T (Occupancy Factor)	U (Use Factor)	W (Workload)	Scattering angle (^{0})	Barrier thickness (mm)					
		Primary	Scattered	Primary	Scattered						Lead	Concrete	Gypsum	Steel	Glass	Wood
1.	Office 1A	0.1064	0.10370	0.0977	1.828E-3	Controlled	1.0	0.25	76.5	120	0.832	69.93	225.9	7.245	81.44	619.0
2.	Office 1B	0.0510	0.04976	0.0195	3.654E-4	Controlled	0.5	0.25	76.5	120	1.124	91.61	294.4	10.36	104.3	749.3
3.	Corridor1A	0.5063	0.49370	0.0975	1.824E-3	Controlled	1.0	0.5	76.5	90	1.383	109.4	349.0	13.01	122.4	851.2
4.	Corridor1B	0.3739	0.36460	0.0978	1.830E-3	uncontrolled	1.0	0.5	76.5	90	1.267	101.4	324.8	11.82	114.4	806.1
5.	Changing Room A	1.5685	0.53441	0.0999	0	Controlled	1.0	1	76.6	90	1.825	139.0	438.1	17.47	151.8	101.6
6.	Changing Room B	0.0800	0.19140	0.0943	4.329E-3	Controlled	1.0	0.1	76.5	90	0.744	64.03	206.7	6.468	74.92	580.8
7.	Dark Room A	0.2222	0.05317	0.0943	4.321E-3	Controlled	0.5	0.1	76.5	120	1.091	89.03	286.1	10.03	101.5	732.9
8.	Dark Room B	0.1760	0.42100	0.0942	4.323E-3	Controlled	0.4	0.1	76.5	120	1.008	83.15	267.7	9.170	95.39	698.2
9.	Reception A	0.1007	0.24090	0.0943	4.328E-3	Controlled	0.4	0.5	76.5	90	0.818	69.47	224.3	7.219	80.85	615.0
10.	Reception B	0.1007	0.24090	0.0188	8.634E-3	Uncontrolled	0.4	0.5	76.5	90	1.400	110.2	351.2	13.19	123.1	854.6
11.	Office 2A	0.3136	0.08337	0.0991	5.065E-3	Controlled	0.4	0.5	76.5	90	1.193	96.46	309.5	11.06	109.3	777.9
12.	Office 2B	0.2420	0.06433	0.0993	5.066E-3	Controlled	1.0	0.5	76.5	90	1.098	113.8	289.0	10.08	102.5	739.3
13.	Console A	1.3449	0.36813	0.1000	0	Controlled	1.0	0.1	76.5	120	1.761	134.8	425.7	18.84	147.7	993.6
14.	Console B	1.3154	0.24309	0.1001	0	Controlled	1.0	0.1	76.5	120	1.752	134.2	423.9	16.75	147.1	990.3

Table 4: Comparison of the measured dose with the design dose and calculated barrier thickness with the design barrier thickness of the general radiograph room of Sokoto Specialist Hospital.

S/No.	Position	Measured Dose (mSv/week)	Design dose (mSv)	Ratio of Measured Dose to Design Dose	Calculated Barrier Thickness (mm)	Design Barrier Thickness (mm)	Ration of Calculated to Design Barrier thickness	Type of Barrier
	Corridor A	0.13	0.100	1.30	69.93	100	0.699	Secondary
	Corridor B	-	-	-	91.61	100	0.916	Secondary
	Office 1A	0.15	0.100	1.50	109.4	100	1.094	Secondary
	Office 1B	0.22	0.100	2.20	101.4	100	1.014	Secondary
	Changing room A	0.20	0.100	2.00	139.0	100	1.390	Primary
	Changing room B	0.20	0.100	2.00	64.03	100	0.643	Secondary
	Dark room A	0.26	0.100	2.60	89.03	100	0.893	Secondary
	Dark room B	0.17	0.100	1.70	83.15	100	0.832	Secondary
	Reception A	0.11	0.100	1.10	69.47	100	0.695	Secondary
	Reception B	0.14	0.020	7.00	110.2	100	1.102	Secondary
	Office 2A	0.34	0.010	3.40	96.46	100	0.965	Secondary
	Office 2B	0.15	0.020	7.50	113.8	100	1.138	Secondary
	Console A	0.35	0.100	3.50	134.8	100	1.348	Secondary
14.	Console B	0.25	0.100	2.50	134.2	100	1.342	Secondary

Table 5: Measured Effective dose of the area surveyed from TLD measurement for the radiographic room of Sokoto specialist hospital.

S/No.	Position	Infront of the Barrier (mSv/week)	Beyond the Barrier (mSv/week)
1.	Office 1	0.15	0.22
2.	Corridor	0.13	-
3.	Changing Room	0.20	0.20
4.	Dark Room	0.26	0.17
5.	Reception	0.11	0.14
6.	Office 2	0.34	0.15
7.	Console	0.35	0.25

Table 1 represent the kilo voltage and workload distribution of the total workload and the total number of patients examined per week in the General Radiographic room of Specialist hospital Sokoto. The number of patients per week amounts to 75 and the kVp range is between the ranges of 50 kVp – 120 kVp. The total workload distribution in this study area therefore amounts to 76.5 mA-min/week.

Table 2 represent the calculated effective doses and the barrier thickness required for the Radiographic room of Specialist hospital Sokoto. The calculated unshielded and shielded radiation dose that is, the dose amount an individual will be exposed to when there is no barrier (unshielded dose) and the dose amount an individual will be exposed to when there is barrier (shielded) inside the X-ray room can be useful to predict the shielding barrier thickness that will reduce the unshielded radiation dose to the design dose beyond the different barrier positions [15].

As seen in the table 3, position 3 and 4 represent Corridor before and after the barrier respectively. Position 5 and 6 represents changing room barriers which protect the workers and patients from excessive radiation. The primary beam is directed towards the changing room which is relatively closer to the source of radiation at position 6, this account for higher unshielded dose value of 1.56 mSv/week and therefore has the highest required shielding barrier thickness of at least 139 mm to reduce the radiation dose.

It can also be seen from table 3 that for the same occupancy factor and use factor at position 13 (Console A) and 14 (Console B), the distance from the radiation source was the reason for the difference in the unshielded primary dose. High thickness shielding barrier is of merit for any radiographic installation. So, in case of any future increase in workload, the design barrier already in place can be adequate in reducing the radiation dose to the recommended dose [15].

Figure 4 shows the attenuation curve of the radiation at console of installation room. The curve revealed that, as the thickness of the shielding material (concrete) increases, the attenuation of the radiation increases (i.e. the less the radiation transmitted).

Table 5 shows the measured effective dose for the area surveyed from the TLD measurement in the general radiographic room of Specialist hospital Sokoto. It can be seen from the table that the radiation doses absorbed by the TLDs in front of the barrier are relatively higher than the doses beyond the barrier except the dose at the position 1 and position 5 corresponding to the office 1 and reception respectively. This can be attributed to the fact that the secondary radiation is scattered more in those position beyond the barrier than in front of the barrier. When comparing the calculated dose from the software (shielded and unshielded) depends greatly on the distance from the source to the occupied area. As can be seen from the table 3.2, the highest unshielded dose calculated was 1.56 m/Sv at position 5 and the lowest calculated unshielded dose was at position 2 with the dose value of 0.051 mSv/week while for the shielded dose, the highest dose recorded was 0.100 mSv/week at position 13 and the lowest dose was at position 10 with dose value of 0.0188 mSv/week. But in table 3.3, for the values within the barrier, the maximum absorbed (measured) dose was 0.35 mSv/week for console A and the lowest was 0.11 mSv/week for reception. For the measured dose beyond the barrier, the highest absorbed dose was 0.25 mSv/week at console B and the lowest was 0.14 mSv/week at position 5 (Reception B). This shows that the measured doses from the TLDs are slightly higher than the measured doses from the software for both shielded and unshielded radiation. These differences attributed to the fact that other source of radiation (e.g. cosmic radiation) can influence the absorbed dose from the TLD to increase since it is not design specifically to absorbed radiation from X-ray machines only.

It can also be seen from Table 3.3 that beyond the barriers highest value measured by the TLD is 0.25 mSv/week and lowest value of 0.14 mSv/week at position 5 (Reception). For positions in front of the barrier, the measured dose amounts to 0.35 mSv/week at position 7 at maximum and has the lowest value of 0.11 mSv/week. It shows that the maximum effective dose absorbed by the TLD within the period at position 7 is 0.35 mSv/week and the least absorption is 0.11 mSv/week corresponding to position 5.

Table 4 presents the radiation dose levels beyond the shielding barrier from the TLD measurement, the corresponding regulatory design dose, the calculated shielding barrier thickness from the XRAYBARR and the corresponding design shielding barrier for the radiography room of Specialist hospital respectively. It can be seen from this table that the ratio of the measured effective dose to design dose is greater than one at all positions indicating that the effective radiation dose level beyond the barrier is greater than the recommended dose. The ratio of the calculated barrier thickness to design barrier thickness is also greater than one in most of the positions, indicating that the barrier put in place is not adequate enough to reduce the effective radiation dose to the recommended regulatory dose of 0.1 mSv/week for controlled areas and 0.02 mSv/week for uncontrolled areas. While for those positions in which the ratio is less than one, it shows that the barrier put in place is adequate to reduce the radiation dose to the recommended dose but still needs to be replace in case of any future increase in workload. The difference in the effectiveness in some positions is due to the non- uniformity of the concrete during the time of the construction. Through the use of concrete, some positions can be thicker than other positions because it is a manual construction by individuals.

4. Conclusion

Optimization of shielding barrier in any diagnostic installation is of great importance. This can be done by proper shielding of the radiographic room and minimizing radiation exposure to the patients, workers and members the general public.

Shielding barrier assessment was carried out using TLDs which were placed in front and beyond the barrier of the radiographic room. The calculated effective doses from the software were compared with the measured or absorbed doses from the TLDs to assess the radiation doses from inside the X-ray room and beyond or outside the X-ray room.

Similarly, the comparison between the calculated barrier thicknesses to the design barrier thickness was carried out. The ratio of the measured shielded effective dose to the design dose was calculated and evaluated to be greater than one, the ratio of the calculated barrier thickness to the design barrier thickness was also found to be greater than one in most of the positions. It is hereby concluded based on the NCRP recommendations that the shielding materials already in place is not adequate. Various shielding materials calculated from the XRAYBARR software shows that the shielding material used (concrete) in Specialist Hospital Sokoto as seen from the result is ineffective.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

We deeply acknowledge the management of Specialist Hospital Sokoto, Sokoto State, Nigeria, for their immense cooperation towards the achievement of this work.

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